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Research Article

Evaluation of the Effectiveness and Efficiency of Atmospheric Particulates Reduction Policy: The Case of South Korea

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ABSTRACT In a situation where various policy measures can be used to reduce atmospheric particulates, effectiveness and efficiency may vary depending on how the policy is designed. Therefore, this study evaluated the effectiveness and efficiency of atmospheric particulates reduction policy in order to contribute to effective and efficient policy design. To this end, this study demonstrated the effectiveness of 1st Basic Plan on Metropolitan Area Air Quality Improvement and explored the cause of the effectiveness. As a result of the study, this study did not confirm that the effect of reducing PM_{10} caused by the plan in the metropolitan area was significantly different from that of the non-metropolitan area where the policy was not implemented. In particular, distinct effect was not confirmed on the installation of DPF, which required a large number of costs. Based on the results, more effective and efficient policy measures will be used based on the causal relationship of atmospheric particulates generation.

KEY WORDS PM_{10}, Atmospheric particulates, Policy evaluation, Policy measure, Road mobile emission

1. INTRODUCTION

The rising levels of atmospheric particulates have become public health threats to growing portion of the world population. A 2021 WHO report on air quality and health estimates that air pollution was behind approximately 7 million premature deaths annually while in 2019 over 90% of the world population was living in air conditions that does not meet WHO air quality guidelines (WHO, 2021)[1]. A research published in Nature in 2017 renders a similar diagnosis (Zhang *et al.*, 2017). Among 3.45 million premature deaths due to air pollution in 2007, 1.19 million were in China, another 0.58 million in India, and still another 0.45 million in the other Asian countries, indicating the fact that a larger share of such deaths is taking place in Asia. In fact, the number of premature deaths due to air pollution accounts for 5–7% of total annual deaths in the world.

Alarmed by the harms of such magnitude done by air pollution, governments

[1]The annual WHO average is below 15 μg/m^3 for PM_{10} and 5 μg/m^3 for $PM_{2.5}$.

around the world have introduced various air pollution reduction measures. Certain municipalities in California[2] have adopted an array of particulates reduction strategies including regulation of outdoors waste incineration, introduction of transportation means with little to no exhaust gas emissions, and scrappages of old vehicles in order to control emissions from fixed sources, road mobile sources as well as non-road mobile sources (SCAQMD, 2012). Japan also strives to reduce air pollution by promoting low-emission vehicles, regulating vehicle emission levels and introducing eco-driving system[3]. China, a country exposed to one of the highest levels of atmospheric particulates concentration, has put into practice industrial dust control technologies, scrappage of old vehicles and removal of arsenics in air particulates (MEE, 2012).

While the type of policy tools varies among different countries, what stands out is the fact that the policy efforts of most countries are in the form of a policy mix. A policy mix, in its original usage, refers to a combination of various economic policy tools governments implement so as to pursue both economic growth and stability. Afterward, its application has expanded to the environmental field to denote governmental efforts characterized by proactive combinations among related policy tools or prioritization of policy tools in order to minimize contradictions (Lafferty and Hovden, 2003). Put differently, a policy mix refers to the pursuit of an optimal policy combination motivated by comprehensive understanding of the interrelations and interactions amongst existing policies and their trade-offs (Flanagan *et al.*, 2010; Sorrel and Sijm, 2003). This is due to the particular characteristic of the issue: the existence of various sources of atmospheric particulates and channels of influx. Inevitably, any measures that aim at controlling those sources and channels involve countermeasures that target each type of sources and influx channel.

Yet, the process of introducing various policy instruments often is the source of issues that hinder effectiveness and efficiency of a policy. For example, if a certain policy measure that is effective but financially costly is prioritized over others, the overall policy response is consequently more likely to be inefficient despite its effectiveness. On the other hand, if a policy measure gives more weight to an instrument that is more efficient but relatively less effective, then such policy response is more likely to fall short of achieving its desired level of effectiveness. Hence, the objective of devising a policy mix in the atmospheric particulates reduction strategy boils down to choosing the combination of policy instruments that achieves the best effectiveness and efficiency possible.

However, identifying the exact levels of effectiveness and efficiency of individual policy instruments is not easy. Regardless of whether the effect of a certain policy instrument can be observed, it is a challenging task to determine whether such effect indeed did originate from the relevant policy instrument. Accordingly, for the same reason, it is hard to estimate the level of efficiency based on its effectiveness vis-à-vis the cost incurred. Yet, such difficulty does not obviate the need for information on the effectiveness and efficiency of individual policy instruments. In order to come up with an optimal policy combination, it is essential to secure reliable information on the effectiveness and efficiency of individual policy instruments despite the inherent difficulty involved confirming the exact levels of effectiveness and efficiency. On the other hand, a government intervention to any policy issues in most cases is translated into expenditure of resources such as manpower, organizations and budget, which in turn is directly related to the issue of allocation of social resources. On this account, developing and selecting more efficient and effective policy instruments is not only the most demanding task but frequently the source of controversy in the policy-making stage (Weimer and Vining, 2015; Christensen, 2006; Salamon, 2002; Kettl, 1988; Rhoads, 1985; Stokey and Zeckhauser, 1978; Kirschen, 1964).

The purpose of this study is to examine the effectiveness and efficiency of policy instruments implemented under the 1st Basic Plan on Metropolitan Area Air Quality Improvement (the Plan) on the basis of the discussion above[4]. To the extent that the policy response for air quality improvement was in the form of a combination

[2]Los Angeles, Riverside, San Bernadino, and Orange County.

[3]Relevant instruments are under the 'Air Pollution Control Law' and 'Japan Revitalization Strategy' (環境省·産業省·国土交通省, 2012).

[4]Han *et al.* (2017) examines the appropriateness of policy targets and instruments and the effectiveness of the 1st Basic Plan on Metropolitan Area Air Quality Improvement. Although this research is similar to Han *et al.* (2017) in that it evaluates the effectiveness of the same policy, this research differs because it constructs a logical framework for evaluating the effectiveness and efficiency of the policy and conducts detailed quantitative analysis to verify them. However, despite the fact that the two papers examine the policy effect through different approaches, similar conclusions are drawn on the effectiveness of the policy.

of various policy instruments, it is difficult to determine the precise levels effect and efficiency of each of those policy instruments. Nevertheless, Korea's policy mix implementation characterized by the fact that the lion's share of the budget was devoted to a small number of policy instruments makes easier the attempt to determine the effectiveness and efficiency of those select policy instruments. Therefore, this study first examines the degree of seriousness of Korea's atmospheric particulates issue and policy instruments implemented in order to improve the air quality under the Plan; secondly, explain the process of estimating policy effects of such instruments. Further, since detailed information on the use of budget per policy instrument is available, it is also possible to estimate the efficiency of the policy instruments once policy effect is estimated. Lastly, the effectiveness of the Plan assessed, and subsequently, better particulates reduction policy design is proposed based upon observed level of effectiveness and efficiency of each policy instruments.

2. THE CLEAN AIR ACT FOR SEOUL METROPOLITAN AREA

The need for and economic benefits of air quality improvement have been noted by many previous researches with a substantial history of various governments devising and implementing their own policy responses. According to OECD (2008), the U.S., for instance, expects that 1 USD spent on air quality improvement policy as mandated in the Clean Air Act would incur a benefit worth 4 USD while Canada projects that reducing PM_{10}, $PM_{2.5}$[5] and O_3 emissions will bring about health benefits worth 3.6 billion USD annually. EU also estimates the net economic benefits for the next 20 years of its EC clean Air for Europe program to amount to 42 to 168 billion in USD. Such projections of large economic benefits, on the flip side, mean that deterioration in air quality can cause damages of corresponding magnitude.

Republic of Korea is not an exception in feeling an urgent need for air quality improvement. Particularly, the Seoul Metropolitan Area houses 46% of the total national population while its geographic area represent only 11.8% of the country's total[6]. The number of cars in the area skyrocketed from 0.27 million units in 1980 to 8.26 million units in 2010, greatly aggravating the concentration of atmospheric particulates such that 32% of national NOx emissions, 23% of PM_{10}, 38% of VoCs and 45% of CO originate in the area. Certain studies estimate that the scale of damages done by such air pollution in the metropolitan area as of early 2000s could be as large as 8 billion in USD (GRI, 2003; Cho *et al*., 2002).

For these reasons, the 'Special Act on Seoul Metropolitan Air Quality Improvement' was enacted in 2005, with its 1st Basic Plan for Metropolitan Area Air Quality Management (the Plan) effective from 2005 to 2014 focusing on reducing emissions of NOx, SOx, VOCs, and PM_{10}, among other atmospheric particulates. As for PM_{10}, the subject of this study, the Plan aimed at reducing the emissions from the 2001 level of 14,681 metric tons to 8,999 metric tons by 2014 and its concentration level from 69 $\mu g/m^3$ in 2003 to 40 $\mu g/m^3$ in 2014 (Kim and Lee, 2018; MOE, 2013)[7]. To this end, the Management by Objective (MBO) approach was adopted in which the municipal governments in the metropolitan area endowed with the freedom to establish and implement specific instruments they independently devise reallocate per-pollutant emissions quota based the original quota the Ministry of Environment assign. As Table 1 shows, sources of atmospheric particulates are classified largely into point sources, green energy and urban sources, area sources, road mobile and non-road mobile sources. Various representative policy tools for each category that have been proposed for each category are also shown.

The collection of Korea's atmospheric particulates reduction policy instruments has the following unique characteristics. First, there are different factors inducing particulates concentration in the atmosphere, such as influx from abroad, pollution from domestic sources domestic, and chemical reaction in the atmosphere (Kim, 2006). In particular, because Korea is adjacent to

[5]PM_{10} refers to particulate matters with an aerodynamic diameter equal or less than 10 μm and $PM_{2.5}$ refers to particulate matters with an aerodynamic diameter equal or less than 2.5 μm.

[6]The population density of the Seoul Metropolitan Area has is more than four times of the national average and 65 times that of the United States.

[7]Recently, Korea government enacted the 2nd Seoul Metropolitan Air Quality Management Plan (2015–2024) based on the results of the 1st Plan and it aims to reach 30 $\mu g/m^3$ for PM_{10} and 20 $\mu g/m^3$ for $PM_{2.5}$ by 2024. Besides, the policy tools are similar to those of the 1st plan. So, the evaluation of the 1st Air Quality Management Plan is important because the plan can be revised with new information through evaluation of the previous plan.

Table 1. Key tools included in the Special Act on Seoul Metropolitan Air Quality Improvement.

Classification	Key measures
Sites (Point sources)	Controlling total emissions from large industrial sites and management of other sites not subject to total emissions control
Green energy and urban sources	Collective energy scheme, renewable energies, installing green buildings, and creating green areas
Area sources	Reducing VOC emissions, controlling non-industrial combustion and arsenic particulates
Road mobile sources	Promotion of low-emissions vehicles, management of on-road vehicles and transportation demand
Non-road mobile sources	Management of construction/agricultural/maritime vehicles

Source: Kim *et al.* (2011, p. 51)

China and the direction of atmospheric circulation is from China to the Korean peninsula, the amount of atmospheric particulates influx from China into the country is presumed to be substantial (Park and Han, 2014). However, generation of particulates from chemical reactions in the atmosphere is hard to manage, and blocking out the influx of particulates from abroad also requires active efforts on the part of governments of all involved countries. For such reasons, policy measures that intend to manage particulates generation in the atmosphere and to stall the inflow of particulates from foreign sources are hard to become realistic options. Hence, the scope of South Korea's atmospheric particulates reduction policy is limited to efforts to suppress pollution from the domestic sources.

Second, Korea's policy prioritized reduction in particulates generation from road mobile sources and non-road mobile sources over the other domestic sources of pollution[8]. Specifically, the Ministry of Environment aimed to achieve reduction of 4,506 metric tons (79%) from the road and non-road mobile sources comparing to the total of 5,682 metric tons of annually generated particulates (MOE, 2005). Such strategy is also confirmed when the use of relevant budget is examined. The figures of budget expenditure shown in the Table 2 reveal a disproportionately large amount of the resources that has been put into programs targeting reduction of the emissions from the road or non-road mobile sources. Of particular note is the fact that 75% of the total budget was spent on lowering emissions level of diesel vehicles (subsidy programs for Diesel Particulate Filter installation). Another 19% was spent on promoting the use of low-emissions vehicles (scrapping subsidies for old diesel vehicles) so that a total of 94% of the budget was expended for the purpose of reducing emissions from diesel vehicles.

Third, during the period of the Plan, there were no specific regulations related to particulates emissions in place, nor did there have been any specific changes with respect to the use of public transportation uses that could have affected the policy. Since there were no other particulates reduction policy in effect other than the one under the Plan, it can be assumed that most of the changes in domestic particulates emissions were based on the policy interventions implemented as mandated by the Plan, provided that there were not significant changes in the amount of influx from the abroad and in meteorological factors. While the budget could have been used for different purposes - implementing various regulations, development and supplying environment friendly energy, monitoring of manufacturing sites and arsenic particulate emissions, creating a green belt or establishing an overall emissions management system, Korea's strategy of particulates reduction can be adequately summarized as reducing emissions of particulates from road mobile sources based on the subsidy program for DPF installations and diesel scrappage scheme.

Indeed, it has been reported that annual PM_{10} emissions in the Seoul metropolitan area decreased from 14,605 metric tons in 2005 to 9,519 metric tons in 2010, while the concentration of the particulate matter in Seoul reduced from 56 $\mu g/m^3$ to 41 $\mu g/m^3$, coming very close to the Plan's original target (MOE, 2013). To look at changes per source, among the 4,396 metric tons of total amount of reduced emissions, 89 metric tons were from point pollution sources, 61 metric tons from area pollu-

[8]Europe, which preferred diesel vehicles with low carbon dioxide emissions, also initiated strong regulations on diesel vehicles with high NOx and PM. Various post-processing devices are installed in the released diesel car, and diesel vehicles were completely banned during the week in Paris. Europe is striving to reduce PM generated by diesel cars, with exhaust gas standards for diesel cars gradually strengthening to Euro 6 and 7.

Table 2. The use of allocated budget for the First Air Quality Improvement Plan[9]. (Unit: million ₩).

Classification	Total	Distribution of low-emission vehicles	Reducing emissions of existing vehicles	Manufacturing site management	Establishment of efficient management system	Reduction of arsenics emitted from the road mobile sources
Total budget	4,002,775	232,480	3,457,602	225,323	77,056	10,314
Total actual expenditure	3,081,914	589,007	2,300,417	114,017	71,558	6,915
2005	209,527	37,533	167,698		4,296	
2006	411,074	66,898	331,973	6,277	5,926	
2007	475,731	59,099	401,703	7,965	6,964	
2008	433,915	96,545	318,787	9,998	8,587	
2009	338,719	83,896	234,823	12,405	7,579	
2010	312,454	312,454	232,507	29,678	7,094	1,061
2011	262,267	46,187	194,752	13,813	6,320	1,195
2012	208,824	47,399	141,469	11,208	7,356	1,392
2013	228,116	55,356	152,091	11,211	7,941	1,517
2014	201,287	53,982	124,614	11,462	9,479	1,750

Source: Ministry of Environment, 2013, p. 17

Fig. 1. Primary particulates reduction strategy under the 1st Plan.

tion sources, 4,393 metric tons from road mobile sources and 26 metric tons from non-road mobile sources. Thus, looking at the absolute figures, we may reasonably determine that most of the goals that government originally intended were achieved, and the air quality in the Seoul Metropolitan Area improved greatly. However, whether this change is caused by the measures implemented under the Plan is a matter that needs further investigation. For example, it is necessary to carefully examine whether the decrease in the particulates concentration in the Seoul metropolitan area is due to actual reduction in emissions from the road mobile sources, rather than due to a third factor such as decreased in the influx from the abroad that is above control. Along the same line, it is necessary to confirm whether the decrease in emissions from road mobile sources is due to the DPF installation policy or due to certain factors outside the policy. As such, we can discuss the effectiveness and efficiency of the individual policies only when it is possible to estimate the effects of individual policy instruments while controlling for the effects of third factors.

3. METHODS OF ANALYSES

As discussed earlier and shown in Fig. 1, the Korean government's primary policy instrument against atmospheric particulates is the subsidy program for DPF installation. The logic behind is that DPF installations will reduce emissions from the road mobile sources, which subsequently will result in lower PM_{10} concentration in the atmosphere. Such strategy is well confirmed by the pattern of budget allocation and emissions reduction targets per source. When put in a slightly more general term, it can be said that there is a policy structure where sub-level policy instrument reduces the emissions from a target type of source, which in turn leads to reduction in the atmospheric particulates concentration.

Given such structure, this study attempts to first identify the net effect of the overall policy; second, the sour-

[9] Due to the limitations of related data, 2013 report information was used. The 2014 figure is budget information.

ces of the identified policy effects; and finally assess the effects of the individual policy instruments that intend to reduce particulates emissions from each type of sources. Therefore, this study seeks to conduct three analyses in sequence in order to estimate the relative effect of each policy instrument.

First, we want to estimate how much of the decrease in the concentration of atmospheric particulates can be attributed to the Plan. The reason for prioritizing the estimation the net effect is that it is possible to trace the source of reduced emissions only after the net effect of the policy is estimated. For example, when there is a policy effect of 10, it is possible to disaggregate policy effects such that a reduction of 5 determined to have come from road mobile sources and another 3 from point sources. Conversely, in a case where the intended policy effect is deemed to have not occurred, it will be necessary to identify the cause of the policy failure and examine the related policy instruments.

Second, after the first analysis confirms whether there is a certain degree of policy effect or not, we want to ascertain the sources of change in emissions that are behind such result. To that end, we tried to estimate the effect of each emissions source on the particulates concentration level while controlling for other factors. As discussed above, the Plan was implemented in the form a policy mix that combines instruments to control emissions from each type of sources and focuses especially on the amount of particulates emissions from the road mobile sources. A problem inherent in the above strategy is that the policy is bound to be mostly ineffective if the amount of particulates emissions from other sources surpasses that of the road mobile sources. In such a situation, future particulates reduction policy will need to address emission sources that has a greater impact on the particulates concentration level, rather than the road mobile sources. Hence, prior to determining the effectiveness of the policy measures, we sought to determine whether changes in the emissions levels from each type of sources originally aimed by the policy instruments have ultimately led to changes in the particulates concentration level.

Third, when the level of contribution from each type of sources in emissions reduction is confirmed, we attempt to single out a policy measure that contributed the most to the particulates emissions reduction. For example, in addition to the DPF installation policy, there are other various policy instruments such as reducing the traffic volume and the number of vehicles. We want to see how effective the policy instrument pushed by the government was in comparison to other policy instruments available. The overall analysis process mentioned above is summarized in Fig. 2.

According to the process mentioned above, we attempted to estimate the policy effects of the Plan. The evaluation of effectiveness generally refers to estimated size of effects that have been generated by a project or a policy, meaning the difference in the size of changes between an experiment group, a sub-group to whom a policy intervention was introduced, and a control group, the rest without the treatment of the policy intervention. In other words, if we regard as the effects generated purely by a policy intervention the difference between a change

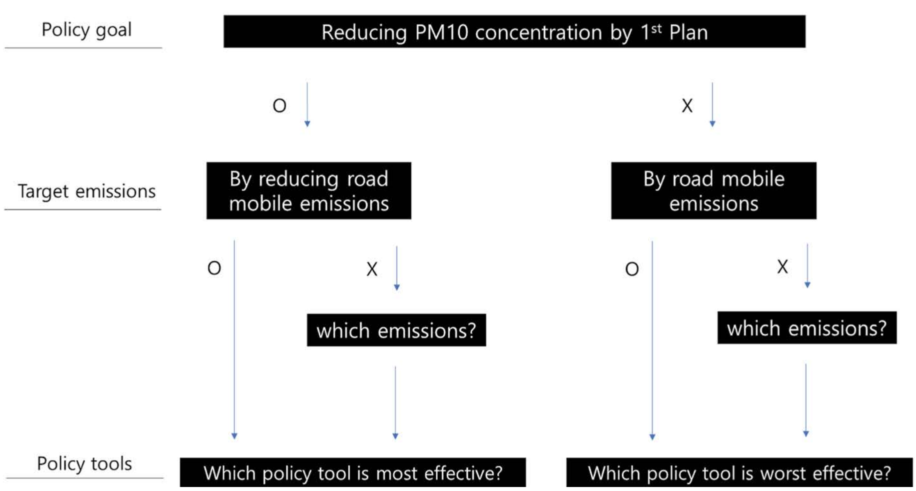

Fig. 2. Logical frame for estimating the policy effects of the dpf installation policy.

in an environment with the policy intervention and a change in an environment identical in all aspects but for the policy intervention (counterfactual) (Angrist and Krueger, 1999; Heckman *et al.*, 1997; Holland, 1986; Rubin, 1974)[10]. Although it is important to secure homogeneity in the initial conditions of the experiment group and control group in order to ensure that the measured difference can appropriately be inferred as generated by the policy intervention rather than by the characteristics of objects[11], since it practically impossible to simultaneously assign an identical object both to the experiment group and the control group, the method of random assignment is the best way to configure the two groups as identical as possible stochastically as well as on average (Hollister and Hill, 1995; Fisher, 1937).

The method of random assignment, however, is also not a practically feasible option in policy evaluation in that random assignment must be carried out in the stage of determining experiment and control groups prior to introducing a policy intervention[12]. Another method that can be used in lieu of random assignment is the propensity score matching and synthetic control methods that obtain similarity between an experiment group and a control group through ex-post application of statistical techniques. Other commonly used methods are the difference-in-differences analysis model, panel model, or Heckman's 2 stage model[13]. All of these methods take as a given the heterogeneity in initial conditions and estimate the effect of policy intervention by controlling a third variable or its mechanism that causes a difference between the two groups.

This paper attempts to estimate the policy effects using the difference-in differences model. The difference-in-differences model estimates the difference in the outcomes between the two groups before and after a policy intervention while controlling the effect of third factors other than the treatment. If the difference between the two groups before a policy intervention is different from the difference between the groups after the intervention, we estimate the difference in differences as caused by the policy intervention[14]. As for the subject of this paper - attempting to estimate the effectiveness of the policy intervention aiming at reduction of atmospheric particulate concentration, the Seoul metropolitan area as the target area of the policy is distinguished from the non-metropolitan areas, and there were differences in the air qualities of those areas that existed prior to the policy intervention. While the method used in this study as a statistical method has its own weaknesses arising from the issues of data and appropriateness of control when compared to the method of random assignment, in light of the constraints inherent in the as-is environment that cannot be identical with the laboratory environment, it is the best available option.

In estimating the difference in the changes in atmospheric particulate mass concentrations using the difference-in-differences model, dummy variables were created distinguish between the Seoul metropolitan area and non-metropolitan areas, the states of pre- and post-policy intervention. An interaction term of the two dummy variables was created in addition such that the ρ value of the Formula 1 indicates the size of the policy effect, the 'difference in the particulate mass concentrations in the Seoul metropolitan area before and after the policy intervention' - 'difference in the particulate mass concentrations in the non-metropolitan before and after the policy intervention' while controlling for the characteristics inherent in different geographic locations and influence

[10]This way of reasoning is referred to collectively as true experimental design. It is common in natural sciences as the most typical way of inferring the causality between policy intervention and changes in the results.

[11]When estimating the effect of a particular stimulus for any metal materials, the substance maintains the unique properties of the material unless external stimuli intervene, and the response to external stimuli is the same under the same circumstances. At this time, it is considered that the control of the same environment can be achieved by creating a same environment as a laboratory. However, with the passage of time, whether it is natural or deliberate, as the characteristic of the material changes or the response to stimuli may become different under the same external environment or it is difficult to control the identity of the external environmental stimulus, it is not easy to estimate the effect of the stimuli.

[12]Gary King *et al.* (2007) stated that it may be difficult to estimate the effects by a random experiment due to political intervention even when a randomized experimental design is made. When viewed in the light of this fact, the post-control of environmental factors as well as the randomized assignment is an important factor in the successful effect estimation by a random experiment.

[13]The Heckman's 2-stage model complements the differences between the two groups by explicitly considering in estimating policy effects the assignment or selection mechanism for the experimental group's and control group (Heckman and Willis, 1977). However, it has limitations in utilization due to the robustness of the model and its strict assumptions.

[14]The study of Card and Krueger (1993), which is counted as the most representative research, estimates the impact of minimum wages on employment in the controlled economic situation of the two regions with similar socio-demographic status.

Formula 1. $Y_{it} = \beta_1 + \beta_2(treat_i) + \beta_3(time_t) + \rho(treat_i \cdot time_t) + \varepsilon_{it}$

	Pre-2005 (before policy)	Post-2005 (after policy)	Difference
Metropolitan area	$\beta_1 + \beta_2$	$\beta_1 + \beta_2 + \beta_3 + \rho$	$\beta_3 + \rho$
Non-metropolitan areas	β_1	$\beta_1 + \beta_3$	β_3
Difference in difference (Policy effect)			ρ

of a third variable.

Consequently, as the difference between the pre-policy air quality and the post-policy air quality in the metropolitan area is estimated as $\beta_3 + \rho$ and that in the non-metropolitan area as β_3, it is proper to deem ρ as indicative of the policy effect. Although the policy was implemented in 2005, the estimation points in time were set at 2005, 2006 and 2007 since we are uncertain of whether the policy effect has occurred and thereby made observable immediately or after a certain period.

Further, in order to determine the exact sources of emissions reduction that contributed to the estimated policy effect, a panel data analysis was used to estimate the relationships between particulates concentration level and the amount of emissions from each type of sources. In that a panel data analysis eliminates unobservable heterogeneity of individual factors as well as macroscopic variability inherent in different time periods, the method is a better option to obtain a more efficient estimator. At the same time, greater credibility as to the estimation of the policy effect by re-estimating the effect can be gained from conducting a panel data analysis in addition to the above DID analysis.

Lastly, in order to assess the exact levels of contributions made by each policy instrument, each type of sources was further divided into their component sources. The amount of particulates emissions can be calculated using existing formulas. For example, in the case of emissions from the road mobile sources, the amount of emissions is a function of emission coefficient, the driving distance and the number of vehicles in operation. In other words, while the previous analysis required controlling over the third factors in order to estimate the emissions amount, since emissions amount is computed based on a particular formula, the size of policy effects of each policy instrument exerted over particular emission component can be independently estimated. For example, since the DPF installation is a mean to reduce the emissions from the road mobile sources by diminishing the emission coefficient, if the value of the coefficient decreased only by little, we can deem the policy tool as relatively ineffective.

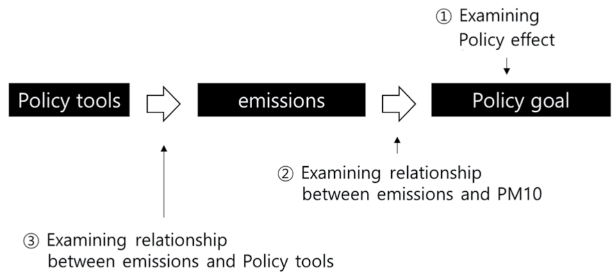

Fig. 3. Scheme of analyses.

Though the Plan employed an array of different policy instruments, as mentioned in Fig. 1, an overwhelming majority of the budget for the Plan was used only on a few. Hence, the appropriateness of the policy design as the government proposed and implemented can be assessed in the process of undertaking the analyses planned for this study. In other words, an indirect assessment of the policy design is attempted in addition to evaluating the effectiveness and efficiency of the policy instruments.

4. DETERMINANTS OF PM_{10} CONCENTRATION

In order to estimate the policy effects as well as the emissions amount from the source that chiefly affects the concentration level, any 3rd factors that may affect the PM_{10} concentration level must be controlled for. Fig. 4 depicts a generalization of determinants of the PM_{10} concentration. As can be seen, the level of PM_{10} concentration is determined by the factors that affect the influx from or outflow to the external environment, factors that generates or eliminates the particulates internally, and factors that affect the process of particulates generation by chemical reactions in the atmosphere.

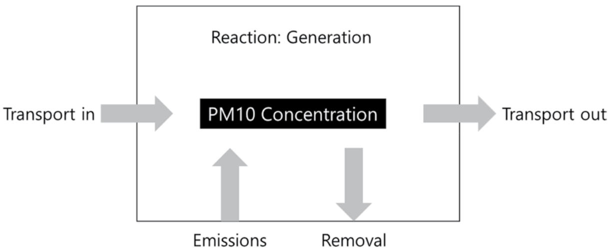

Fig. 4. Determinant factors of PM_{10} concentration. Source: Kim (2006).

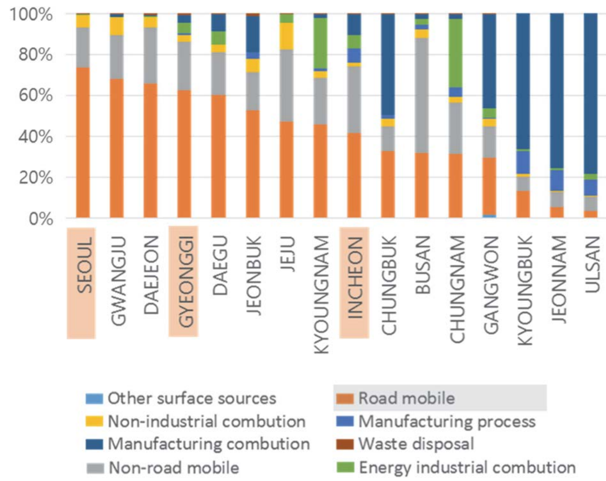

Fig. 5. Emissions amount per city and province in South Korea in 2012. Source: National Pollutants Emission Service (http://airemiss.nier.go.kr). *Metropolitan areas emphasized while the rest are non-metropolitan areas.

Although it is possible to generalize the determinants of the PM_{10} concentration, in the process of its application, the geographic characteristics must be taken into account. For example, the PM_{10} level in South Korea, located adjacent to China, is more susceptible to and greatly affected by the influx of atmospheric particulates that originate from China. On the other hand, countries that are not located as close by, will experience little effect of such PM_{10} influx. In a similar fashion, the emissions from the road mobile sources in Seoul metropolitan areas is greater than those from the other sources. Further, in certain areas, emissions from point sources surpass those from the road mobile sources. As such, regional characteristics must be appropriately considered in the process of examining determinant of atmospheric particulates concentration.

First, in terms of external influx into South Korea, it is suspected that the influx from China is the primary factor that affects the PM_{10} level in the country. This is because China consumes enormous amounts of coals, among other fossil fuels, that generate immense amount of exhaust emissions (Kim, 2006; Kim *et al.*, 1999). Many previous researches have already examined how much domestic PM_{10} concentration level is affected by external influx of atmospheric particulates into Korea, and such researches does estimate that a substantial part of the domestic PM_{10} concentration level is due to the influx from external sources (Kwon *et al.*, 2016; Nawahda *et al.*, 2012; Song and Calmichael, 2001). As such, this study attempted to control for the effects of the external influx, using the number of days of continued yellow dust from abroad that Government records[15].

Second, government data were used to represent the amount of domestic emissions. According to the government classification system of emission sources - point, area, road mobile and non-road mobile sources, data for each type of sources per region and per year were aggregated in order to come up with annualized data that properly reflect regional characteristics. In particular, as there has been a modification in the formula for calculating the amount of emissions that yield different figures of estimated emission amount at different points in time during the period of the Plan, this study uses only one formula throughout the process of estimating emissions amount in order to enhance the accuracy of the analysis results.

Third, since the amount of emissions of each region reflects the characteristics of the relevant city or province, we viewed specific characteristics of each city as a determinant of PM_{10} concentration. Many studies on the relationship between urban characteristics and air pollution levels have found that the traffic volume and the size of population within a geographic boundary affects the level of air pollution in area (Choi, 2009; Mats *et al.*, 2008; Jerrett *et al.*, 2007). However, as the correlation coefficient between the number of registered vehicles and the population size within a certain area is as high as 0.98 while the correlation coefficient between the number of registered vehicles and the number of enterprises

[15]Since the measure of number of days of continued yellow dusts is nationwide figures, the measure shows variability among different years but is subject to identical regional limitations. While the effect of number of days of continued yellow dust is expected to vary depending on regions, the data was still used because available data is limited.

expected to cause atmospheric particulates emissions, except for the services sector, is 0.89, we viewed that the population size in a certain region properly represent the severity of traffic volume and industrial activities and used it as the only regional characteristic that is controlled for. As a result, the socioeconomic difference between the metropolitan area and the non-metropolitan area was statistically controlled by population that reflects socioeconomic status.

Fourth, the generation of atmospheric particulates by chemical reactions in the atmosphere, its outflow, and removal of particulates within a country are closely related with the meteorological conditions of the country[16]. Hence, regional weather characteristics were also attempted to be controlled for. In particular, wind speed and precipitation are generally considered as the main meteorological factors that affect the particulates concentration. This is because wind speed is responsible for the influx as well as efflux of atmospheric particulates while precipitation lowers the PM_{10} concentration level by washing down the particulates in the atmosphere (Chae, 2009). While there is a contrasting view as to the role of relative humidity - one view that it increases the concentration level because of moisture in the air absorbing particulates (Shin *et al.*, 2007) whereas another views it decreases the level by washing down particulates (Chae, 2009), regardless of the direction, it is regarded to have a statistically significant effect on the PM_{10} concentration level. Finally, we viewed average temperature of a region as another determinant of particulates concentration as it affects the people's behavior pattern as well as other meteorological elements within the region.

Fifth, we assume oil price as an important external factor that may affect the particulates concentration level by affecting people's behavior. Since higher price of oil leads to greater number of people using public transportation, the emissions from the use of private cars is likely to decrease[17]. At the same time, the level of domestic production also fluctuates due to its sensitivity to changes in the oil prices. Higher oil prices are likely to lead to lower emissions of particulates from point sources. Therefore, oil price was included in the study as an external determinant as it changes of people's driving and production behavior. As a variable to represent the oil prices, the Dubai crude oil price was used. The selection of the Dubai crude oil price is justified based on the correlation coefficient of 0.97 or higher between the price of Dubai crude oil and those of gasoline and diesel.

All of the data used in this study are from the official data made available by the Korean government for 16 cities and provinces between 2000 and 2014[18,19]. Further, annual average figures were used because certain data were available only in those terms while certain data such as PM_{10} concentration levels were also available on daily as well as monthly basis. Thus, for the purpose of ensuring uniformity, annual average data were used to construct the panel data used in the analysis and accordingly the data does not consider intra-year variations.

5. RESULTS OF ANALYSES

5.1 Analysis of the Policy Effect in the Target Area: Difference-in-Differences Analysis

Because the policy instruments of the Plan were put into effect in 2005 with its scope limited to the Seoul metropolitan area, the case can be well regarded as a natural experiment. Thus, it is possible to gauge the presence as well as the size of the policy effect by examining the differences in the atmospheric particulates concentration levels between the target area and the non-target area as well as between a pre-intervention point in time and a post-intervention point in time - before and after 2005, the year of policy implementation. Fig. 6 compares the time-series trends of the atmospheric particulates concentration levels in the metropolitan area and the non-metropolitan areas. In the case of the metropolitan area, a decrease in the particulates concentration level before

[16]Secondary generated PM_{10} was not directly considered because it was difficult to measure. Therefore, this study attempted to consider the meteorological environment that affects secondary generation.

[17]In Seoul metropolitan area with relatively advanced and convenient public transportation system, the share of public transportation out of total transportation use reaches 54.3% (Ministry of Land, Transport and Maritime Affairs, 2010). Thus, the substitution of public transportation for private cars is easy in a relative sense.

[18]While there are total 17 metropolitan areas and provinces, Sejong City is excluded from the scope of this study as it was established only after 2012.

[19]The number of registered residents and meteorological information were obtained from the Statistics Korea (https://kostat.go.kr) using the 2000–2014 annual average figures in 16 cities and provinces., and annual average price of Dubai crude from https://www.statista.com/statistics/262858/change-in-opec-crude-oil-prices-since-1960.

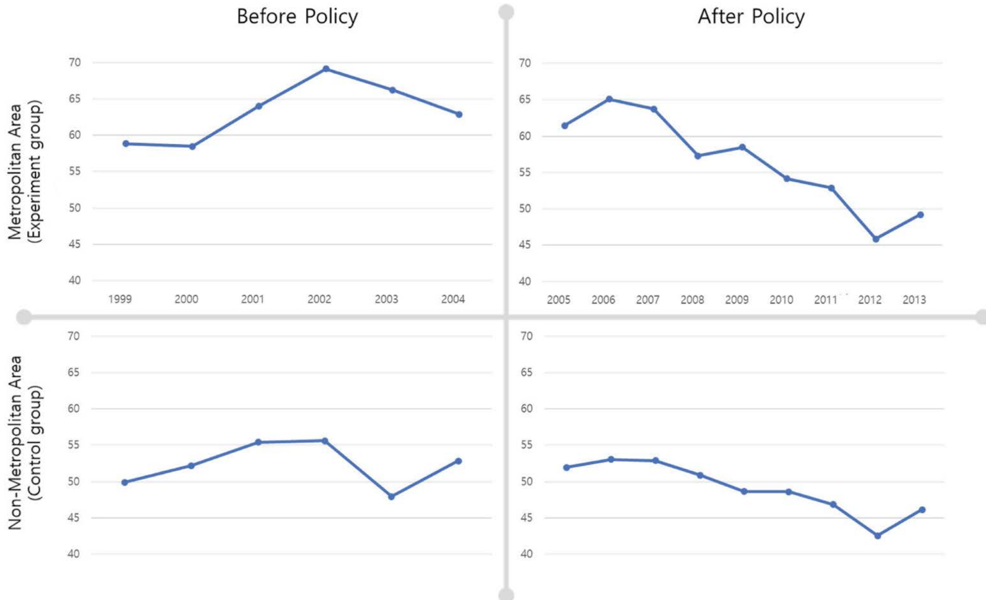

Fig. 6. Trends in particulates concentration levels in metropolitan areas and non-metropolitan areas.

and after the introduction of the policy is obvious. While there was a decrease in the level in the non-metropolitan areas, the size of the decrease is slightly smaller. In addition, given the fact that the downturn has started after their peaks in 2002, the policy effect of the plan is better interpreted to have accelerated the speed of emissions reduction, rather than reversing a pattern of increase into a pattern of decrease. Particularly, while there was an apparent gap between the patterns shown in the metropolitan area and the non-metropolitan areas prior to 2005, post-2005 levels show similar patterns in both the metropolitan area and the non-metropolitan areas. However, as discussed above, factors such as population size, characteristics of type of emission sources, meteorological factors, and external factors must be also taken into account in order to accurately evaluate the policy effect.

Estimating the policy effect while controlling for other factors that may affect particulates concentration level produces the results shown in Table 3. Expressed in standardized coefficients, the effects of policy measures implemented under the Special Act on Seoul Metropolitan Air Quality Improvement are not statistically significant. In other words, the extent of emissions reduction in the metropolitan area, was not sufficiently differentiated so as to give statistical significance from that of the non-metropolitan. The results are the same when the time of policy effect expression is adjusted to 2006 and 2007. However, what was discovered that the role of the road mobile sources and the number of days of continued yellow dusts are remarkable for atmospheric particulates concentration. Meteorological factors such as temperature and relative humidity also appear to play a role. Further, oil prices have been shown to have the strongest impact on the reduction of particulates concentration level[20].

5.2 The Relationship between Emissions and PM_{10} Concentration

Although the PM_{10} concentration level in the Seoul metropolitan area did show a downward trend since the policy implementation, the size of the reduction was not differentiated enough from that of non-metropolitan areas, and therefore a clear policy effect could not be observed in the process of estimation. Thus, it becomes necessary as mentioned in the research design, to determine which type of emission sources affects particulates concentration level. If the effect of the policy instrument the government has chosen is insignificant, we can

[20]The reason why the point pollution source is significant in the concentration of PM_{10} is because it acted as an outlier in 2007 due to the surge of point pollution sources in the non-metropolitan area. These changes have been raised by the addition of items (non-metallic mineral products) for emission aggregation in the estimation of point pollutants and are not significant if regional characteristics are controlled.

Table 3. Estimation of policy effects using the difference-in differences model (Using standardized coefficients).

		2005	2006	2007
Metropolitan area or non-metropolitan areas (Metropolitan area = 1)		0.479** (0.237)	0.531** (0.226)	0.648*** (0.217)
Pre- and Post-policy implementation (Post-policy implementation = 1)		−0.0748 (0.177)	−0.197 (0.180)	−0.169 (0.166)
Policy effects (cross terms)		−0.274 (0.244)	−0.287 (0.235)	−0.433* (0.229)
Sources (Unit: KT)	Point sources	−0.173*** (0.0511)	−0.172*** (0.0508)	−0.171*** (0.0505)
	Area sources	−0.0276 (0.0497)	−0.0248 (0.0495)	−0.0165 (0.0493)
	Road mobile sources	0.372*** (0.0946)	0.355*** (0.0950)	0.317*** (0.0961)
	Non-road mobile sources	0.0115 (0.0656)	0.0201 (0.0656)	0.0369 (0.0658)
Population as number of registered residents (Unit: Million)		−0.0115 (0.0890)	−0.0245 (0.0889)	−0.0244 (0.0878)
Meteorological factors	Precipitation	−0.0842 (0.0513)	−0.0722 (0.0516)	−0.0741 (0.0508)
	Average temperatures	−0.253*** (0.0597)	−0.258*** (0.0587)	−0.248*** (0.0587)
	Average wind speed	0.0496 (0.0632)	0.0437 (0.0626)	0.0267 (0.0632)
	Average relative humidity	−0.173*** (0.0488)	−0.179*** (0.0486)	−0.179*** (0.0489)
	Number of days of sustained yellow dust influx	0.192*** (0.0596)	0.216*** (0.0615)	0.199*** (0.0566)
External factors	International oil prices (Dubai crude)	−0.136 (0.0895)	−0.0811 (0.0928)	−0.0951 (0.0833)
Constant		−0.00966 (0.117)	0.0390 (0.106)	0.00557 (0.0922)
Observations		240	240	240
R-squared		0.517	0.522	0.528

conclude that the policy response has been wrongly designed. Further, if the emissions from the road mobile sources does have a statistically significant impact on the particulates concentration level, we must examine relevant policy instruments that are behind such result. In this study, a panel data analysis was employed to investigate the effects of emission amounts on the PM_{10} concentration level.

Table 4 shows the coefficient estimates obtained from applying the fixed-effects model to the relationship between the PM_{10} concentration levels and emissions from each type of sources. The fixed-effect model differs from the difference-in-differences model in that the former controls for the regional characteristics and time-specific characteristics (two-way fixed effects model) the difference-in-differences model does not observe or thus is unable to take into account. Particularly, from Model 1 to Model 4 the fixed-effect models can affirm the robust-

Table 4. Panel regression analysis of the PM_{10} concentration (Using standardized coefficients).

Classification	Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Sources of emissions (Unit: KT)	Point sources	−0.100* (0.0581)	−0.0884 (0.0576)	−0.0579 (0.0531)	−0.0905* (0.0534)	−0.0291 (0.0521)
	Area sources	−0.0159 (0.0430)	−0.0142 (0.0424)	−0.0166 (0.0390)	−0.0323 (0.0413)	−0.0257 (0.0389)
	Road mobile sources	1.005*** (0.0949)	1.115*** (0.103)	1.101*** (0.0968)	0.700*** (0.0997)	0.899*** (0.142)
	Non-road mobile sources	0.0874 (0.149)	0.00836 (0.150)	0.118 (0.139)	−0.0105 (0.100)	0.0676 (0.143)
Metropolitan factors (Unit: millions)	Population of registered residents		1.316*** (0.505)	1.557*** (0.481)	−0.0488 (0.125)	1.517*** (0.495)
Meteorological factors	Precipitation			−0.0168 (0.0405)	−0.0313 (0.0434)	−0.0114 (0.0469)
	Average temperatures			0.0816 (0.0893)	−0.0506 (0.0757)	−0.00194 (0.0980)
	Average wind speed			0.105 (0.0691)	0.0369 (0.0655)	0.135* (0.0694)
	Average relative humidity			−0.0858 (0.0520)	−0.0552 (0.0505)	−0.0444 (0.0561)
	Days of continued yellow dust influx			0.227*** (0.0390)	0.196*** (0.0440)	
External factor	International oil price (Dubai crude oil)				−0.107** (0.0489)	
Policy factor	Post 2005 Metropolitan area					0.0156 (0.195)
Constant		0.0517 (0.0364)	0.0497 (0.0360)	0.0104 (0.0335)	0.0183 (0.103)	0.125 (0.226)
Observations		240	240	240	240	240
R-squared		0.352	0.372	0.491		0.557
Number of regions		16	16	16	16	16
Panel effects		Fixed	Fixed	Fixed	Random	Fixed

ness of coefficient estimates by estimating per-source emission levels, thought to be the primary factor affecting the concentration, while sequentially controlling for regional characteristics, meteorological factors, external and other factors in the process. In addition, using standardized coefficients, the study attempts to identify the relative size of each factor's impact on the PM_{10} concentration levels.

First, it shows that only the road mobile emissions had consistent effect on the PM_{10} concentration. In all four models, concentration level increased as emissions from the road mobile sources associated with vehicle operation increased. The standardized coefficients are relatively large and stable, implying the need for regulating this particular type of sources of emissions. In addition, the number of registered residents, an urban characteristic, appear to have a statistically significant and, in a relative sense, the greatest effect on PM_{10} concentration, meaning that when all other factors are held constant, greater number of people is likely to translate into greater frequency of activities in daily life, increasing the PM_{10} concentration.

Model 3 and Model 4 take into consideration the meteorological factors. It was found that among several factors, the number of days of continued yellow dust influx has a statistically significant effect on PM_{10} concentration and the amount of such influx is substantial. Further, it appears that higher international oil price as an external factor decreases the concentration. Thus, it can be interpreted that a rise in the oil price will also raise the fuel prices, such as those of gasoline and diesel, that in turn lead to reduction in the frequency of vehicle use as well as total driving distance along with increased use of public transportation. Resulting was the reduction in the PM_{10} emissions from road mobile sources and in the emissions of atmospheric arsenic. However, in that effects of the oil price on PM_{10} concentration could have been partly reflected in the estimation of the emissions from the road mobile sources, there is a possibility that the estimate at hand is somewhat underestimated. Also, unlike the other models, Model 4 does not control for the time characteristics because the factors of number of days of continued yellow dust influx and international oil price have been measured on the annual basis[21].

The panel analysis revealed that only emissions amount of the road mobile sources has consistent effect on the PM_{10} concentration level regardless of whether various other factors are held constant. As shown in Fig. 5, except for some cities, the emissions from the road mobile sources accounts for the largest shares of total emissions. Thus, it is reasonable to predict that among domestic sources, emissions from the road mobile sources play a major role. The data listed in Table 4 further confirms the role of emissions from the road mobile sources as the primary factor that affects the particulates concentration level even as all other variables are controlled for. This result indicates that the design of the policy that emphasized reduction in the emissions from the road mobile sources is not ill founded.

Having proved that the emissions from the road mobile sources does have a statistically significant effect on the particulates concentration level, why the government policy instrument did not succeed in reducing particulates concentration level in the policy target area needs to be explained. In other words, the effects of individual policy instruments that target reduced emissions from the road mobile sources must be assessed.

5.3 The Effect of the DPF Installation Subsidy as a Policy Instrument

Thus far we have confirmed a reduction in the particulates concentration level in the Seoul metropolitan area as well as in the non-metropolitan areas. We have also found that emissions from the road mobile sources are the primary determinant of particulates concentration level. Consequently, it is reasonable to test the hypothesis that the particulates concentration levels in the target area and the non-target areas decreased because the emissions from the road mobile sources decreased in both areas.

As shown in Fig. 7, the changes in emissions from each type of vehicles from 2000 to 2012 reveals that almost all emission sources had comparable changes in both the metropolitan and non-metropolitan areas. Particularly, emissions from buses and vans started to decrease prior to 2005, while emissions from RVs, freight vehicles, and special vehicles showed little difference between the metropolitan and the non-metropolitan area despite observable ups and downs. Emissions from passenger vehicles, on the other hand, increased after the policy intervention albeit a slight difference between those in the metropolitan and the non-metropolitan areas. In short, although emissions from all type of vehicles with the exception of passenger vehicles decreased since 2005, when the Plan targeting emissions reduction in the metropolitan area was implemented, the difference in the amounts of reduced emissions between the metropolitan area and the non-metropolitan area is not different[22].

[21]As policy effect can be estimated from a panel data analysis, this study employed the method in order to reaffirm the policy effect. The DID method used above has advantages of allowing using different years as a point of policy effect expression, its analysis results are limited in that it does not consider intra-region characteristics. On the other hand, a panel data analysis can consider such characteristics. Model 5 that estimates the overall policy effects of the 1st plan using the dummy variable designated for the post 2005 metropolitan area did not find any statistically significant effects of any of the included factors. In other words, when taking into account the regional and year-specific characteristics as well as the PM_{10} emissions and meteorological factors, the PM_{10} concentration in post 2005 metropolitan area did not show an appreciable difference when compared to other regions.

[22]Point and non-road mobile sources emissions did not show much difference between the metropolitan and the non-metropolitan areas or post-2005 decrease only in the metropolitan area either.

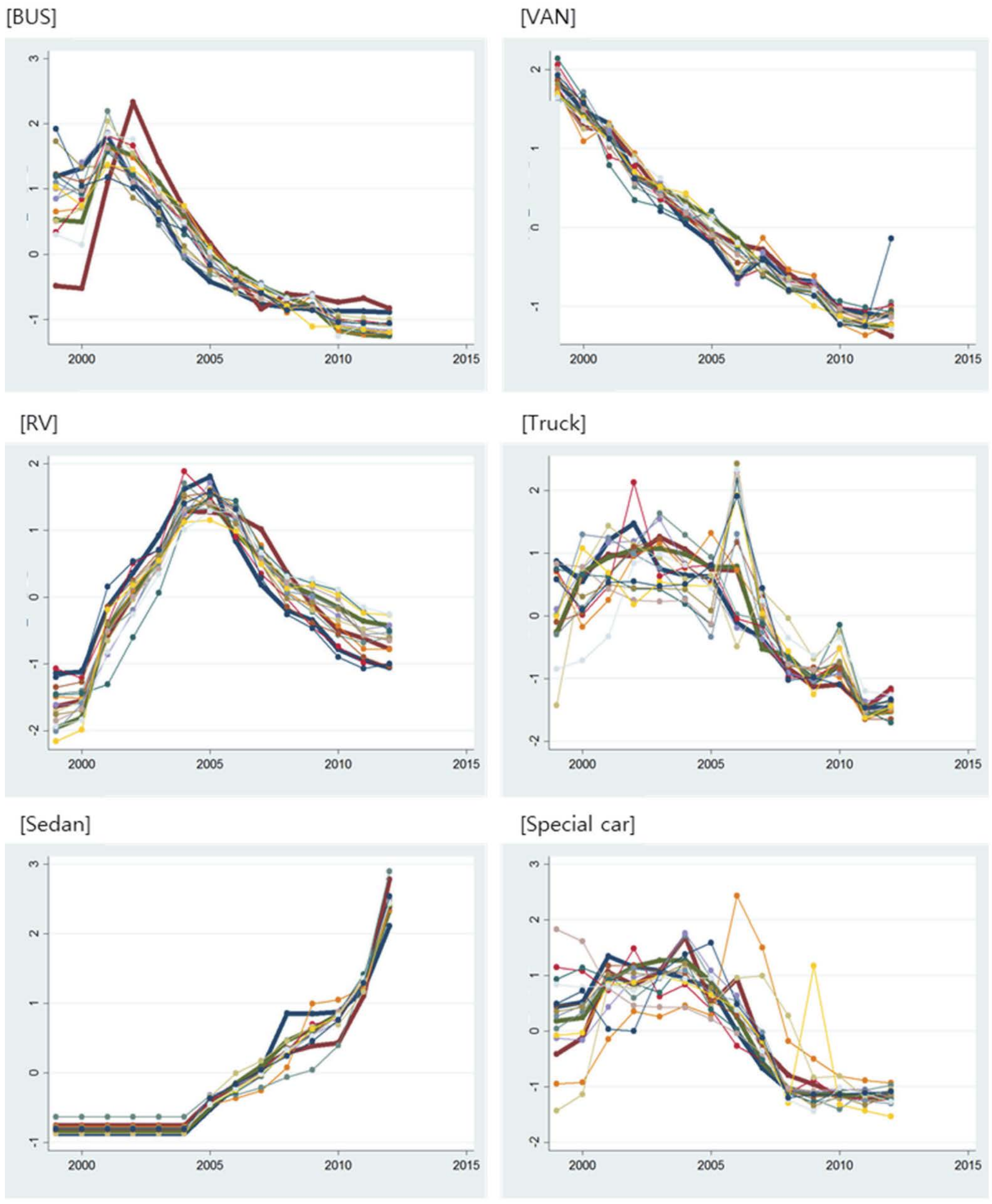

Fig. 7. The trends of emissions from road mobile sources in 16 cities and provinces (Metropolitan area in thick line).

The above findings necessitate a return to the discussion of the policy instruments that generate policy effects in order to account for why there were no policy effects sufficiently differentiated between the Seoul metropolitan and the non-metropolitan areas. As mentioned earlier, the government's policy to reduce emissions from the road mobile sources focused on the strategy of installation of diesel particulate filter (DPF) in diesel-powered vehicles. An audit report on the Plans by the Board of Audit and Inspection of Korea shed a light on a critical aspect in the implementation of the program: while the rate of DPF installation on vehicles of high exhaust gas emissions (exhaust concentration levels above 50%) decreased annually, the rate of installation on low-emissions vehicles (exhaust concentration under 10%) showed annual increase (the Board of Audit and Inspection of Korea, 2016: 28). Needless to say, the resulting policy effect of expanding DPF installations was in reality far less than originally expected.

However, it is still hard to reconcile the fact that the

PM_{10} emissions in both the metropolitan and the non-metropolitan areas decreased to a similar extent and in a similar pattern with the fact that in the Seoul metropolitan area the subsidy programs for engine conversion and early vehicle scrappage programs were implemented based on the Plan and the emissions from road mobile sources decreased to a great extent. An alternative explanation could be that a third factor's effect that reduced emissions in both areas outdid the Plan's policy effect in the Seoul metropolitan area. To examine this hypothesis, we need to assess the emissions from on-road mobile sources. The formula for estimation is below:

Formula 2

Emissions (kg/year)
= ∑[emissions coefficient (kg/km: vehicle model, fuel, speed)
× driving distance (km/year) × number of cars (model)]
(as for engine combustion emissions)

Source: Kim *et al.* (2020, p. 60)

Thus, the emissions from the road mobile sources is a function of emission coefficient of each car model, driving distance and the number of cars of the same model, while emission coefficient is a function of car model, fuel and speed and driving distance is a function of car model and driving route. The number of cars is the number of on-road vehicles of each car model. The installation of DPF mentioned earlier and engine conversion program is a representative policy instruments chosen for the purpose of reducing emission coefficient. Early vehicle scrappage program, on the other hand, is a policy instrument that reduces the number of vehicles on the road.

What is important, as implied in the formula, is that emissions from the road mobile source can be reduced by reducing emission coefficients as well as cutting down the driving distance and the number of cars on the road. For example, Fig. 8 and Fig. 9 depicting the rate of change in the number of registered vehicles and average daily driving distance in each province and major city show that the rate of increase in the number of registered vehicles in metropolitan areas is not markedly higher than those in the non-metropolitan areas. In fact, the rate of increase is the lowest in Seoul. That is, the number of registered vehicles rose in all provinces and cities, and it can be inferred that the PM_{10} emissions has increased accordingly. Yet, the daily average driving distances in all provinces

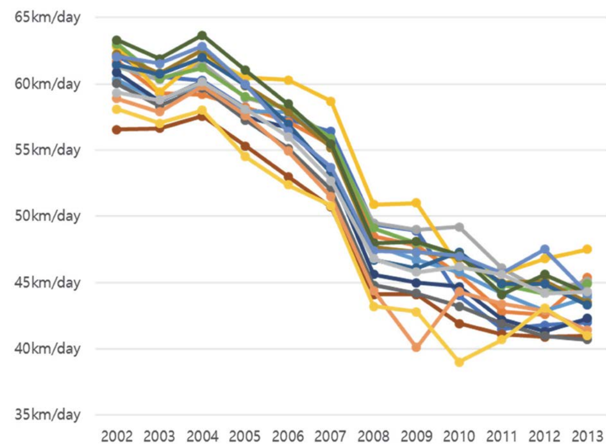

Fig. 8. The rate of change in the number of registered vehicles per city and province (as of 2004). Source: The Korea Transportation Safety Authority[23], Han *et al.* (2017).

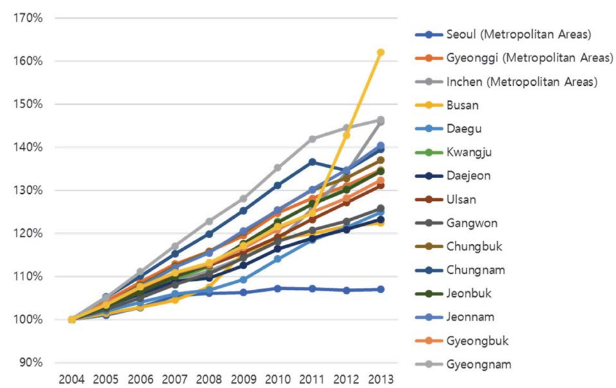

Fig. 9. Daily average driving distance per city and province. Source: stat.molit.go.kr, Han *et al.* (2017).

and major cities, an important factor in calculating the emissions, have decreased since around 2005 displaying a similar overall fashion among them.

In sum, the most reasonable inference is that DPF installation and other emissions reduction programs did decrease the emission coefficients while the number of registered vehicles has increased and the average driving distance decreased. In such a circumstance where the effects of the factors that affect both the metropolitan and the non-metropolitan areas overshadow the effect of the policy instrument that was differentially applied between the control and the target areas, reduction in emissions depends on not just one factor, but on multiple factors as

[23]https://www.kotems.or.kr/app/kotems/forward?pageUrl=kotems/ptl/bbs/KotemsPtlBbsStatsLs& topmenu=07&leftmenu=03#003

well as their relevant sizes of effect, complicating the attempt to estimate the policy effect.

Nonetheless, such inference does not mean that the government policy to reduce the emissions coefficient has failed. Rather, more appropriate conclusion is that the policy instrument implemented with the objective of reducing emission coefficient has not produced a notable outcome in light of the changes in the non-metropolitan area despite the fact that it was the government's primary policy instrument that exhausted the majority of the budget. Therefore, its effectiveness is less than satisfactory even as there does exist sufficient causality between the policy instrument and the policy objective. Furthermore, the results obtained from analyses indicate that the rising oil price is more likely to be the factor that was behind the reduced nationwide driving distance. As can be seen in Table 4, higher oil price is likely to lead to lower particulates concentration level. As the oil price has hovered its record high since 2005, it is likely that people were motivated to use public transportations rather than driving private cars. Consequently, despite the fact that the lion's share of the budget was used to reduce emission coefficients of the road mobile sources, the primary factor that had the most dominant effect on the actual decrease in the particulates concentration level was the decrease in the total nationwide driving distance due to the rise in the oil price.

The Table 5 summarizes the discussions above. In all geographic areas, the number of registered vehicles increased while the average driving distance per car decreased. On the other hand, the emission coefficients in the target area and the control areas moved in different directions - a decrease in the emission coefficient in the metropolitan area, the presumed policy effect. As iterated earlier, what appears puzzling here is the fact that emissions from the road mobile sources have decreased in both the metropolitan and the non-metropolitan areas to a similar extent. Given the factors in the formula, a likely explanation is a case where the extent of decrease in the driving distance is overwhelmingly dominant so as to obscure the differences in the number of registered vehicles and the differences in the size of decreases in emission coefficients, the policy effect, between the metropolitan and the non-metropolitan areas. In other words, although the Plan must have reduced the emission coefficients in the metropolitan area, the fact that such policy effect nonetheless did not result in critical difference between the metropolitan and the non-metropolitan areas means that it was not a cost-efficient policy instrument vis-à-vis the nationwide decrease in the average driving distance. Also, assuming that such result did arise from differences in driving distances, it can be inferred that more efficient policy instruments should have been

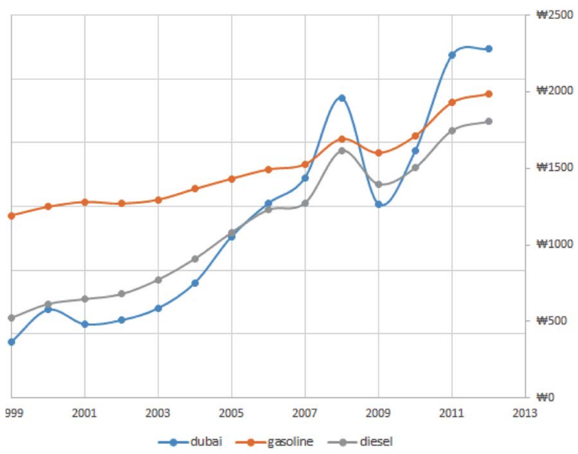

Fig. 10. Gasoline and diesel oil price movements in Korea. Source: http://www.opinet.co.kr.

Table 5. Changes in the components of road mobile emission sources.

Components of road mobile source emissions	Metropolitan area	Non-metropolitan areas
Road mobile source emissions	Decreased ↓ (Positive effect)	Decreased ↓ (Positive effect)
Emissions coefficients	Decreased ↓ (policy effect)	
Number of registered vehicles	Increased ↑ (Negative effect)	Increased ↑ (Negative effect)
Driving distances	Decreased ↓ (Positive effect)	Decreased ↓ (Positive effect)

expansion of rotated no driving day campaign, promotion of public transportation and decrease in the driving distance due to higher oil prices rather than the DPF installation program, the cost of which accounted for an overwhelming portion of the budget expenditure[24].

5.4 Evaluation of the Effectiveness and Efficiency of the DPF Installation Subsidy Program

In sum, whereas the South Korean government's strategy of reducing emissions from the road mobile sources was supported given the role of emissions from the road mobile sources in increasing the level of particulates concentration, the policy instruments chosen to accomplish the objective became the source of ineffectiveness and inefficiency of the overall policy implementation. This is because the policy instruments of reducing emissions from the road mobile sources through DPF installations that took up 75% of the total budget showed little effect while resulting amount of emissions reduction was little different from that in the non-target area where the DPF installation program was not implemented. In view of such findings, it is more reasonable to conclude that strategies of bolstering the emissions standards as to diesel vehicles and reducing overall driving distance of private vehicles would have been more effective and efficient policy instruments[25].

For example, in order to reduce the operation of diesel-powered automobiles, introducing regulatory measures such as rotated no driving day system or raising the price of diesel fuel and adoption of environmental tax can be considered as potential policy instruments[26]. In that the above measures incur little costs for introduction, such measures with their scope limited to the objective of reducing particulates concentration level can be very cost-efficient. However, from the perspective of the society as a whole, since an increase in the diesel fuel price may inadvertently result in unwanted social costs such as rising living costs, the efficiency of a government policy instrument must also consider such risk. In this regard, domestic studies have argued for raising the price of diesel fuel as the current diesel pricing scheme underestimates and therefore does not properly reflect the full social cost incurred by using it (Kang, 2010; Lee and Han, 2009)[27]. Thus, when the expected social benefit of raising diesel prices and introduction of environmental tax is greater than the expected social cost, the efficiency of these measures is expected to be superior to that of the DPF installation subsidy program.

6. CONCLUSION

Among the broader range of atmospheric environmental issues that have attracted global attention in recent years, this study attempts to evaluate South Korea's atmospheric particulates reduction policy that was in effect from 2005 to 2015. Specifically, it attempted to test whether the policy was effective and efficient in reducing atmospheric particulates and proposed more effective and efficient policy instruments. The examination of Korea's case has following implications:

First, as the scope of this study is limited to Korea's atmospheric particulates reduction policy which was devised based on Korea's specific contextual setting, it must be noted that there may exist substantial contextual difference when applied to different countries. For one instance, while the primary domestic determinant of particulates concentration level is the emissions from the road mobile sources, it is likely that some other type of emission sources is the main culprit in other countries. Nevertheless, the most significant implication of this study is that the effectiveness and the efficiency of each

[24]The specific extent of emissions attributable to distance, nationally implemented policy specific contribution and the number of registered vehicles cannot be estimated without concrete data. However, since government organizations keep relevant data, estimation of relative contribution is possible, and based upon such findings, we can determine what potential policy tools are expected to be efficient for reduction in emissions from on-road mobile sources.

[25]Some have mentioned that DPF can remove black carbon emitted from diesel vehicles, reducing adverse health effects. In this way, DPF may have caused unexpected positive effects, but this study examined the policy effects focusing on PM_{10} based on the policy goals initially set.

[26]Among these, providing economic incentives is regarded a more efficient tool. While the option of imposing environmental tax is advantageous in that it can impose differentiated rates to old diesel vehicles and relatively fewer old vehicles, such tax cannot differentiate depending on the actual distance traveled. To the contrary, raising the price of diesel fuel can impose tax that is differentiated based on the driving distance, the limitation of the measure was imposing tax on diesel vehicles with relatively little particulates emissions. Thus, for implementation, a discrete mix of environmental tax and raising the price of diesel fuel is expected to be the most efficient.

[27]The relevant studies argue that the social costs arising from air pollution due to the use of diesel fuel is not properly are not properly known and therefore reflected, and such social cost must be reflected properly in the pricing of diesel fuel. Furthermore, the pricing must also reflect the social cost of increasing traffic volume.

policy mix used in individual countries can be examined according to the structure of analyses and process presented in this research. This study was conducted with the purpose of determining the policy effect of the Plan, identifying emissions amount per different type of emission sources that affect particulates concentration level, and evaluating the effectiveness and the efficiency of the relevant policy instruments. Such structure and process is equally applicable to policy design and evaluation in other countries.

Second, while the exact components of policy mix vary among different countries, most of the policy mixes in place include measures that aim at reducing emissions from the road mobile sources. This study has identified effective and efficient policy instruments that can reduce emissions from the road mobile sources, and such conclusion is applicable to other countries. This is because, unlike other type of emissions sources, policy instrument available for consideration must target diesel fueled vehicles by reducing the emission coefficients, travel distance, or the number of those vehicles on the road. Particularly, since reducing the travel distance is a tool of superior efficiency that requires no cost on the part of the government, the strategy can be adopted in countries where it is hard to secure budget for the purpose of alleviating atmospheric particulates concentration. However, while the means of raising the diesel fuel prices was deemed to be efficient in the case of Korea since its social benefit is expected to be larger than the social cost, the actual ratio between social benefit and social cost is strictly contingent upon the specific contextual factors each country face, and therefore, introduction of such measure may be difficult whereas the social cost exceeds the social benefit. As such, careful assessment of expected social benefits and costs must be conducted prior to introduction.

Third, due to the unpredictability inherent in the atmospheric environment, evaluation of policies that aim at improving air quality is conducted on the basis of simulations or statistical methods that compare differences between the states with and without government intervention. Regardless of which method is used, the most important task in estimating policy effect is to obtain a control group that is as similar to the treatment group as possible. In a field that takes the ever-changing atmospheric environment as its subject, more refined evaluation methods must be continuously devised.

Lastly, when dealing with issues characterized by sporadic changes and unpredictability such as air quality, oftentimes, there is insufficient information to determine causality and effectiveness of a policy. Nevertheless, when a policy needs to be consistently pursued on a long-term basis, utilization of scientific information and planning as well as careful coordination among relevant policy instruments are essential. This is because the longer a policy's time scope is, the bigger the opportunity cost and the cost of policy implementation become. Moreover, discordance among policy instruments due to lack of coordination can cancel out intended policy effects. Of no less importance, proactive efforts must be made to accumulate information on various aspects of a policy regardless of sources - pilot studies as well as existing policy instruments - and to utilize them in all stages of policy analysis, formation and coordination.

However, this study has the following limitations in the research process. First, this study focused on the targets and effects mentioned in the 1st Basic Plan and examined whether PM_{10} was reduced, but DPF could have additional effects except for PM_{10} reduction. Second, secondary generation for PM_{10} was not considered as a measurement problem. Third, although there are costs paid by the private sector during the plan, there is a limit that considers only government budgets as an input factor due to measurement problems. Fourth, there is a limit to not being able to consider a new emission source by changing the emission calculation method. This limitation was partially considered by controlling the year in the process of estimating the policy effect through panel analysis.

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