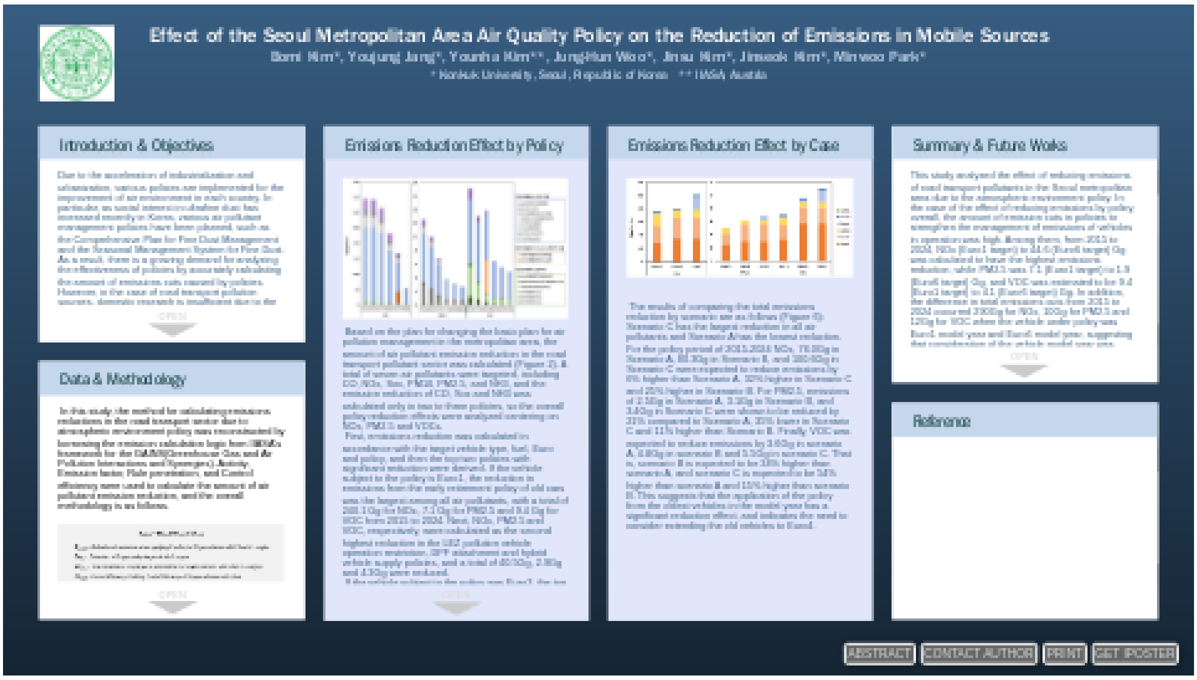
Effect of the Seoul Metropolitan Area Air Quality Policy on the Reduction of Emissions in Mobile Sources



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Climate change
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Information
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Research group

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Ⅰ. INTRODUCTION & OBJECTIVES

As the amount of air pollutant emissions increased due to the acceleration of industrialization and urbanization, various policies are implemented for the improvement of the air quality in South Korea. As social interest in high $PM_{2.5}$ concentration has been increased, more stringent air pollution management policies have been implemented, such as the Comprehensive Plan for Fine Particle Management and the Seasonal Policy for Fine Particle Management. As a result, there is a growing demands for analyzing the effectiveness of policy measures by accurately estimating the amounts of emission reduction. The emissions reduction estimation, however, have not been estimated accurately due to the complexity of activity data, high uncertainty of emission factors, and/or limited control technology application information, especially in Seoul Metropolitan Area(SMA), the capitol region of South Korea.

The Seoul Metropolitan Area(SMA) is an area where air pollution and human damage are aggravated due to high population density. Currently, the total population of South Korea is about 52 million, with the SMA's total population of 26 million, accounting for 50 percent of the nation's population. Also, the total number of cars registered in the SMA is about 11 million, accounting for 44 percent of the country. For fine particle improvement, 2.7 billion US dollars will be spent from 2015 to 2024 in the SMA, of which 75 percent will be spent on the emission control of mobile sources pollutants.

Therefore, The purpose of this study is to:

- Estimate the emissions reductions on mobile sources by the current fine particle improvement policy
- Analyze the effect of applying policy measures to the most polluted vehicles first
- Analyze the effects expanding the target of the early retirement policy from pre Euro-3 to pre Euro-4

Ⅱ. RESEARCH FRAMEWORK

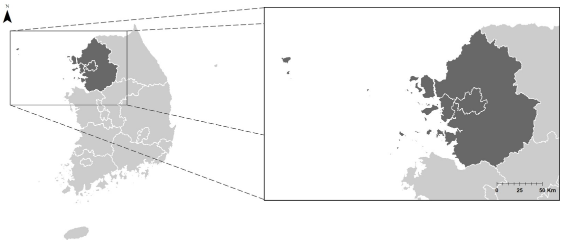

Figure 1. Target location

: Seoul Metropolitan Area (SMA)

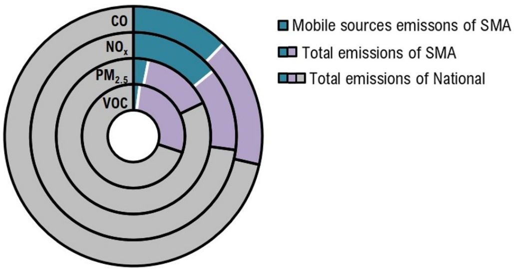

Figure 2. Mobile sources emissions ratio

As shown in Figure 1, the areas subject to this study were set as Seoul Metropolitan Area. Annual NO_x, $PM_{2.5}$ and VOC emissions in the Seoul metropolitan area are 322.9 Gg/yr, 16.4 Gg/yr and 314.9 Gg/yr, respectively, accounting for 27%, 18%, and 30%, respectively of entire country(NIER, 2017).

In 2019, the population of the SMA is 50 percent of South Korea's total population, which are vulnerable to the air pollution induced diseases. In addition, NO_x and $PM_{2.5}$ emitted from mobile sources accounted for 52% and 18% of the metropolitan area's emissions, which were determined to be of the highest importance to SMA air environment policy. The detail emission ratios of SMA and mobile sources are shown in Figure 2.

Figure 3. GUIDE / MICS-PM model

(GUIDE, GHGs and air pollutants Unified Information Design System for Environment; Woo et al., 2019) / (MICS-PM, Multi-information Convergence System for fine particle Policy Management; Woo et al., 2020)

The framework for calculating reductions by policy measures is the GUIDE / MICS-PM model, developed by this research team(Figure 3). This model was developed based on South Korean data and is an integrated management decision-making system that links the optimal energy-activity mitigation model of greenhouse gas and air pollutants, and the follow-up air pollutant reduction model based on the current air pollution policies.

Ⅲ. DATA & METHODOLOGY

In this study, the emissions reduction calculation methodologies in the GUIDE/MICS-PM framework were used to estimate emission reductions in the mobile source sector. Activity, emission factor, rule penetration, and control efficiency were used to calculate the amount of air pollutant emission reduction, and the overall methodology is as follows.

$$R_{L,F,S,P} = Em_{L,S} \times RP_{L,S,P} \times CE_{F,S,P}$$

$R_{L,F,S,R}$: *Reduction of emissions when applying P-policy to S-type vehicles with F-fuel in L-region*

$Em_{L,S}$: *Emissions of S-type policy targets in the L-region*

$RP_{L,S,P}$: *Rule Penetration, P-policy rule penetration for S-type vehicles with F-fuel in L-region*

$CE_{F,S,P}$: *Control Efficiency, P-Policy Control Efficiency of S-type vehicles with F-fuel*

Since the policies of this study are implemented between years 2015 and 2024, BAU emissions over the period were utilized for the purpose of calculating relatively accurate emissions reductions. Based on the 2015 emissions of CAPSS, the national emission inventory, the emissions were predicted until 2024, using energy and non-energy activities, such as coal/oil/gas use, industrial production, and waste. The calculation method of rule penetration and control efficiency is as shown in Table 1, and in the case of control efficiency, the calculation method of policies with and without control technology are different. The definition of reduction scenarios (i.e. cases) to be used in our analysis are shown in Table 2.

Table 1. **Calculation method by factors**

Factor	Policy type	Method of calculation
Control Efficiency	Technology-based policy	Use technology control efficiency as policy reduction efficiency
	Non-technical policy / System-based policy	**$CE = 1 - (EF_c^{*} / EF_{uc}^{**})$** * EF_c : Controlled Emission Factor ** EF_{uc} : Uncontrolled Emission Factor
Rule Penetration	All policy	**$RP = Em_{L,F,S}^{*} / Em_{L,S}^{**}$** * $Em_{L,F,S}$: Emissions before policy application of S-type with F-fuel in L-area ** $Em_{L,S}$: Emissions of S-type policy targets in the L-region

Table 2. **Definition of cases**

<table>
<tr><th rowspan="2">Case</th><th colspan="3">Definition</th></tr>
<tr><th>Common application</th><th>Changing application order of policy measures</th><th>Measures to old operating vehicles</th></tr>
<tr><td>Case 1</td><td rowspan="3">- Based on the plan for changing the 2nd basic plan for air environment management in the Seoul metropolitan area
- Based on the number of registered cars of CAPSS 2015
- Preferential application from policies with large emission reductions</td><td>Equal allocation for all Euro</td><td>Euro1 ~ Euro3</td></tr>
<tr><td>Case 2</td><td>Applying policy measures to the most polluted vehicles first(i,e, from Euro1)</td><td>Euro1 ~ Euro3</td></tr>
<tr><td>Case 3</td><td>Same as above</td><td>Euro1 ~ Euro4</td></tr>
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Ⅳ. RESULTS (Ⅰ)

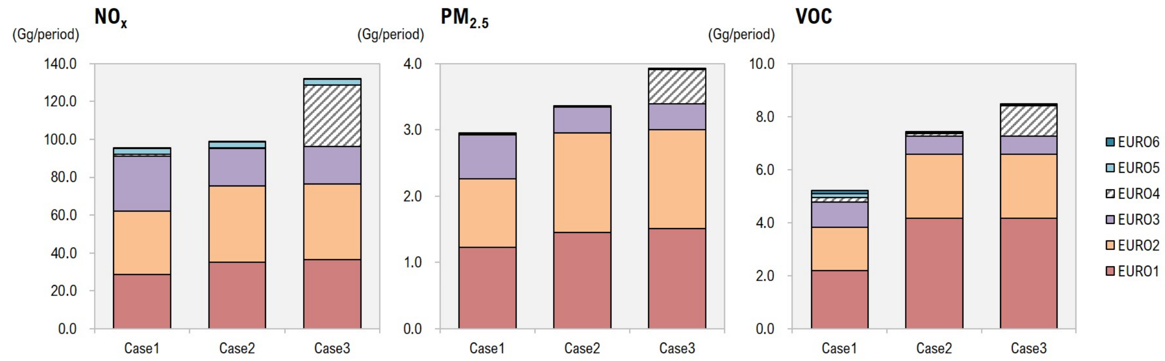

Figure 4. **Total reduction of emissions by Euro**

(period : 2015 ~ 2024)

The total emission reductions by Euro are shown in Figure 4. In Case1, 2 and 3, NO_X reduction amounts are 95.7 Gg/yr, 98.6 Gg/yr, 131.8 Gg/yr, respectively, and $PM_{2.5}$ decreased 2.9 Gg/yr, 3.4 Gg/yr and 3.9 Gg/yr, respectively. VOC reductions are 5.2 Gg/yr, 7.4 Gg/yr and 8.5 Gg/yr, respectively, showing the highest reduction in Case3 for all pollutants. For NO_X and $PM_{2.5}$, the effect of old vehicles (pre-Euro4) in operation was greater than the applying policy measures to the most polluted vehicles first policy(apply Euro1 first). This means that the measures to old vehicles in operation targeting NO_X and $PM_{2.5}$, including early retirement, DPF attachment, and SCR attachment, will have a significant reduction effect when extended to Euro4 vehicles, suggesting that the current policies for old vehicles need to be considered for extending to pre-Euro4. On the other hand, in the case of VOC, the reduction effect indicated that the most polluted vehicles first was greater effects. This suggests that the current policies for old cars are mainly effective to NO_X and $PM_{2.5}$, whereas change the most polluted vehicles first measures, such as supplying eco-friendly cars, are more effective to VOC.

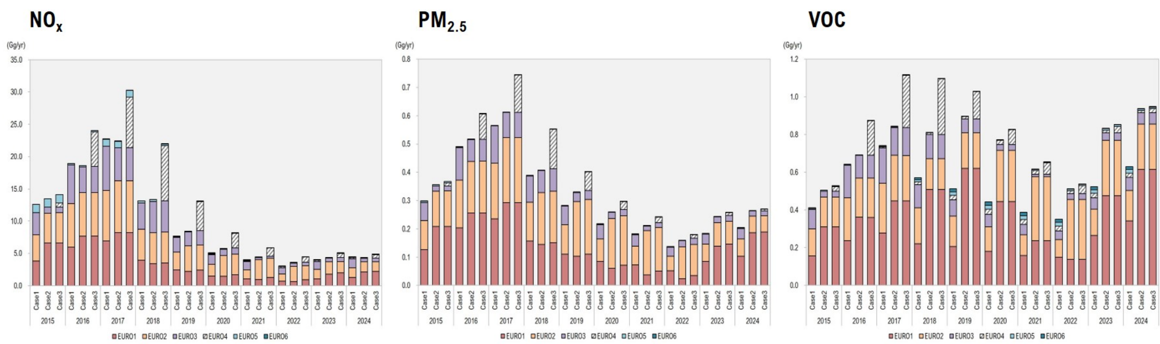

Figure 5. **Annual reduction of NO_X, $PM_{2.5}$, VOC**

by Euro

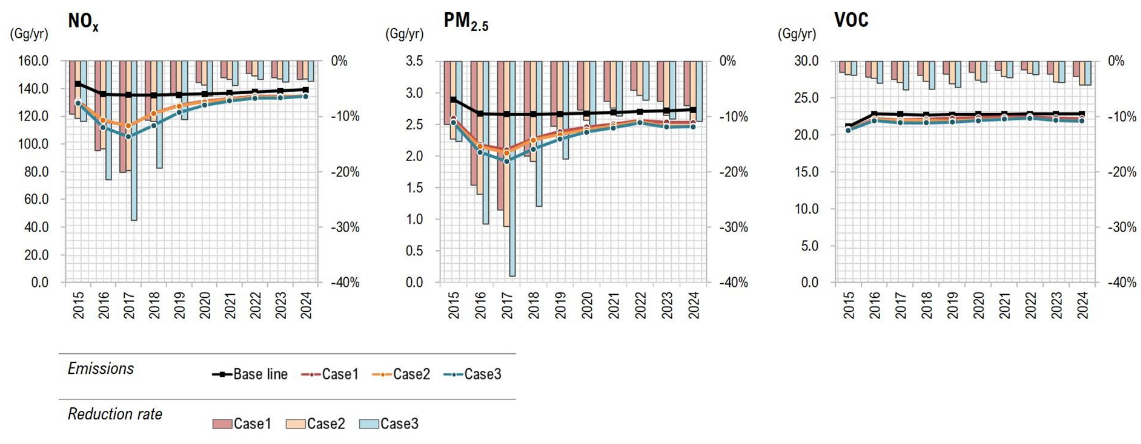

Figure 6. **Annual emissions and**

annual reduction rate by Case

The annual emission reductions and reduction rate are as follows Figure 5 and Figure 6. Overall, the 2017 reduction was the highest in all air pollutants and cases. It was judged that the policy volume was the highest in the year, and that the policy applied from 2015 had an impact. It is noteworthy that Case3, which expanded the target of old vehicles to pre-Euro4, shows a significant increase in emission reductions compared to Case2. In 2018, when the biggest difference occurs, Case3 cuts were calculated to be 65% higher for NO_x, 36% higher for $PM_{2.5}$ and 35% higher for VOC than Case2.

Ⅳ. RESULTS (Ⅱ)

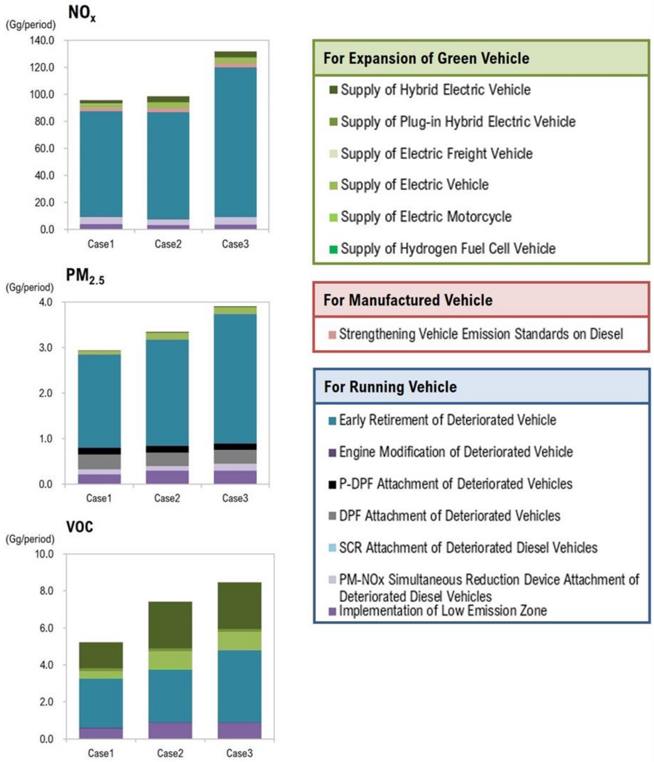

Figure 7. Total reduction of emissions by policy

(period : 2015 ~ 2024)

The total emission reductions by policy are shown in Figure 7. The policy of early retirement of old vehicles is the strongest policy, accounting for 81%, 80% and 84% of the reduction in NO_X emissions in cases 1, 2 and 3, respectively. It also led cuts of 69%, 70% and 72% , respectively for $PM_{2.5}$, and 51%, 38% and 46%, respectively for VOC. In particular, the amounts of cuts in Case3 due to early retirement policy alone increased by 40% for NO_X, 22% for $PM_{2.5}$ and 37% for VOC compared to Case2. This is a cut-off effect that can be obtained by expanding the policy of early retirement of old vehicles to pre-Euro4, which explains the high reductions in Case3.

In addition, the reduction of Case2 with the policy volume preferential allocated from Euro1 was calculated to be higher than Case1 with the same policy volume allocated to all Euro. VOC reduction in the Case 2 was calculated to be 42% higher than Case1, and only the green vehicle expansion policy increased by 88%, which resulted in a significant reduction in VOC emissions. On the other hand, NO_X and $PM_{2.5}$ were only 3% and 14% higher than Case1.

Ⅴ. CONCLUSION & FUTURE WORKS

In this study, we summarized our finding as follows;

- Assuming that the current policy will be applied until 2024, the total reduction rate in the SMA from 2015 to 2024 is 7% for NO_x, 11% for $PM_{2.5}$ and 2% for VOC.
- In Case 1, where the current policy is assumed to be maintained, the NO_x was reduced by 7%, $PM_{2.5}$ by 11%, and VOC by 2%. In addition, in case 2, where the policy was applied from the most polluted vehicles first, NO_x was reduced by 7%, $PM_{2.5}$ by 12%, and VOC by 3%. Finally, in Case 3, which was based on Case 2, but expanded the definition of old vehicles to before Euro 4, reducing NO_x 10%, $PM_{2.5}$ 14%, and VOC 4%, was reduced to be the most of the three cases.
- Considerations need to be made to expand the current policy measures of old vehicles from pre-Euro3 to pre-Euro4, to increase reduction amounts for $PM_{2.5}$ and NO_x.
- Applying measures to the most polluted vehicles first method are more effective to the eco-friendly car policy which help reducing VOC emissions.

Our study has several limitation which need to be improved in the future.

- It is necessary to have the vehicle model year information to effectively implement the atmospheric environment policy
- The year-by year BAU emissions used in this study were not reflected emission reductions from the previous year. Therefore, the remaining emissions after applying reductions may have been somewhat over-calculated. Future studies will consider BAU emissions modified in accordance with reduction of previous policy measures.

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ABSTRACT

The Seoul Metropolitan Area(SMA) is one of largest megacities in the world and the most important area in managing air pollution in Korea as well. Due to its densely populated cars and people, fine particle pollution in the metro area has been a big pollution issue for decades. The mobile sources have the greatest impact on air pollution in the SMA, accounting for more than 52% and 18% of annual NO_x and $PM_{2.5}$ emissions, respectively. Various policies have been set to reduce the mobile source emissions. Stringent air quality improvement plans, such as the 'Seoul metropolitan Air quality Improvement Plan(SAIP)' and the 'Comprehensive Plan for Fine Particles Management(CPFPM)', were ambitiously set to control the emissions, including vehicle emissions. The policy measures like the early retirement of old vehicles and banning the operation for dirty vehicles were also announced. The actual ambient air pollution level, however, has not been improved much compared to the big efforts put into the anti-pollution policies. The concentration of NO_2 and $PM_{2.5}$ in Seoul was 0.032ppm and 23$\mu g/m^3$ in 2015, respectively, which remain similar level of 0.028 ppm and 23$\mu g/m^3$, respectively, in 2018. To make substantial improvement, we first need to analyze emissions reductions from the policies and control technologies accurately, to ensure air quality policies were being implemented properly. In this study, the emission reductions for mobile sources were estimated using the proposed reduction methodologies in the SAIP to understand quantitative effects of mobile source control policies. The expected amount of emissions reduction by the policy measure was calculated by multiplying the designated BAU emissions, policy penetration rate, and the control efficiency. The emission factor, Vehicle Kilometers Traveled(VKT) and deterioration factor were also used for this process. Accurate and specific reduction estimates were derived by considering the model year of the vehicle which represents degradations and applied regulations for each vehicle. Amount of emission reduction by control measures and their impacts on the air quality will be discussed at the conference.

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