Ph.D. Dissertation of Economics

Analysis of the Health Effects and Social Welfare Impacts of Policy Improvements Targeting Particular Matter Levels

미세먼지로 인한 건강영향 및
정책개선의 사회적 후생효과 분석

February 2023

Graduate School of Agricultural Economic and Rural Development
Seoul National University
Major in Regional Information Studies

HyunJi Lee

Analysis of the Health Effects and Social Welfare Impacts of Policy Improvements Targeting Particular Matter Levels

Hong Sok (Brian) Kim

Submitting a Ph.D. Dissertation of Economics
February 2023

Graduate School of Agricultural Economic and Rural Development
Seoul National University
Major in Regional Information Studies

HyunJi Lee

Confirming the Ph.D. Dissertation written by HyunJi Lee

February 2023

Chair ______________________(Seal)

Vice Chair ______________________(Seal)

Examiner ______________________(Seal)

Examiner ______________________(Seal)

Examiner ______________________(Seal)

Abstract

Among the causes of PM2.5, PM2.5 generated from roads in the transportation sector is a pollutant that can easily be exposed to citizens and cause health risks. It enters the lungs through breathing and negatively affects human diseases and deaths. Empirical analysis studies related to PM2.5 in the transportation sector are critical in establishing the validity and basis for alternatives to PM2.5 policies. This study aims to determine whether the generation of PM2.5 from diesel vehicles in the transportation sector affects the mortality rate of disease and to identify the social welfare effects of PM policy improvement by reviewing the policy implementation direction for PM2.5 reduction. The first study aims to analyze the effect of PM2.5 emissions from diesel vehicles on the mortality rate of respiratory diseases and other cardiovascular disease and to identify the factors that affect them. A spatial panel model was applied in this study to consider the spatial adjacency between regions by using autonomous district, city, and county data in the metropolitan area from 2015 to 2019. The main results of the study are as follows. First, it was confirmed that the higher the PM2.5 emission of diesel vehicles, the higher the mortality rate of respiratory diseases. Since PM2.5 emissions from diesel vehicles are one of the causes of PM2.5 emissions, the effect on the mortality rate of respiratory diseases may be smaller than that of PM2.5 emissions or concentrations. However, it is significant in that it is an important finding about the mortality rate of respiratory diseases. Second, SO2, a secondary product of PM2.5, was found to have a positive (+) effect on the mortality rate of other cardiovascular disease. In addition, through Spatial Durbin Model analysis, it was found that SO2 generated in the area affects the other cardiovascular disease mortality rate in the neighboring area, and SO2 in the neighboring area has a positive (+) effect on the dependent variable in the area. Third, after generating dummy variables for the metropolitan area and small and medium-sized cities, the difference between the non-metropolitan area and the metropolitan area was examined using the interaction term with the PM2.5 emissions of diesel vehicles. It was found to be more affected by respiratory mortality than metropolitan areas when PM2.5 emissions from diesel cars increased.

These results are attributed to the difference in infrastructure between non-metropolitan and metropolitan areas since various factors can affect the mortality rate of respiratory diseases. Therefore, it is necessary to examine regional differences in-depth in the future by considering medical and environmental infrastructure.

This study examines how the PM2.5 emissions of diesel vehicles differ from existing research papers when analyzing the effect of the mortality rate of respiratory and cardiovascular systems in consideration of spatial correlation. The significance and differentiation of the study are as follows. First, the analysis model prevented the possibility of underestimating or overestimating the estimate by considering spatial autocorrelation. To confirm spatial autocorrelation, we selected an Inverse Distance Weighting (IDW) method that is suitable for continuous data as it can be applied when the closer the distance between regions is, the higher the possibility of interacting or influencing each other.

Second, this study calculated PM2.5 emissions of diesel vehicles using the National Clean Air Policy Support System (CAPSS) method of calculating air pollutant emissions from road non-point pollutant sources and used them as the main variable of the model. The study results showed that the variable of PM2.5 emissions of diesel vehicles had a significant effect on the mortality rate from the respiratory tract. Third, the higher the temperature and humidity, the more positive the mortality rate of the respiratory and cardiovascular systems was found. Furthermore, in the case of SO2, only the mortality rate of the cardiovascular system was found to have a significant positive effect. In the spatial Durbin model analysis, it was found that SO2 generated in the area affects other cardiovascular disease mortality rate of the nearby area, and SO2 in the neighboring area also affects the dependent variable. This was not found in the general econometric model that did not consider spatial correlation. It was confirmed that the characteristics became clear when constructing the spatial weight matrix through the IDW method. Fourth, to consider meteorological factors in China, monthly average temperature, relative absorption, and precipitation data in Shandong Provinces, Hebei Provinces, and Jiangsu Provinces in China were considered. Consideration of foreign variables is essential in PM2.5-related studies, and studies between neighboring countries need to be conducted in the future. Fifth, it was found that the respiratory mortality rate in non-metropolitan areas was relatively more affected by PM2.5 emissions from diesel vehicles than in metropolitan areas. This difference is likely due to the medical and environmental infrastructure of non-metropolitan and metropolitan areas. The need for additional research on the reason for regional differences has been raised. Suppose further research confirms that the non-metropolitan area is relatively more affected by the PM2.5 emissions of diesel cars. In that case, short-term measures to install PM2.5 shelters in the non-metropolitan area will be needed to protect citizens' health from PM2.5.

The second study analyzed the effect of PM2.5 emissions from diesel vehicles by vehicle type (passenger car, van, cargo) and size (small, medium, large) on PM2.5 concentration in Korea and identified whether there were differences in results depending on large and small cities. The analysis results are as follows. First, the amount of PM2.5 generated by diesel passenger cars, vans, and trucks all significantly affected the concentration of PM2.5in Korea, and trucks were found to have the most significant effect. Second, it was found that the amount of PM2.5 generated by small trucks among cargo trucks significantly influenced the dependent variable. This result is believed to be the result of the fact that there are more small trucks that are ten years older compared to medium and large trucks. In particular, small trucks for business use have a higher mileage than passenger cars (Kyujin Lee, 2018). Third, the PM2.5 generation of large passenger cars, small vans, and medium-sized cargo trucks in large cities was found to have a more significant impact on the concentration of PM2.5 in Korea than in small and medium-sized cities. This is seen as a result of the fact that large cities, including the metropolitan area, are densely populated and often experience traffic jams, and reflects the reality that high concentrations of PM2.5 occur in the metropolitan area. The implications of the study results are as follows. First, among diesel vehicles, the amount of PM2.5 generated by trucks significantly impacts the concentration of PM2.5 in Korea. Therefore, improving and implementing the system centered on trucks in diesel vehicle measures such as early scrapping and low-emission vehicle operation is considered necessary. In particular, it is necessary to expand the supply of fuel vehicles that can replace diesel vehicles in the short term in the truck market and to combine strategies to supply PM2.5-free trucks in the mid-to-long term (Hhan, 2020). Second, considering the size of each car type, the PM2.5 generation of small trucks has a more significant impact on Korea's PM2.5 concentration. Therefore, detailed measures should be prepared according to the type and size of PM2.5 measures, especially for small trucks with many old vehicles. Third, the PM2.5 generation of large passenger cars, small vans, and small trucks significantly impact Korea's PM2.5 in large cities, proving the importance of customized PM2.5 reduction measures by region, and the government must establish and evaluate PM2.5 management measures for each local government. The study is significant because it derives and analyzes representative variables by sector through previous studies and examines Korea's policy direction. In particular, the study's differentiation can be emphasized by analyzing the effect of the PM2.5 generation of diesel vehicles on Korea's PM2.5 concentration by vehicle types (passenger car, van, cargo) and size (small, medium, large). The third study aims to solve the current PM problem in Korea and classify the opinions of experts (government officials and researchers) on policies and management directions related to PM policies for diesel fuel and vehicles. As a result of the study, experts' perceptions of diesel policy are divided into advocacy type, passive regulation type, government budget support type, and public opinion sensitive response type. Based on the Q-methodology and system accident analysis results, the main causes of inefficient diesel policy are the lack of role of ministries, lack of information delivery to stakeholders, and uncertainty of citizen participation. Experts are concerned about the public backlash against the policy, delaying its implementation. Therefore, it is necessary to review the following implications. First, finding a group that can mediate among the four types is necessary. Among the four types, the government budget support type is the best group to serve as a mediator because it not only emphasizes the strengths and weaknesses of the policy and accepts most of the need for improvement but also positively evaluates the policy effects. After selecting an organization that can act as a mediator, it is necessary to receive feedback on whether it wants to participate in citizenship and what funding it will provide. Second, the functions and roles of ministries should be reconsidered to enhance understanding and organization among ministries. Furthermore, a better understanding of inter-ministerial roles and functions must be considered and redefined for more sustained and continuous stakeholder cooperation. In the fourth study, respondents' willingness to pay (WTP) was derived for a scenario that

reduces the possibility of death due to air pollution by 0.0001 through policy improvement using the conditional evaluation method. According to the results of the Double Bounded Dichotomous Choice (DBDC) analysis, including control variables, the average willingness to pay is KRW 41,643 per year (on average KRW 3,470 per month). The average willingness to pay is KRW 22,397 per year (on average KRW 1,866 per month), including those who refuse to pay. The economic value to reduce the mortality rate due to PM2.5 to one in ten thousand of the level is about KRW 894 billion (KRW 89.4 million 9007,100) per year. The statistical life value is calculated as KRW 0.4164 billion, and the statistical life value derived by applying a 10-year payment period was estimated to be about KRW 4.114 billion. In future studies, there may be differences in willingness to pay due to the improvement of PM2.5 by region. Furthermore, the cause of such differences needs to be investigated. In addition, if the level of utility for reducing premature mortality rates due to PM2.5 is identified through a comparison of domestic and foreign studies, it can be used as basic data for establishing measures for PM2.5 and health protection.

This study consists of understanding the current status and health effects of PM2.5 in transportation, presenting policies for reducing PM2.5, and analyzing social welfare effects according to policy improvement. This study is expected to be used as basic research material to improve PM2.5 policy and respond to social policy issues in the future.

Keyword: Fine Particulate Matter (PM2.5), Spatial Econometrics Model, Contingent Valuation Methods, Willing to Pay (WTP), Value of a Statistical Life (VSL), Social Welfare Impacts, Fixed/Random Effect Model, Perception for Environmental Policy, Q-Methodology

Student Number: 2018-33158

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1. Background

It has been argued that the health impact of PM2.5 caused by road non-point pollutant sources is more significant than of other pollutants (Lee et al., 2017). Once exposed to particulate matter, various respiratory and cardiovascular diseases and even death can be caused. WHO designated PM2.5 as a group 1 carcinogen in 2013. As the WHO reported 7 million premature deaths from PM2.5 in 2014, the interest in policies to reduce PM2.5 has been raised internationally. The government has been steadily reducing PM2.5, but despite these efforts, the average exposure level of PM2.5 in Korea exceeds the WHO's recommended standards of air quality guidelines, raising public concerns about diseases and premature deaths caused by PM2.5. In addition, PM2.5 is known to have a high impact on the respiratory system, cardiovascular and cerebrovascular systems, and also affects mental health such as cognitive disorder and depression due to PM2.5 (Reşitoğlu et al., 2017).

There are many causes that contribute to the generation of PM2.5, but the biggest contributor to air pollution in the metropolitan area is diesel cars (Interagency Coordination, 2019). Transportation is subdivided into three sectors: Road, railway, marine transport, and airline. Diesel vehicles emit more nitrogen oxides, the causal agent of secondary PM2.5, than gasoline vehicles, generating a lot of secondary PM2.5. Accordingly, national-scale efforts are being made to reduce PM2.5 in the transportation sector (hereafter PM2.5).

Although the government continuously invested budget to reduce diesel vehicles, the number of diesel vehicles increased by 2020. Experts have pointed out that the cause is the lack of priorities of countermeasures in the PM2.5 management plan. Regarding measures to reduce PM2.5 caused by diesel vehicles, there are also issues of conflict between the truck fuel subsidy system and ministries. In addition, it is included in the PM2.5 management measures centered on passenger cars, but the need for measures related to trucks rather than passenger cars is being raised. Moreover, it was found that citizens' trust in PM2.5 measures was low. To solve these issues, it is necessary to closely analyze the problems of diesel-related issues and conduct research to reduce damage caused by fine dust from diesel vehicles (Hhan, 2020).

However, PM2.5 generated in the transportation sector is the most exposed pollutant to citizens. Despite the intensive performance of the establishment and implementation of PM2.5 reduction policies in the transportation sector, securing data on the PM2.5 generation of diesel vehicles by city, country, and the district is challenging. Therefore, there are not enough studies to establish the basis of the policy’s validity.

Looking at the major research, although there are many studies dealing with socioeconomic damage or health impact caused by PM2.5, studies related to diesel vehicles and PM2.5 are focused on evaluating the effectiveness of vehicle emission reduction projects and evaluating the performance and effectiveness of emission reduction devices. (Kim et al., 2021; Reşitoğlu et al., 2015; Laybourn-Langton et al., 2020). Kim et al., (2021) analyzed the effect of PM2.5 concentration caused by diesel vehicle emissions in the metropolitan area during the seasonal management system period through the Air Quality Simulation method. Furthermore, Liu et al. (2018) reviewed the adverse effects of diesel vehicle emissions on children in the UK and discussed ways to reduce health damage at the individual and national levels.

Likewise, it is challenging to distinguish PM2.5 emissions from diesel vehicles in the domestic Clean Air Policy Support System (CAPSS) emission list (Hhan, 2020a). Considering the exhaust emission characteristics of specific vehicle models in Korea, it is essential to conduct empirical studies to reduce PM2.5 emissions in the transportation sector (Hhan, 2020).

1.2. Research Scope and Purpose

The transportation sector is subdivided into three sectors: Roads, railways, marine transport, and aviation. This study conducts an analysis focusing on the PM2.5 of diesel vehicles on roads that citizens are most exposed to in citizen's daily lives. Unlike point pollutant source, non-point pollutant source has limitations in building data through measurement, so additional data calculation processes are required. Diesel cars, which are non-point pollutant sources, emit more nitrogen oxides, the cause of secondary PM2.5, than gasoline vehicles.

The purpose of this study is to determine whether the generation of PM2.5 from diesel vehicles in the transportation sector affects the mortality rate from diseases, and to identify the social welfare effects of PM policy improvement by reviewing policy implementation directions to reduce PM2.5.

1.3. Research Structure

To achieve the ultimate goal, the following research questions and detailed goals are set to construct this paper. Figure 1-1 is a Research Conceptual Diagram that can understand the connection of the research contents between essays, and Figure

1-2 shows the detailed purpose of each chapter of this study.

Chapter 2 identifies the existence of spatial adjacencies between diesel PM2.5 emissions and mortality due to respiratory and ischemic cardiovascular systems and define their mechanisms. Chapter 3 identifies the difference in the effect on PM2.5 concentration according to diesel vehicles by type and size and examines whether there is a difference between large cities and small-and-medium-sized cities. Chapter 3 is connected to Chapter 4. Chapter 4 identifies main factors that prevent PM2.5 measures for diesel vehicles from being carried out smoothly. Fourth, in Chapter5, by monetizing the value of the reduction in the probability of death due to the reduction of PM2.5, it is intended to understand the level of citizens' utility for the effect of the PM2.5 policy on diesel vehicles. The structure of the study is shown in Figure 1-1.

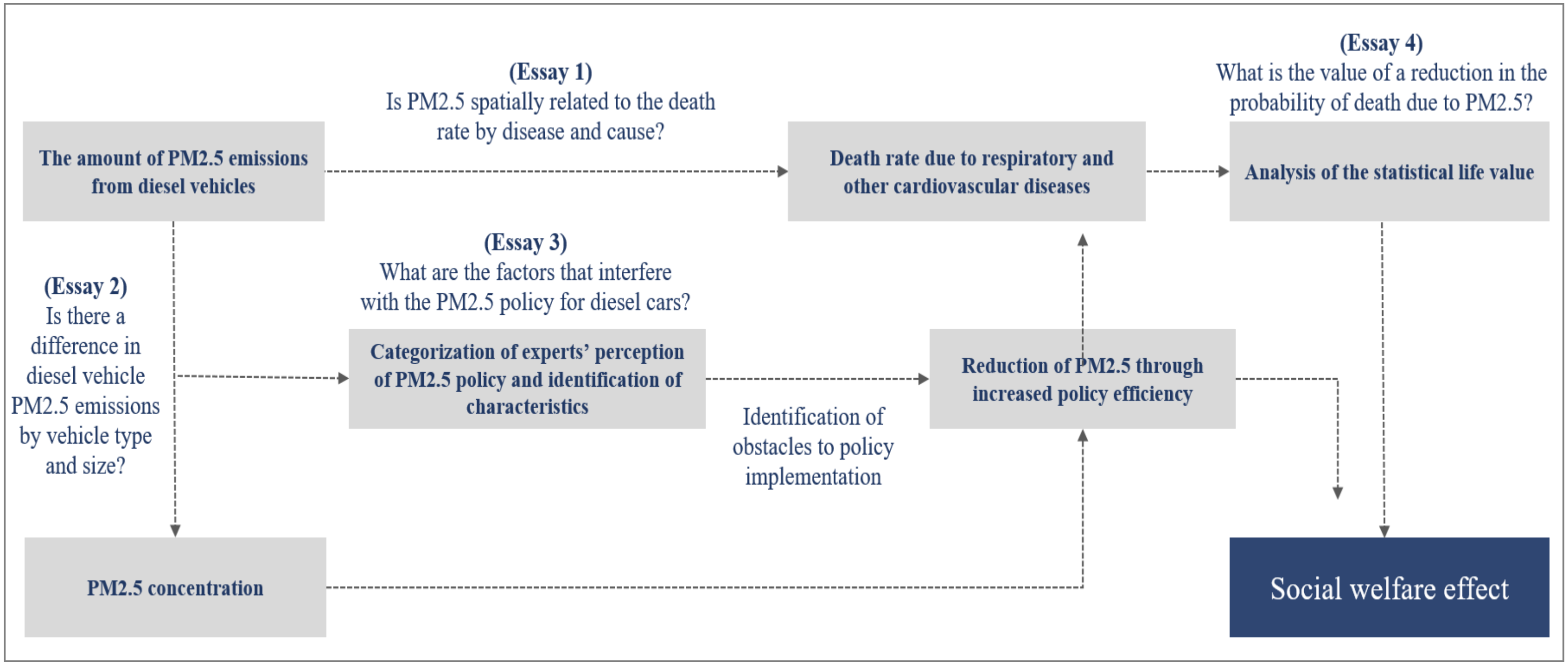


Figure 1-1 Research Conceptual Diagram

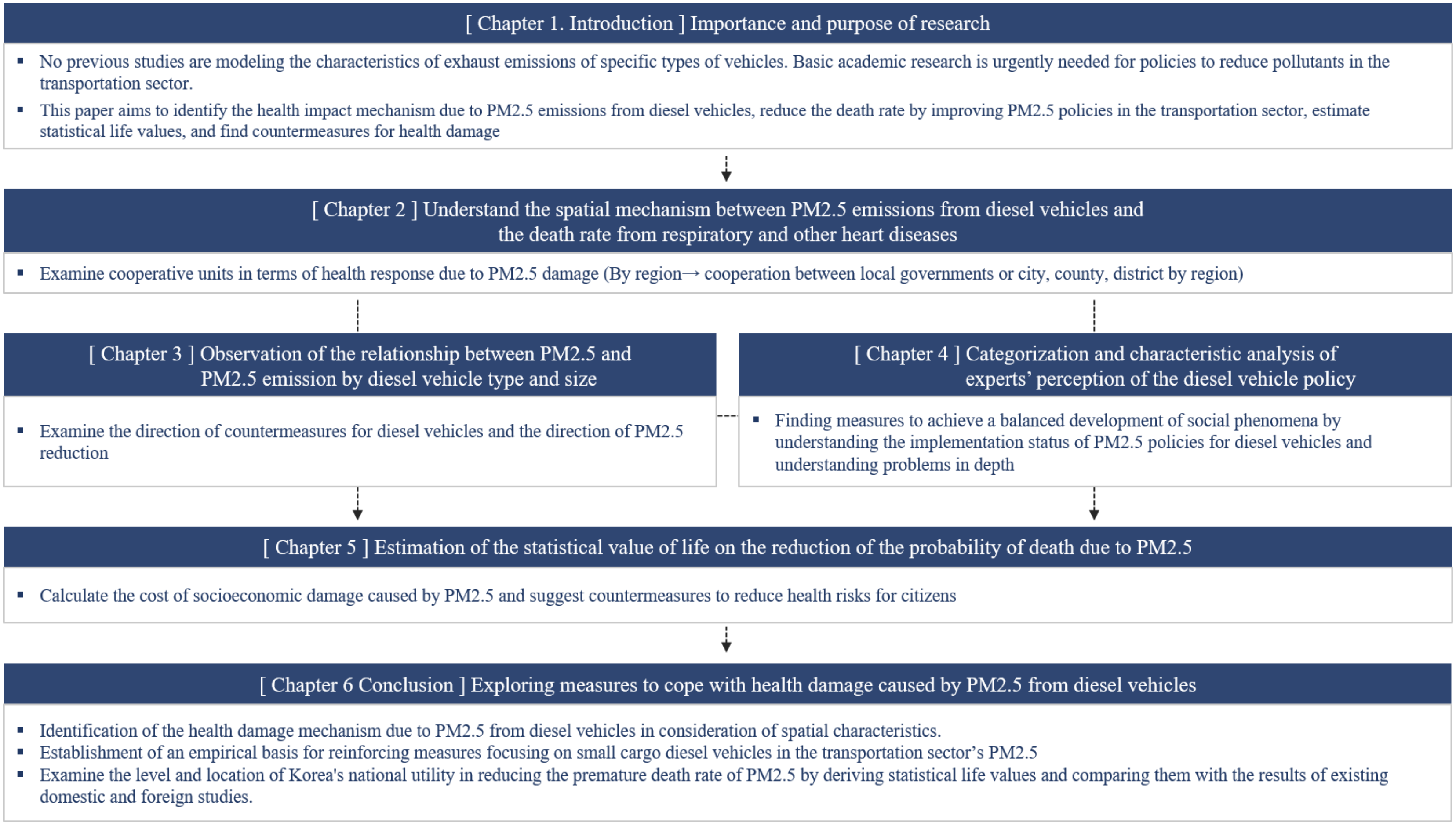


Figure 1-2 The Structure of the Study

Chapter 2. Is the mortality rate by disease spatially linked to the PM2.5 emissions in the transportation sector?

2.1. Study Background

Despite the decrease in PM2.5 concentrations in Korea, PM2.5 is still affecting premature death and disease. According to the study, it is found that there is a significant link between transport-related air pollution and premature death. (Perez et al. 2015). The biggest contributing factor to air pollution in the transport sector is diesel cars (Interagency Coordination, 2019). Vehicle exhaust fumes emit particles such as smoke, dust, soot, volatile organic compounds (VOC), and nitrogen oxides. Nitrogen oxides from diesel vehicles combine with water vapor and ozone in the air to turn into PM2.5. This is called secondary PM2.5. Since more than 90% of med-to-large-sized trucks use diesel, the proportion of PM2.5 emissions generated by diesel vehicles is also higher than that of other vehicle types.

There are empirical studies on the mortality rate from diesel vehicles and PM2.5. Looking at studies similar to the purpose of this study, Mazzi and Dowlatabadi (2007) investigated consumers switching from gasoline to diesel cars in the UK, estimated PM2.5 emitted from diesel cars from 2001 to 2020, and estimated mortality rate through concentration-reaction functions based on PM2.5. Brugge (2007) found an increased risk of respiratory and cardiovascular diseases associated with residential proximity to transport pollution. In addition, Atkinson et al. (2016) revealed the need for a study as the link between short-term exposure to pollutants in the transport sector was not found to be associated with the mortality rate. Furthermore, Atkinson et al. (2016) investigated the link between the daily concentration of certain transport-related pollutants in London between 2011 and 2012.

This study measured more than 100 air pollutant concentrations every day and presents a change in the percentage of death risk through Poisson regression analysis that explains weather factors. Yorifuji(2016) analysis counts of all-cause and cause-specific mortality and concentrations of nitrogen dioxide (NO2) and particulate matter less than 2.5 μm in diameter (PM2.5) during the study period with interrupted time-series analysis. Yorifuji(2016) is significant in evaluating whether air pollution reduction due to regulatory measures improves public health.

Since Korea's clean air policy support system (CAPSS) emission list does not provide PM2.5 emissions from diesel cars, there aren't many studies that have conducted empirical analysis focusing on diesel cars that closely affect citizens. Therefore, to reduce PM2.5 emissions in the transportation sector, a study that examines the relationship between diesel vehicles' PM2.5 emissions and health is needed (Hhan, 2020).

This study aims to confirm whether there is a spatial adjacency between PM2.5 emissions from diesel vehicles and the mortality rate from respiratory and ischemic cardiovascular systems and to define its mechanism. The PM2.5 emission or standard excess ratio varies by city, county, and district. The spatial range was set in units of city, county, and district based on previous studies. For example, the Korea Environment Corporation (2017) suggested that the roads with the most severe PM2.5 are Seohae-daero in Jung-gu, Incheon, Jojeong-daero in Hanam-si, Gyeonggi-do, MagokJungang-ro in Gangseo-gu, Seoul, and Chunghang-daero in Jung-gu, Incheon. It is suggested that the reason for the high detection on the road is that there are more semi or cargo vehicles than in other areas, mainly in industrial complexes and port areas.

In addition, although cities in units of cities, counties, and districts have homogeneity in terms of economic and social characteristics since they are divided into heterogeneous space units for administrative reasons, it is necessary to consider that diesel vehicle emission characteristics are different. Moreover, it is necessary to consider that the difference in infrastructure accessibility to medical infrastructure and environmental infrastructures such as transportation facilities and large hospitals by city, county, and district can occur as a difference in the impact on the mortality rate.

2.2. Literature Review

2.2.1 Effects of PM2.5 Emissions from Diesel Vehicle on Disease and Mortality

As the particles of PM2.5 are smaller than of PM10, they enter the alveoli more easily and poses a greater health risk. In addition, long-term exposure to PM2.5 is known to increase mortality rate (USEPA, 2022).

Previous studies are on PM2.5 disease, and mortality rate mainly include medical experiments, comparative controls, and statistical analysis studies on the relationship between PM2.5 effects. First, studies on statistics and quantitative analysis considering space are as follows. Gu and Jun (2021) analyzed the effect of PM2.5 concentration by region on lung disease death using a spatial panel model. The results showed that the longer the exposure time to PM2.5 and SO2, and the higher the temperature and humidity, the higher the number of deaths due to lung diseases. In addition, the analysis results suggest that the higher the elderly population (65-year-old population ratio) and the higher the ratio of sewage treatment, which affects air quality, the higher the mortality rate of lung diseases. Yim et al. (2021) analyzed the effect of PM2.5 on pneumonia through spatial panel analysis from 2010 to 2015. By applying a spatial weights matrix for each wind direction, it was suggested that PM2.5 increases the incidence of respiratory diseases and that pneumonia due to PM2.5 develops the most when the northwest wind blows. Cardoso et al. (2019) analyzed the relationship between lung cancer mortality rate and PM10 concentration in Portuguese men and women using a graphically weighted regression (GWR) model and presented the analysis results that the risk of lung cancer mortality rate from PM10 is higher in areas with a high proportion of urbanization and industrial complexes.

In addition, although it is not a study on the health effects of PM2.5, Kang (2019) conducted a panel econometric analysis considering spatial correlation between regions to analyze the causes of PM2.5 in Korea. The study revealed that income levels not only increase the concentration of PM2.5 in the region, but also have a positive effect on the concentration of PM2.5 in adjacent areas using the Spatial Durbin Model. Moreover, Hao and Liao (2016) used Space Lag Model (SLM) and Space Error Model (SEM) to understand the effect of GDP per capita, industry and transport of 73 Chinese cities on air quality. In addition, they showed that vehicle population and secondary industry have an important and positive effect on urban PM 2.5 concentration.

On the other hand, Ciabattini et al. (2020) suggested in a system review that exposure to PM2.5 and PM10 increases the risk of lung cancer mortality and considered variables such as individual physical characteristics and lifestyle in the analysis model. Seo Hyung-joon and Lee Hyung-seok (2019), Seo and Lee (2019) analyzed the effect of the concentration of sulfur dioxide, nitrogen dioxide, ozone, carbon monoxide, and PM10 on the number of allergic rhinitis patients and the number of asthma patients. The study showed that as the concentration of ozone and PM2.5 increases, the number of allergic rhinitis patients increases. Furthermore, as the concentration of sulfur dioxide increases, the number of allergic rhinitis patients increases.

Wang et al. (2019) analyzed the relationship between air pollution and lung cancer mortality in a time series model, focusing on three Chinese cities from 2013 to 2015, and showed that deaths due to PM2.5, PM10, SO2 and lung cancer increased significantly as the city's average annual temperature and humidity increased. In addition, Pope et al. (2020) showed through a meta-analysis that increased PM2.5 concentrations were associated with increased mortality rate of lung cancer, and Shi et al.. (2023) conducted a national cohort research of the association between PM2.5 and dementia and Alzheimer's disease. In particular, it was suggested that sulfate (SO 4 2-), black carbon (BC), and organic matter (OM) generated from transportation and fossil fuel combustion may have a relationship with dementia and Alzheimer's disease.

Through previous studies, this study confirmed that pollutants such as PM2.5, weather factors such as temperature and humidity, personal characteristics such as education level, and socioeconomic factors such as urbanization rate affect death from diseases.

However, although PM2.5 is caused by various factors, only a few studies have observed the health effects of each cause. Among the factors that cause PM2.5, road sources in the transportation sector are known to have a relatively greater impact on citizens' health (Lee et al., 2017), and this study focuses on road sources. In particular, since diesel vehicles emit more secondary pollutants than gasoline vehicles (Lee et al., 2017), this study examines the health effect of the amount of PM2.5 generated from diesel vehicles.

Compared to previous studies, this study has the following differentiation. First, this study calculates the amount of PM2.5 generated by diesel vehicles and uses for analysis. In previous studies, concentrations of PM10 or PM2.5 were mainly used. However, there is a difference in the budget for each PM2.5 control policy, and since each PM2.5 factor has the possibility of affecting health more, it is important to check the health effects of PM2.5 generation factors. The basis for calculating the variables is to use the Clean Air Policy Support System (CAPSS) method of calculating air pollutant emissions from road pollution sources (National Air Emission Inventory and Research Center Homepage).

Second, this study considered China's meteorological factors as control variables. Previous studies related to PM2.5, disease and mortality rate considered variables related to meteorological factors, development and socio-economic factors, and population characteristics, but only a few studies considered foreign variables. However, according to a study on factors affecting PM2.5, China's air quality appears to affect domestic PM2.5 pollution (Kim and Kang, 2018). Therefore, it is necessary to consider China-related factors in health-related analysis models. The data was obtained from the website of the Ministry of Ecology and Environment of the People's Republic of China (https://www.mee.gov.cn/), and the details of contents related to variables will be explained in detail in the next part.

2.2.2 Various factors affecting mortality from disease

A study analyzing the factors influencing PM2.5 in Korea presents the sector by dividing them into industrial, transportation, and power generation sectors. Regarding the manufacturing index among industries, Park and Shin (2017) analyzed using the chemical industry manufacturing and industrial manufacturing production index, and Kim and Kang (2018) used the manufacturing product index. This study utilized the total manufacturing production index to analyze the domestic supply trends of manufacturing products, including domestic products and imports.

To understand the effect of PM2.5 in the power generation sector, Park and Shin (2017) used coal-fired power generation transactions, and Jo and Kang (2017) used fossil fuel combustion. Although emission acceptance standards for coal-fired power plants vary depending on the construction year and capacity of facilities. On the other hand, PM2.5 (PM10, PM2.5) is a particle produced by chemical reactions with the atmosphere of air pollutants such as nitrogen oxides (NOx) and sulfur oxides (SOx) produced during combustion and is observed for a long time in the atmosphere. Although the amount of PM2.5 generated from emissions varies depending on temperature, meteorological conditions, and geography, it is difficult to estimate the exact value (Kim et al., 2016). It is argued that the second generation of PM2.5 in Korea has more influence on social science compared to the primary generation. In addition, PM2.5 concentrations may be affected by meteorological factors, so they should be considered in the analysis (Park and Shin, 2017; Zhao et al., 2018). Studies analyzing the causes of PM2.5 can be found mainly in Korea and China, and there are relatively few research data in the U.S. and Europe. In Korea, representative variables were selected and analyzed in transportation, power generation, and industry. At the same time, China applied socioeconomic indicators such as per capita GDP, urbanization, and energy intensity as independent variables. Chinese literature has secured PM2.5 data since 2015, and PM2.5 data has been used in analysis since 2017. In addition, there are differences in the selection of indicators that affect PM2.5 by country because there are differences in the characteristics of statistical data provided by each country.

Focusing on the studies mainly related to the influence of PM2.5, Park and Shin (2017) conducted a fixed-effect model analysis by considering diesel consumption, coal power generation production index, domestic cement manufacturing production index, and regional cement industry production index. As a result of the study, the manufacturing production index of the cement industry had a significant effect on PM2.5. Still, the regional domestic diesel consumption and the domestic cement manufacturing production index did not have a significant effect on PM2.5 concentration. In addition, Park and Shin (2017) differentiated from other studies by considering the western wind direction ratio. Furthermore, they concluded that the variable affects PM2.5 concentration.

Kim and Kang (2018) analyzed air pollutant concentrations (SO2, CO, O3, NO2 concentrations), meteorological climate factors (temperature, atmospheric pressure, sea level pressure, water vapor pressure, humidity, precipitation, wind speed, wind direction, sunshine, snow cover, number of yellow dust days observed), air pollutant emissions (CO, NOx, SOx, TSP, PM10 VOC, NH3, and PM2.5 emitted from manufacturing combustion, non-industrial combustion, production process, energy transportation and storage, organic solvent use, road transport pollutants, non-road transport pollutants, and waste disposal) and air quality in China (PM2.5 concentration in Beijing and Shanghai, Beijing and Tianjin Air

Quality Index (AQI)), and machine learning analysis was performed by applying listed variables. As a result of the study, it was suggested that China's air quality affects the level of PM2.5 pollution in Korea and that the concentration of sulfur oxides and nitrous oxides among domestic air pollutants greatly affects the level of PM2.5 pollution. Hao and Lio (2016) used Space Lag Model (SLM) and Space Error Model (SEM) to investigate how GDP per capita, industry, and transport affects air quality in 73 cities in China. As a result of the study, PM2.5 concentrations and per capita GDP have a relationship of the inverted U-shaped. Although the studies on the influencing factors of PM2.5 was conducted the most in Korea and China, it is not easy to directly compare the results of Korea and China due to the different characteristics of statistical data for each country.

2.3. Research Method

2.3.1 Variable Selection and Creation

This study performs a spatial econometrics model using panel data from 219 city, county, and district regions from the years 2015 to 2019. The variables of the study are as follows. Dependent Variable is diseases of the respiratory system (standardized mortality_total)(%). The independent variable is PM2.5 emissions from diesel vehicles (Ln_DC_PM). The method of calculating air pollutant emissions from road non-point pollutant sources of the clean air policy support system (CAPSS) was supplemented and utilized (National Air Emission Inventory and Research Center Homepage). Following processes were performed to reflect factors such as model year, mileage, driving speed, and PM2.5 emission coefficient when calculating variables.

First, the number of registered diesel vehicles (unit) by city, county, district, and month by model year is taken from the vehicle registration status data of the Ministry of Land. As for the vehicle model year, data are provided on an annual basis from 1995 to 2018, and diesel vehicles have different emissions depending on model year. Second, in the vehicle mileage data of the Korea transportation safety authority (2018), the average daily mileage (km/unit) per city, county, and district is multiplied by 365 days, and then multiplied by the number of registered vehicles. Third, based on the data of air pollutant emission coefficient provided by the national institute of environment research, the PM2.5 emissions from diesel vehicles is calculated by multiplying the PM2.5 emission coefficient by model year. V is assumed to be an average vehicle speed of 50km/h. PM2.5 emission coefficient[①] is calculated based on the model year and speed. For example, in the case of diesel vehicle (midsize) after 2006, the emission coefficient is k x 0.0396 x v^(-0.3420). k indicates the fraction of PM2.5. 0.92 is used as the value of k in the data of Korea transport institutes at the national institute of environmental research. In other words, the fraction of PM2.5 among PM10 emitted from road non-point pollutant sources accounts for 92%.

Control variables are PM 2.5 Concentration Level in Korea(μg/m³), sulfur dioxide pollution level(ppm), ozone pollution level(ppm), the temperature in Korea(°C), precipitation level in Korea(mm), humidity in Korea(%), amount of power consumption(MWh), quality of Life Index, ln_total Population(Number), ln_number of employee per thousand people(Number), ln_number of a manufacturing business(Number), GRDP(billion KRW), the temperature in China(°C), precipitation level in China(mm), humidity in China(%).

This study applied the kriging technique through GIS Pro, and calculated the concentration values of PM, SO2, O3, Temperature, Precipitation, Humidity by city. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is similar to IDW in that it weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for both interpolators is formed as a weighted sum of the data:

---

① The emission coefficient is calibrated and calculated by the air pollutant emission management committee when calculating CAPSS emissions every year, and CAPSS has been transferred and managed from the Ministry of Environment's National Air Emission Inventory and Research Center to the PM2.5 Information Center after 2019 (Seoul metropolitan city, 2021)

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

where Z(s_i) = the measured value at the ith location
λ_i= an unknown weight for the measured value at the ith location
s_0= the prediction location
N = the number of measured values

Table 2-1 Definition of Variables

	Variable Name		Unit	Variable Description
Dependent Variable	Resp_mort	Diseases of the respiratory system (standardized mortality_total)	%	Standardized mortality rate by respiratory diseases (J00-J98, U04) per 100,000 population (data standardized in 2005)
Independent Variable	Ln_DC_PM	PM2.5 emissions from diesel vehicles	kg/km	Natural logarithm of (Average mileage by city * 30) * monthly PM2.5 emission coefficient (number of registered diesel vehicles considering model year * diesel vehicle emission coefficient)
Control Variables	K_PMC	PM 2.5 Concentration Level in Korea	μg/m³	Monthly average value of PM2.5 *12 months
	SO2	Sulfur dioxide pollution level	ppm	Monthly average value of Sulfur dioxide pollution level measured *12 months
	O3	Ozone pollution level	ppm	Monthly average value of Ozone pollution level measured *12 months
	K_ATM	Temperature in Korea	℃	Mean of daily temperatures in each Korean city
	ln_K_RAIN	Precipitation level in Korea	mm	Regional precipitation levels
	ln_K_HMD	Humidity in Korea	%	Mean of Relative humidity levels in each Korean city
	ln_PWC	Amount of power consumption	MWh	Power consumption means power consumption per unit time and is calculated by multiplying power by the period of use
	QoL	Quality of Life Index	Index	The Quality of Life Index (EQ-5D Index) is an indicator of the five dimensions of health-related quality of life (exercise ability, self-management, daily activities, pain/discomfort, anxiety/depression)
	Pop	ln_total Population	Number	Number of people registered as residents (residents) by local government
	ln_business_num	Businesses in all industries	Number	Businesses in all industries (agriculture, forestry and fishing, mining, and manufacturing business) located in all regions
	empl	ln_number of employee per thousand people	Number	(Number of employee /total population)*1000, Number of employee = Number of employees in the entire industry
	manuf	ln_number of manufacturing business	Number	number of manufacturing business
	ln_K_GRDP	GRDP	1 billion KRW	Ln(GRDP = Sum of market prices of all final goods and services)
	ln_c_rain_~n	Precipitation level in China	mm	Monthly average precipitation levels of Shandong, Hebei, and Jiangsu Provinces
	c_temp_mean	Temperature in China	℃	Monthly average temperature of Shandong, Hebei, and Jiangsu Provinces
	c_humid_mean	Humidity in China	%	Mean of Relative humidity levels in Shandong, Hebei, and Jiangsu Provinces

2.3.2 Spatial Panel Model

Using panel-type data has the advantage of being able to consider endogeneity that may exist between independent variables and error terms, and endogeneity can be controlled by applying a model that considers endogeneity as a fixed effect. In addition, when the characteristics of spatial correlation are considered, all aforementioned characteristics can be reflected, so this study applies the spatial panel model (Anselin et al., 2008; Elhorst, 2014; Elhorst and Vega, 2013) research method.

Due to spatial interaction, there is a possibility that the health damage in one area due to fine dust is affected by the health damage in the surrounding area. Therefore, when the dependent variable is used in consideration of the spatial concept, as discussed above, it is not possible to construct a correct model through general linear regression analysis due to spatial dependence and spatial heterogeneity (Anselin, 1988; Elhorst & Vega, 2013; Lesage, 2014; LeSage & Pace, 2009). This property of spatial data is defined as spatial autocorrelation. Anselin (1988) proposed spatial econometrics for the analysis of regression models using spatial data, and a general linear regression model considering spatial autocorrelation is shown in Equation (1).

$$\begin{aligned} y &= \rho W_1 y + X\beta + u \\ u &= \lambda W_2 u + \epsilon \\ \epsilon &\sim N(0, \sigma^2 I_n) \end{aligned} \tag{1}$$

Here, W1 and W2 represent a spatial weighted matrix, respectively, and ρ and λ are coefficients of the spatial weighted matrix, and serve to provide a measure of spatial autocorrelation. According to Anselin (1988), there are two cases where spatial autocorrelation works in the explanatory variable term and in the error term. As shown in Equation (1), the case where both types of spatial autocorrelation exist is called a general spatial model (SAC: Spatial Lagged Term with Spatially Correlated Error Structure Model).

On the other hand, the case where only the explanatory variable has spatial autocorrelation (λ=0) is called the Spatially Autoregressive Model (SAR), and the case where only the error term has spatial autocorrelation (ρ=0) is called the Spatial Errors Model (SEM). The spatial panel model can be configured in various ways according to how the spatial effect is considered in the original panel model, starting from the following formula.

$$Y_t = \gamma Y_{t-1} + \rho W_1 Y_t + \beta X_t + \theta W_2 Z_t + \mu_i + \gamma_t + \lambda W_3 \nu_t + \epsilon_t$$

γ: Coefficients of lag dependent variables, ρ: Spatial lag coefficients of dependent variables, W_1: Autoregressive spatial weighted matrix, β: Coefficients of independent variables, X: Independent variables, θ: Spatial lag coefficients of independent variables, W_2: Spatial weighted matrix applied to spatial lag independent variables, Z: Spatial lag independent variables, λ: Spatial error coefficient, W_3: Spatial weighted matrix of error term, μ_i: Entity fixed effect on health damage: unobserved intrinsic characteristics unique to each local government, γ_t: Year fixed effect: unobserved intrinsic characteristics unique to each year of the analysis period, ν_t: Error term, ϵ_t: residual error term (error term that remains even after considering spatial error). In the above formula, the Spatial autoregressive panel model (SAR) is a model that estimates the lag coefficient λ of the dependent variable, the space lag coefficient ρ, and the independent variable coefficient β by considering the lag effect (λ) and the space lag effect (ρ) of the dependent variable in the spatial panel model formula, taking the following form.

$$Y_t = \gamma Y_{t-1} + \rho W Y_t + \beta X_t + \mu_i + \gamma_t + \epsilon_t$$

The Spatial Error Panel Model (SEM) considers only the spatial error effect (λ) in the basic form of the spatial panel model and estimates both the spatial error coefficient λ and the independent variable coefficient β, which can be expressed as follows.

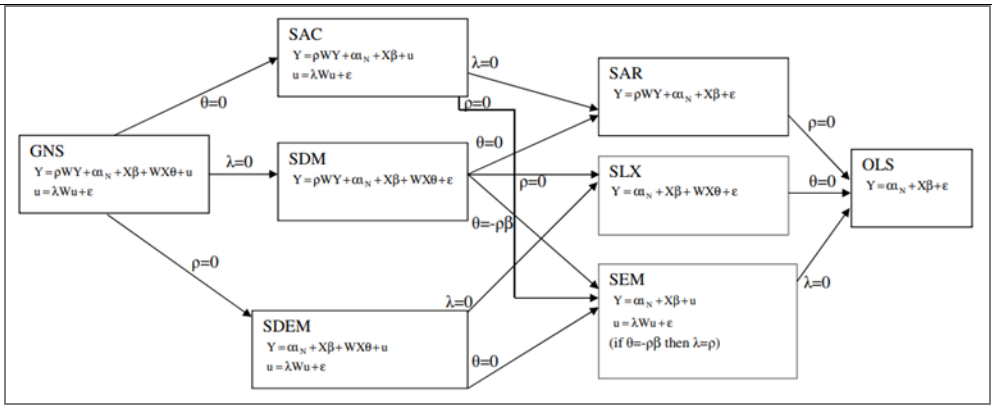
$$Y_t = \beta X_t + \mu_i + \gamma_t + \lambda W v_t + \epsilon_1$$

The Spatial Auto Correlation Panel Model (SAC)/general spatial panel model considers both the spatial lag effect (ρ) and the spatial error effect (λ) in the basic form of the spatial panel model. Therefore, it is characterized by estimating both the spatial lag coefficient ρ of the dependent variable, the spatial error coefficient λ, and the coefficient β of the independent variable.

$$Y_t = \rho W Y_t + \beta X_t + \mu_i + \gamma_t + \lambda W v_t + \epsilon_1$$

The Spatial Durbin Panel Model (SDM) considers the lag effect (γ) of the dependent variable, the spatial lag effect (ρ), and the spatial lag effect (Θ) of the independent variable in the basic form of the spatial panel model and calculates the lag coefficient γ of the dependent variable, the spatial lag coefficient ρ, the spatial lag coefficient θ of the independent variable, and the coefficient β of the independent variable are all estimated. Accordingly, this model is characterized by considering spatial effects not only for the dependent variable but also for the independent variable.

$$Y_t = \gamma Y_{t-1} + \rho W Y_t + \beta X_t + \theta W Z_t + \mu_i + \gamma_t + \epsilon_t$$



Note: GNS=general nesting spatial model, SAC=Spatial Autoregressive Combined Model (SARAR), SCM=Spatial Durbin Model, SDEM=Spatial Durbin Error Model, SAR=Spatial Autoregressive Model (Spatial Lag Model), LAX=Spatial Lag of X model, SEM=Spatial Error Model, OLS=Ordinary Least Squares Model

Figure 2-1 Spatial Econometrics Model Specification
Reference: Elhorst and S.H. Vega, 2013, 53rd Congress of the European Regional Science Association, p. 24

Furthermore, what needs to be additionally looked at in the spatial metric model is classification of the total effect, which means the association between the independent variable and the dependent variable into direct/indirect effects, respectively. Among the models examined above, in the case of the Spatial Autoregressive Panel Model (SAR) and the Spatial Durbin Panel Model (SDM), the lag effect (γ) of the dependent variable is considered simultaneously within the model. Therefore, it is based on the fact that the interpretation of the coefficient value, which means the association between each independent variable and the dependent variable, can be unclear. In the above formula, the direct effect equals the average of elements corresponding to the diagonal in the matrix on the right side of the formula, and the indirect effect equals the average of the sum of elements aside from the diagonal for each column. This study constructed models of SAR, SEM, SDM, and selected a model with high explanatory power and meaningful interpretation.

$$\begin{bmatrix} \frac{\partial E(Y_1)}{\partial x_{1k}} & \cdots & \frac{\partial E(Y_1)}{\partial x_{Nk}} \\ \vdots & \vdots & \vdots \\ \frac{\partial E(Y_N)}{\partial x_{1k}} & \cdots & \frac{\partial E(Y_1)}{\partial x_{Nk}} \end{bmatrix} = (I-\rho W)^{-1} \begin{bmatrix} \beta_k & w_{12}\theta_k \cdots\cdots & w_{1N}\theta_k \\ w_{21}\theta_k & \beta_k \cdots\cdots & w_{2N}\theta_k \\ \vdots & \vdots & \vdots \\ w_{N1}\theta_k & w_{N2}\theta_k & \beta_k \end{bmatrix} = (I-\rho W)^{-1}(\beta_k I_N + W\theta_k)$$

2.3.3 Method process

1) Spatial Weight Matrix

The spatial weight matrix is calculated according to the criterion of proximity of distance, and the weight matrix is constructed in such a way that 1 and 0 are assigned according to whether they are adjacent or not. If region i and region j are adjacent, dij = 1, if not adjacent, dij = 0, and the spatial weight matrix W of equation (2) is expressed as equation (3) below.

$$W_{ij} = d_{ij} / \sum_{j=1, i \neq j}^{n} d_{ij} \qquad (3)$$

In this study, weighting was created using the methods of Contiguity edges corners, Contiguity edges only, Dulaunay triangulation, Fixed distance, Inverse distance, and K nearest neighbors through GIS Pro. It is known that it is common to determine the weight matrix by referring to previous studies as there is no specific selection criterion (Anselin, 1988). This study referred to the spatial relationship conceptualization selection presented on the ArcGIS Pro homepage, and the weighting selection criteria were summarized in previous studies.

In this study, the Inverse Distance Weighting (IDW) method was selected, which is suitable for continuous data and can be applied when the closer the distance between regions, the higher the possibility of interacting or influencing each other. As a result of calculating the weights of 219 regions based on the inverse distance, the average was 0.0045, and the minimum value greater than 0 was 0.00746. There are a total of 219 regions in this study. The minimum number of adjacent areas is 1, and on average, one area is adjacent to 15.488 areas, and the maximum number of adjacent areas is 50. The total number of adjacent links is 3,392.

2) F-test, BP & LM test, Hausman test

After estimating using a basic linear regression model, the LM-Lag and LM-Error values of the Lagrange Multiplier Test (LM), which test the null hypothesis that no spatial effect exists in the dependent variable or error, can be determined based on the significance of 0.05.

The sample of this study is panel data measured by city, county, district, and year. Since it has both cross-sectional characteristics and time series characteristics, it is highly likely to violate the assumption of the error term during regression analysis. Therefore, this study conducted F-test, Breusch and Pagan's LM test (Lagrangian Multiplier), t, and Hausman test sequentially to reduce statistical errors.

Since the sample in this study is panel data measured by city, county, and year, it has both cross-sectional characteristics and time series characteristics, so there is a high possibility of violating the assumption of error terms during regression analysis. Therefore, in order to reduce statistical errors, F-test, Breusch and Pagan's Lagrangian Multiplier test, and Hausman test were sequentially performed.

First, the results of the F-test are as follows. The F-value was confirmed to be 5.43, and the p-value was confirmed to reject the null hypothesis at the 1% significance level. At this time, the null hypothesis of the F-test is that the pooled OLS is relatively more suitable than the fixed effect model, and this was rejected at the 1% significance level, and the analysis confirmed that the fixed effect model was more suitable than the pooled OLS.

Second, the results of Breusch and Pagan's LM test (Lagrangian Multiplier) are as follows. The Chibar2 value was confirmed to be 455.63, and the p-value was confirmed to reject the null hypothesis at the 1% significance level. At this time, the above analysis method was relatively more suitable than the pooled OLS, and it was rejected at the 1% significance level, confirming that the random effect model was relatively more suitable than the pooled OLS.

Third, the results of Hausman verification are as follows. As a result of the analysis, the chi2 value was confirmed to be 32.67, and the p-value was confirmed to reject at the 1% significance level. In the verification method mentioned above, the null hypothesis confirmed that the random effect model was relatively more suitable than the fixed effect model, and that the fixed effect model was relatively more suitable than the random effect model by rejecting it at the 1% significance level. As a result, it is appropriate to use a fixed-effect model.

Table 2-2 Model of RE vs. FE

Resp_mort	OLS	Fixed Effect	Random Effect
Ln_DC_PM	1.289* (1.80)	6.481** (2.42)	1.869 (1.61)
K_PMC	0.419*** (2.92)	0.564*** (3.73)	0.568*** (4.43)
SO2	6.868** (2.04)	8.150** (2.18)	8.405** (2.33)
O3	467.874*** (8.79)	379.666*** (7.74)	441.363*** (10.79)
K_ATM	0.313 (1.10)	-1.816 (-1.14)	0.301 (0.84)
ln_K_RAIN	-5.469*** (-4.42)	-9.108*** (-6.78)	-6.985*** (-6.07)
ln_K_HMD	-6.409 (-1.15)	37.973*** (3.09)	3.742 (0.55)
ln_DC	1.986*** (3.33)	0.638 (0.15)	1.989** (2.16)
ln_PWC	6.199 (0.38)	-8.697 (-0.46)	0.036 (0.00)
QoL	-3.345*** (-3.46)	8.614 (1.13)	-3.210** (-2.17)
Pop	-0.686 (-0.52)	12.149* (1.90)	0.084 (0.05)
empl	0.803*** (3.30)	-2.279 (-1.27)	0.599 (1.41)
manuf	-3.299*** (-3.11)	-1.714 (-0.47)	-3.616** (-2.50)
ln_K_GRDP	-6.957*** (-7.57)	-6.649*** (-6.35)	-7.246*** (-8.94)
ln_c_rain_~n	-1.284*** (-6.56)	-1.249*** (-7.68)	-1.252*** (-7.84)
c_temp_mean	2.709*** (3.97)	2.498** (2.49)	2.506*** (4.42)
_cons	-42.693 (-0.99)	-459.912*** (-4.29)	-72.410* (-1.83)
N	1095	1095	1095
R-sq	0.279	0.178	0.284

1) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

3) Spatial autocorrelation and heteroscedasticity test (Moran's I)

To confirm spatial autocorrelation, the Global Moran's I was tested for respiratory mortality. Moran's I examines overall cluster trends, focusing on similar respiratory mortality rate values across the country. Due to the existence of spatial autocorrelation, the more similar the observed values are, the more positive (+) values are derived. In the opposite case, the negative (-) values appear. Moran's indices for respiratory mortality rate, the dependent variable of this study, was derived in the positive (+) direction. This means that the null hypothesis that indicates that there is no spatial autocorrelation is rejected at the 1% significance level, and the spatial data of this study has autocorrelation. Therefore, since the dependent variable has a positive (+) relationship with the influence of neighboring regions calculated as a spatial weighting matrix, it is necessary to control the spatial effect.

In Table 2-3, the Global Moran's I test for respiratory mortality was conducted to confirm spatial autocorrelation. Moran's I examines overall cluster trends, focusing on similar respiratory mortality values throughout South Korea. Spatial autocorrelation exists, so the more similar the observed values are, the more positive values are derived, and in the opposite case, the negative values appear. Moran's I for respiratory mortality, the dependent variable of this study, was all derived in the positive direction. This means that the null hypothesis that there is no spatial autocorrelation is rejected at the significance level of 1%, and that the spatial data in this study have autocorrelation. Therefore, it is necessary to control the spatial effect because the dependent variable has a positive relationship with the influence of neighboring regions calculated by the spatial weighted matrix.

Table 2-3 Moran's I

Variables	I	E(I)	sd(I)	z	p-value*
Resp_mort	0.253	-0.001	0.002	116.639	0.000

*1-tail test

2.4. Results

2.4.1 Descriptive Statistics and Correlation Analysis

The total sample size is 1,095, and the average VIF value is 6.06 and is less than 10, so multicollinearity does not exist. Descriptive statistics show differences in observed values of variables between regions. Mortality rate varies by region. The PM2.5 concentration level (K_PMC) varies by region and time, with a minimum value of 17μg/m3 and a maximum value of 29μg/m3. The temperature (K_ATM) in Korea is 9.9-15.7℃, precipitation (ln_K_RAIN) is 3-5mm, and humidity (ln_K_HMD) is 4% on average. Sulfur dioxide contamination level (SO2) is included in a value between 0.002 ppm and 0.533 ppm.

Table 2-4 Descriptive Statistics

Variable	N	mean	sd	min	p50	max
Resp_mort	1095	34.5526	8.43684	17.5	33.9	78.6
Ln_DC_PM	1095	18.53118	.8620254	16.49742	18.65142	20.45569
K_PMC	1095	24.94516	2.065282	17.1565	25.077	29.61265
SO2	1095	.0110696	.0518947	.0024434	.0039282	.5338866
O3	1095	.0213489	.0067938	.0091519	.0229201	.03511
K_ATM	1095	13.23039	1.07399	9.929298	13.09099	15.77698
ln_K_RAIN	1095	4.530451	.2506509	3.932448	4.525208	5.218419
ln_K_HMD	1095	4.211396	.0540441	4.07842	4.19841	4.38897
ln_DC	1095	11.01083	.865856	9.039581	11.11241	12.92994
ln_PWC	1095	18.482	1.016033	16.02787	18.49249	21.17157
QoL	1095	.9383425	.0188845	.869	.941	.978
Pop	1095	11.8569	1.022753	9.74809	11.93419	13.99783
empl	1095	5.978015	.3655845	5.171165	5.932059	8.122876
manuf	1095	4.744529	1.438377	1.386294	4.663439	8.357024
ln_K_GRDP	1095	15.28505	1.10632	12.83133	15.25683	18.1688
ln_c_rain_~n	1095	4.699434	.5455369	4.04704	4.616934	5.666408
c_temp_mean	1095	18.11278	2.245818	16.39167	16.59167	22.16389
c_humid_mean	1095	68.03333	.6696079	66.94444	68.02778	68.83334

Table 2-5 Correlation analysis

	Resp_mort	Ln_DC_PM	K_PMC	SO2	O3	K_ATM	ln_K_RAIN	ln_K_HMD	ln_PWC	QoL	Pop	empl	manuf	ln_K_GRDP	ln_c_rain_~n	c_temp_mean
Resp_mort	1.000															
Ln_DC_PM	0.004	1.000														
K_PMC	-0.021	0.033	1.000													
SO2	0.200***	-0.210***	0.151***	1.000												
O3	-0.089***	-0.272***	0.255***	0.061**	1.000											
K_ATM	0.071**	-0.236***	0.113***	0.145***	0.334***	1.000										
ln_K_RAIN	0.112***	0.067**	-0.051*	0.188***	0.183***	0.067**	1.000									
ln_K_HMD	-0.335***	0.120***	0.026	-0.146***	0.139***	-0.097***	-0.206***	1.000								
ln_PWC	-0.263***	0.017	0.085***	-0.096***	0.104***	-0.007	-0.352***	0.620***	1.000							
QoL	-0.393***	0.152***	0.050*	-0.172***	0.125***	-0.106***	-0.238***	0.949***	0.633***	1.000						
Pop	0.101***	-0.129***	0.017	0.065**	0.040	0.092***	-0.057*	-0.242***	-0.145***	-0.302***	1.000					
empl	-0.096***	-0.009	0.023	-0.017	0.073**	0.030	-0.131***	0.096***	0.157***	0.031	0.791***	1.000				
manuf	-0.148***	0.193***	0.011	-0.096***	0.078***	-0.107***	-0.116***	0.688***	0.394***	0.653***	-0.090***	0.254***	1.000			
ln_K_GRDP	-0.370***	0.150***	0.023	-0.153***	0.096***	-0.103***	-0.218***	0.861***	0.610***	0.870***	-0.000	0.436***	0.725***	1.000		
ln_c_rain_~n	-0.045	0.413***	0.246***	0.243***	0.047	-0.241***	0.174***	-0.048	-0.028	0.002	-0.092***	-0.090***	-0.002	-0.041	1.000	
c_temp_mean	-0.053*	-0.397***	0.049	0.405***	0.106***	-0.175***	0.065**	0.015	-0.036	-0.003	0.053*	0.058*	0.003	0.013	-0.220***	1.000
c_humid_mean	-0.065**	0.212***	0.165***	0.178***	0.184***	-0.048	0.309***	-0.032	-0.074**	0.001	-0.048	-0.043	0.001	-0.027	0.667***	0.239***

1) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

2.4.2 Spatial Panel Model

As a result of estimating the mortality rate from respiratory② and other cardiovascular disease③ by applying the spatial panel model, both the coefficients of the spatial lag model and the spatial error model showing the spatial autocorrelation of the data are estimated to be positive (+), and all results secured statistical significance. The suitability of the model can be determined through the coefficient of determination (R2), log likelihood, Akaike Info Criterion (AIC) value, and Bayesian information criterion (BIC) value. Among the spatial metering models, a suitable model with high coefficient of determination (R2) and log likelihood values, and lower AIC (Akaike Info Criterion) and Bayesian information criterion (BIC) values is selected (Anselin 2005; Lee et al. 2006). First, in the model test result of mortality rate due to the respiratory system, the SDM model showed the highest determination coefficient (R2) value. In the case of considering the Log Likelihood value, the SEM model was presented as a suitable model, and in the case of AIC and BIC values, the SAR model was presented as a suitable model, indicating that the suitable model appeared differently depending on the model selection criteria. However, the size of the Log Likelihood, AIC, and BIC values did not differ significantly in the range of values even though there were differences between models, and the determinant (R2) value and degree of freedom of SDM were significantly higher than other models. In the case of PM2.5 in the surrounding area, various factors such as PM2.5 and pollutants, emissions from

② Respiratory disease _ standardized mortality rate _ total = Standardized mortality rate of other cardiovascular disease (J00-J98, U04) per 100,000 population (standardized to population of the middle of the year in 2005)

③ Other cardiovascular disease _ standardized mortality rate _ total = Standardized mortality rate of other cardiovascular disease (I25-I51) per 100,000 population (standardized to population of the middle of the year in 2005) diesel vehicle driving in the area, precipitation, GRDP, etc. may affect the surrounding area, and the SDM model was finally selected.

Table 2-6 Model Comparison

Resp_mort	FE	SAR	SEM	SAC	SDM
Ln_DC_PM	6.481** (2.42)	1.148* (1.66)	1.390** (1.98)	0.571 (1.04)	1.749** (2.37)
K_PMC	0.564*** (3.73)	0.254* (1.95)	0.300 (1.43)	0.133* (1.88)	-0.256 (-0.46)
SO2	8.150** (2.18)	3.650 (0.86)	3.764 (0.52)	2.255 (1.02)	-21.282 (-1.02)
O3	379.666*** (7.74)	659.224*** (4.83)	1286.193*** (6.77)	171.962** (2.14)	695.724 (1.63)
K_ATM	-1.816 (-1.14)	-0.283 (-1.13)	-1.018** (-2.49)	-0.015 (-0.11)	-3.678** (-2.30)
ln_K_RAIN	-9.108*** (-6.78)	-3.308*** (-2.62)	-4.381** (-2.05)	-1.416** (-2.14)	3.189 (0.53)
ln_K_HMD	37.973*** (3.09)	-7.988* (-1.68)	-8.638 (-1.09)	-2.404 (-0.93)	-2.344 (-0.07)
ln_PWC	0.638 (0.15)	0.167 (0.30)	-0.214 (-0.36)	0.088 (0.22)	-0.900 (-1.24)
QoL	-8.697 (-0.46)	-1.708 (-0.12)	-9.465 (-0.64)	4.359 (0.39)	-1.056 (-0.05)
Pop	8.614 (1.13)	-1.697* (-1.89)	-1.263 (-1.32)	-1.387** (-2.12)	-1.788 (-1.32)
empl	12.149* (1.90)	-0.505 (-0.47)	-0.536 (-0.46)	-0.332 (-0.43)	-1.066 (-0.63)
manuf	-2.279 (-1.27)	0.905*** (3.73)	0.956*** (3.83)	0.824*** (4.37)	0.884*** (2.74)
ln_K_GRDP	-1.714 (-0.47)	-1.717** (-1.97)	-1.485 (-1.56)	-1.200* (-1.96)	-0.251 (-0.19)
ln_c_rain_~n	-6.649*** (-6.35)	0.000 (.)	0.000 (.)	0.000 (.)	0.001 (0.02)
c_temp_mean	-1.249*** (-7.68)	0.000 (.)	0.000 (.)	0.000 (.)	0.000 (0.01)
c_humid_mean	2.498** (2.49)	0.000 (.)	0.000 (.)	0.000 (.)	0.001 (0.03)
Wx					
Ln_DC_PM					-1.622 (-0.46)
K_PMC					0.840 (1.48)
SO2					27.443 (1.22)
O3					-747.173 (-1.47)
K_ATM					4.699*** (2.78)

ln_K_RAIN					-8.299 (-1.31)
ln_K_HMD					2.064 (0.06)
ln_PWC					3.420 (1.58)
QoL					67.716* (1.89)
Pop					-3.515 (-1.08)
empl					10.545** (2.12)
manuf					-0.996 (-1.02)
ln_K_GRDP					-2.695 (-1.03)
ln_c_rain_~n					0.001 (0.02)
c_temp_mean					0.000 (0.01)
c_humid_mean					0.001 (0.03)
Spatial					
rho		0.437*** (13.22)		0.790*** (34.52)	0.319*** (7.96)
lambda			0.459*** (12.58)	-0.699*** (-15.86)	
LL		-3627.469	-3639.585	-3570.785	-3568.4160
AIC		7284.94	7309.171	7173.571	7192.832
BIC		7359.918	7384.149	7253.548	7332.79
		15	15	16	28
Variance					
sigma2_e		42.402*** (23.10)	43.136*** (23.00)	30.47*** (20.26)	38.827*** (11.40)
N	1095	1095	1095	1095	1095
R-sq	0.100	0.070	0.069	0.168	0.304

1) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

In addition, to examine the difference in the model for each disease, SDM analysis was additionally performed with the mortality rate from other cardiovascular disease as a dependent variable. In the case of the suitability of the model, the suitability model was different according to the determination coefficient (R2), log likelihood, Akaike Info Criterion (AIC) value, and Bayesian information criterion (BIC). However, as in the model test result of mortality rate from respiratory diseases, the determinant (R2) value and degree of freedom were larger than other models, and the SDM model was finally selected for comparison according to the mortality rate by disease.

As a result of examining the SDM model estimation results for mortality rate by disease in Table 2-7, it was confirmed that fine dust emissions from diesel vehicles had a positive (+) effect on mortality due to the respiratory system at a significance level of 5%. On the other hand, in terms of mortality rate from other cardiovascular disease, PM2.5 emissions from diesel vehicles did not significantly affect the mortality rate. Previous studies have shown that PM2.5 has a negative effect on other cardiovascular disease, disease (Cai et al., 2018; Chen et al., 2022; Du et al., 2016; Ann, 2014), but diesel vehicle PM2.5 emissions have a minimal effect on other cardiovascular disease among various causes that cause PM2.5. Nevertheless, due to the characteristics of respiratory diseases, the result that the mortality rate from the respiratory system is affected by the PM2.5 emission from diesel cars is noteworthy. In addition, it was found that as the number of manufacturing companies increased, the mortality rate from the respiratory system increased. Lee et al. (2017) judged that the more manufacturing businesses there are, the higher the factory operation rate, which could affect the mortality rate of the industry.

Model analysis of other cardiovascular disease mortality rate shows that SO2 and O3, which are produced from diesel vehicle emissions and cause secondary PM2.5 in the atmosphere, have a positive effect on other cardiovascular disease mortality rate at a 5-10% significance level (Table 2-7). In addition, SO2 in the nearby area had a positive (+) effect on the mortality rate from other cardiovascular disease in the area at the 5% significance level. This shows that SO2 has a significant effect on the mortality rate between neighboring regions due to spatial mobility, and it is justifiable to promote policies to prevent the spread of SO2 through linkage and cooperation system establishment between neighboring local governments.

Meanwhile, in the two SDM models for each disease, it was found that as the temperature in the nearby area increased, the mortality rate from respiratory and other cardiovascular disease in the region had a positive (+) effect at 1% and 5% significance levels, respectively. There are a number of previous studies (Ciabattini et al., 2020; Kang et al., 2019; Proietti et al., 2013 Pope et al., 2020) showing that increasing temperature promotes the production of secondary generating substances due to SO2. However, contrary to these results, the mortality rate model results from the respiratory system showed that as the temperature rises, the mortality rate from the respiratory system has a negative (-) effect at 5% significance level, suggesting that further research is needed on whether there is a difference in mortality rate from fine dust depending on seasonal factors.

Table 2-7 Comparison of SDM estimation results by disease

	Respiratory system mortality rate	**Other cardiovascular disease mortality rate**
Ln_DC_PM	1.749** (2.37)	-0.972 (-1.22)
K_PMC	-0.256 (-0.46)	0.269 (0.64)
SO2	-21.282 (-1.02)	-39.089** (-2.21)
O3	695.724 (1.63)	546.802* (1.74)
K_ATM	-3.678** (-2.30)	-0.773 (-0.93)

ln_K_RAIN	3.189 (0.53)	-1.857 (-0.30)
ln_K_HMD	-2.344 (-0.07)	16.318 (0.69)
ln_PWC	-0.900 (-1.24)	0.031 (0.05)
QoL	-1.056 (-0.05)	-5.727 (-0.35)
Pop	-1.788 (-1.32)	1.527* (1.65)
empl	-1.066 (-0.63)	**2.150**** **(1.97)**
manuf	**0.884***** **(2.74)**	**0.634***** **(2.89)**
ln_K_GRDP	-0.251 (-0.19)	-1.785* (-1.78)
ln_c_rain_~n	0.001 (0.02)	0.000 (.)
c_temp_mean	0.000 (0.01)	0.000 (.)
c_humid_mean	0.001 (0.03)	0.000 (.)
Wx		
Ln_DC_PM	-1.622 (-0.46)	-4.535** (-2.16)
K_PMC	0.840 (1.48)	-0.169 (-0.35)
SO2	27.443 (1.22)	47.322** (2.42)
O3	-747.173 (-1.47)	-667.928 (-1.60)
K_ATM	4.699*** (2.78)	2.326** (2.43)
ln_K_RAIN	-8.299 (-1.31)	1.230 (0.19)
ln_K_HMD	2.064 (0.06)	-34.593 (-1.45)
ln_PWC	3.420 (1.58)	2.177 (1.47)
QoL	67.716* (1.89)	25.886 (1.00)
Pop	-3.515 (-1.08)	0.343 (0.17)
empl	10.545** (2.12)	3.119 (0.81)
manuf	-0.996 (-1.02)	1.129 (1.35)
ln_K_GRDP	-2.695 (-1.03)	-1.135 (-0.57)
ln_c_rain_~n	0.001 (0.02)	0.001 (0.02)

c_temp_mean	0.000 (0.01)	0.000 (0.01)
c_humid_mean	0.001 (0.03)	0.001 (0.03)
Spatial		
rho	0.319*** (7.96)	0.373*** (9.11)
LL	-3568.4160	-3245.7667
AIC	7192.832	6547.533
BIC	7332.79	6687.492
Variance		
sigma2_e	38.827*** (11.40)	21.362*** (11.17)
N	1095	1095
R-sq	0.304	0.279

1) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

Table 2-8 examines the direct, indirect, and total effects of the mortality rate model by disease, and in the mortality rate model due to the respiratory system, the concentration of ultrafine dust in the region has a positive (+) effect on the mortality rate due to the respiratory system in the vicinity. On the other hand, in the mortality rate model from other cardiovascular disease, the concentration of PM2.5 in the area did not significantly affect the mortality rate from the respiratory system in the nearby area. However, in other cardiovascular disease mortality rate model, SO2 in the area was found to have a positive (+) effect on the mortality rate other cardiovascular disease in the neighboring area at a 10% significance level.

As a result of examining weather factors, it was found that as the temperature in the region rises, the mortality rate from respiratory and other cardiovascular disease in the nearby area has a positive (+) effect at 1% and 5% significance levels, respectively. Previously, Table 2-7 suggested that the temperature of the nearby area is affecting the region, and Table 2-8 shows the effect of the temperature of the region on the neighboring region, confirming that weather factors are affecting the spatial correlation between regions. In addition, an increase in precipitation in the area has a negative (-) effect on the mortality rate from the respiratory system in the nearby area, and an increase in humidity in the area has a negative (-) effect on the mortality rate from other cardiovascular disease in the nearby area.

Table 2-8 Direct, Indirect and Total Effects of Disease-Specific Mortality Models

	Respiratory mortality rate			**Other cardiovascular disease mortality rate**		
	Direct Effect	Indirect Effect	Total Effect	Direct Effect	Indirect Effect	Total Effect
Ln_DC_PM	1.712** (2.19)	-1.183 (-0.25)	0.529 (0.11)	-1.343 (-1.59)	-7.278** (-2.21)	-8.622** (-2.40)
K_PMC	-0.228 (-0.44)	1.073* (1.90)	0.846*** (3.26)	0.244 (0.64)	-0.095 (-0.19)	0.150 (0.66)
SO2	-17.912 (-0.94)	26.786 (1.25)	8.873* (1.85)	-34.723** (-2.19)	47.502** (2.51)	12.779*** (2.91)
O3	648.957* (1.69)	-719.391 (-1.41)	-70.434 (-0.27)	497.766* (1.77)	-681.574 (-1.47)	-183.809 (-0.63)
K_ATM	-3.402** (-2.34)	4.859*** (3.01)	1.457** (2.54)	-0.592 (-0.77)	3.036*** (2.96)	2.444*** (5.21)
ln_K_RAIN	2.961 (0.52)	-10.418* (-1.70)	-7.457*** (-4.09)	-1.542 (-0.27)	0.539 (0.09)	-1.002 (-0.65)
ln_K_HMD	-1.079 (-0.03)	0.733 (0.02)	-0.346 (-0.03)	14.764 (0.65)	-43.884* (-1.87)	-29.119*** (-3.69)
ln_PWC	-0.704 (-1.06)	4.330 (1.49)	3.627 (1.21)	0.202 (0.32)	3.159 (1.38)	3.362 (1.31)
QoL	4.782 (0.22)	91.759* (1.73)	96.540 (1.59)	-2.655 (-0.16)	34.392 (0.84)	31.737 (0.67)
Pop	-2.046 (-1.41)	-5.864 (-1.35)	-7.910 (-1.60)	1.584 (1.61)	1.297 (0.44)	2.881 (0.90)
empl	-0.340 (-0.21)	14.456** (2.06)	14.116** (1.97)	2.461** (2.23)	5.870 (1.05)	8.331 (1.41)
manuf	0.850** (2.52)	-1.015 (-0.75)	-0.166 (-0.11)	0.760*** (3.19)	2.134 (1.63)	2.894** (2.07)
ln_K_GRDP	-0.499 (-0.37)	-3.881 (-1.10)	-4.380 (-1.08)	-1.972* (-1.96)	-2.618 (-0.89)	-4.590 (-1.41)
ln_c_rain_~n	0.001 (0.08)	0.009 (0.18)	0.010 (0.18)	0.002 (0.06)	0.009 (0.18)	0.011 (0.16)
c_temp_mean	-0.001 (-0.04)	0.001 (0.01)	-0.000 (-0.00)	-0.002 (-0.06)	-0.001 (-0.07)	-0.003 (-0.06)
c_humid_mean	0.001 (0.05)	0.001 (0.05)	0.002 (0.05)	-0.001 (-0.06)	0.001 (0.03)	0.000 (0.00)

1) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

2.4.3 The difference of the metropolitan and non-metropolitan areas

Additional analysis was conducted to determine whether PM2.5 emissions from diesel vehicles affect the mortality rate due to the respiratory system according to urban characteristics. Variables were created by dividing 219 regions into metropolitan and non-metropolitan areas, including Seoul, Incheon, and Gyeonggi-do's city-county-district areas, and small-and medium-sized cities include areas excluding the metropolitan area. Dummy variables were generated in the metropolitan area as 1 and small and medium-sized cities as 0, and then analyzed using the interaction term with the fine dust emission of diesel vehicles. The analysis results are as follows.

In the non-metropolitan area, when PM2.5 emissions from diesel vehicles increased, the mortality rate from the respiratory system was positively affected at the 1% significance level, but in the metropolitan area, no significant results were confirmed. In addition, in the case of non-metropolitan areas, the higher the concentration of domestic pollutants (ultra-fine dust, SO2, O3), the higher the mortality rate from the respiratory system. On the other hand, in the metropolitan area, the higher the concentration of PM2.5, the lower the mortality rate from the respiratory system at the 10% significance level. This difference is believed to be due to the medical and environmental infrastructure of the non-metropolitan area and the metropolitan area. In other words, considering that the gap in medical services between the metropolitan and non-metropolitan areas where more than half of Korea's population resides is not small (Jang et al, 2018), the number of doctors and specialists per unit population is relatively insufficient compared to the metropolitan area, which can affect the mortality rate from the respiratory system.

Table 2-9 Comparison of non-metropolitan area and metropolitan area

	Non-metropolitan area	**metropolitan area**
Ln_DC_PM	7.297** (1.97)	1.497 (0.52)
K_PMC	0.803*** (3.81)	-0.544* (-1.96)
SO2	10.689** (2.52)	-100.463 (-0.09)
O3	508.849*** (8.07)	-137.575 (-0.81)
K_ATM	0.116 (0.06)	-16.178*** (-3.87)
ln_K_RAIN	-12.931*** (-6.86)	-3.427 (-0.81)
ln_K_HMD	45.499*** (2.84)	2.302 (0.08)
ln_PWC	2.156 (0.41)	-4.930 (-0.80)
QoL	-7.988 (-0.35)	-2.595 (-0.09)
Pop	-0.323 (-0.03)	15.089* (1.73)
empl	6.010 (0.72)	11.911 (1.40)
manuf	-3.561 (-1.46)	0.819 (0.38)
ln_K_GRDP	0.776 (0.16)	-5.279 (-1.07)
ln_c_rain_~n	-9.572*** (-6.14)	-5.733** (-2.50)
c_temp_mean	-1.571*** (-6.88)	-0.273 (-0.58)
c_humid_mean	3.856*** (2.86)	8.297*** (3.51)
N	775	320
R-sq	0.193	0.360

1) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

2.5. Conclusion and Discussion

This study aims to analyze the effect of PM2.5 emissions from diesel vehicles on the mortality rate from local respiratory and other cardiovascular disease, and to investigate the relationship that affects them. To prepare a logic for cooperation by region, by local government, and even by city and province for fine dust policy, a spatial panel model considering spatial adjacency between regions was applied. The main findings of the study are as follows.

First, it was confirmed that PM2.5 emissions from diesel vehicles had a positive (+) effect on the mortality rate from the respiratory system, but in the mortality rate from other cardiovascular disease, PM2.5 emissions from diesel vehicles did not significantly affect the mortality rate.

Since PM2.5 emissions from diesel vehicles, an independent variable of this study, are one of the causes of PM2.5 emissions, the effect on mortality rate may have smaller effect than PM2.5 emissions or PM2.5 concentrations. Nevertheless, the fact that significant results were obtained on mortality rate of respiratory disease is meaningful in that it identifies the relationship between PM2.5 emissions from diesel vehicles and the respiratory mortality rate.

Second, SO2 was found to have an inter-regional effect on the mortality rate from other cardiovascular disease. SO2 is a secondary product of PM2.5, a major pollutant generated by diesel vehicles. SO2 occurring in the area affects the mortality rate from other cardiovascular disease in the nearby area, and SO2 in the nearby area also affects the dependent variables in the area. These results are consistent with finding of Wang et al. (2019) and Gu and Jun (2021) that lung disease mortality rate increases as the annual average SO2 in a city increases.

Further research is needed to determine whether there is a difference in the results depending on the mortality rate by disease. Likewise, it was confirmed that as the temperature in the neighboring area increases, it has a positive (+) effect on the mortality rate of respiratory and other cardiovascular disease in the area. As with SO2, this supports the findings of Wang et al. (2019) and Gu and Jun (2021) that lung disease mortality rate increases as the city's annual average SO2 increases.

It is noteworthy that increasing temperature promotes secondary generating substances due to SO2 (Ciabattini et al., 2020; Kang et al., 2019; Proietti et al., 2013 Pope et al., 2020), so secondary generating substances such as temperature and SO2 can increase regional mortality through interaction, which is expected to be studied in the future.

Third, as a result of examining the difference between the non-metropolitan area and the metropolitan area, it was found that the non-metropolitan area is relatively more affected by the mortality rate due to the respiratory system than the metropolitan area when PM2.5 emissions from diesel vehicles increased. This is thought to be due to the difference in infrastructure between non-metropolitan and metropolitan areas, and since various factors can affect mortality rate due to the respiratory system, it is necessary to examine regional differences in the future by considering medical and environmental infrastructure.

This study observes the relationship between the respiratory system and the cardiovascular system in consideration of spatial proximity. The government is preparing measures for PM2.5 by region and is devising cooperative measures between local governments to reduce PM2.5. In addition to preparing long-term measures, short-term support is needed to install PM2.5 shelters in non-metropolitan areas to protect citizens' health from PM2.5.

This study examines the difference between the spatial correlation of the econometric model for PM2.5 emissions from diesel vehicles on the mortality rate from local respiratory and other cardiovascular disease. The differentiation and significance of this study are as follows.

First, the possibility of underestimating or overestimating the estimate was prevented by considering spatial autocorrelation. In addition, to confirm spatial autocorrelation, the Inverse Distance Weighting (IDW) method was selected, which is suitable for continuous data and can be applied when the closer the distance between regions is, the higher the possibility of interacting or influencing each other. Furthermore, IDW method was found to be suitable for conducting an analysis of the impact on PM2.5 emissions from diesel vehicles on the mortality rate from local respiratory and other cardiovascular disease.

Second, this study calculated the amount of PM2.5 generated by diesel vehicles by using the air pollutant emission calculation method of road non-point pollutant sources of the Clean Air Policy Support System (CAPSS) and considered it as a major variable in the analysis. The amount of PM2.5 generation of diesel vehicles in the transportation sector is the most likely pollutant to be exposed to citizens, but PM10 or PM2.5 concentrations were mainly used in previous studies due to the difficulty of obtaining data by city, county, and district. Through this, this study suggested that the variable of PM2.5 emissions from diesel vehicles had a significant influence on the mortality rate of local respiratory. It is noteworthy that a significant effect was found in the mortality rate from local respiratory variable, even though PM2.5 emissions from diesel vehicles, one of the PM2.5

emission factors, may have a smaller impact compared to the total PM2.5 concentration. Since PM2.5 flows into the human body through breathing, it was confirmed that the mortality rate from local respiratory was more relevant than the mortality rate of other causes. However, further research is continuously needed in the future. In addition, further research will be needed on whether these results appear in the PM2.5 generation variable from diesel vehicles, a non-point pollutant sources, or in other individual factors.

Third, it was found that the higher the temperature and humidity, the more positive the mortality rate from local respiratory and other cardiovascular disease. Moreover, in the case of SO2, only the mortality rate from other cardiovascular disease causes were found to have a significant positive effect. By applying the Spatial Durbin Model, it was suggested that SO2 occurring in the area affects the mortality rate of other cardiovascular disease in the neighboring area, and SO2 in the neighboring area also affects the dependent variable in the area. This was not revealed in the general econometric model that did not consider spatial correlation, and in particular, it was confirmed that its characteristics became clear when constructing a spatial weight matrix through the IDW method.

Fourth, to take meteorological factors of China into account, data for monthly average of temperature level, relative humidity levels and precipitation levels of Shandong, Hebei, and Jiangsu Provinces were considered. Among studies on health effects, there are only a few empirical studies considering foreign variables. However, the consideration of foreign variables is important in studies related to PM2.5. Therefore, it must be considered not only in neighboring regions but also in studies between neighboring countries.

Fifth, respiratory mortality rate in the non-metropolitan area was found to be relatively more affected by PM2.5 emissions from diesel vehicles than in the metropolitan area, raising the need for additional research on why regional differences exist. If further research confirms that the non-metropolitan area is relatively more affected by the PM2.5 emissions of diesel vehicles, short-term measures to install PM2.5 shelters in the non-metropolitan area will be needed to protect citizens' health from PM2.5.

The limitations of this study are as follows. First, in the Spatial Durbin Model analysis, the mortality rate of respiratory diseases in the region decreased as the temperature in the region increased, while the mortality rate of respiratory diseases in the region increased as the temperature in the neighboring region increased, indicating inconsistency. This is believed to be a limitation of not being able to closely examine monthly data by applying annual data. It is necessary to more accurately investigate the cause through further research. In addition, in the result table for direct and indirect effects of Mortality Models, the higher the PM2.5 emissions from diesel vehicles in the region, the lower the mortality rate from other cardiovascular disease in the region, and the lower the PM2.5 emissions from diesel vehicles in the neighboring region, the more difficult it is to explain. This may be a problem regarding the reliability of the data, or it may mean that the variables constituting the model should be additionally considered. It is believed that further analysis is needed in the future by securing data on prevalence as well as mortality variables.

Second, this study created spatial autocorrelation by setting the spatial range to cities, counties, and districts based on previous studies and proceeded. Since the city, country, and district area is a division of administrative districts, it is easy to present policy implications. However, depending on the purpose and direction of the study, if a grid pattern is set based on a specific distance, there may be differences in the interpretation of the study results. Additional analysis by setting the spatial range in various ways is needed in the future.

Third, this study only compares the mortality rate of respiratory system and of chemical other cardiovascular disease. However, considering diseases and mortality rates by various causes such as diabetes, dementia, Alzheimer's disease, and skin disease, it is expected that more useful research results can be derived if research results on pollutants, meteorological factors, power generation and industrial factors, and regional factors are reviewed whether they are the same or different.

Chapter 3. Does PM2.5 emission by diesel vehicle type and size have a different effect on PM2.5 concentration?

3.1. Study Background

Long-term exposure to particulate matter (PM)[④] can cause various health risks such as respiratory diseases, cardiovascular diseases, and even death (USEPA, 2022). The OECD (2016) reported that premature mortality and the social cost associated with atmospheric pollution will be the highest in South Korea by 2060 if it does not take drastic actions to abate it. Though its PM2.5 concentration level has been decreasing, South Korea has ranked 27th in 2018, 26th in 2019, 41st in 2020, and 52th in 2021 of 117 countries for PM2.5 level (IQAir, 2021). As public concern over the health risks of PM2.5 worsened and Seoul's PM2.5 concentration peaked at 135μg/m3 in 2019, the Korean government issued urgent measures to reduce PM2.5 pollution. Following research findings that diesel vehicles are the primary emitters of PM2.5 in the Seoul Metropolitan Area (SMA: Seoul, Incheon, and Gyeonggi Province), government measures included efforts to curtail the use of diesel vehicles, such as subsidizing early disposal of old diesel vehicles and trucks (Interagency coordination, 2017).

Despite these measures and about 845.4 billion Korean Won (US$770 million) investments to dispose nearly a million diesel vehicles, the number of registered diesel vehicles increased by 9 percent between 2016 and 2020 (MOE, 2021). Further, it was found that more than half of people who received subsidy for disposing old diesel vehicles repurchased diesel vehicle, highlighting 'loopholes in

[④] PM 10 is defined as "inhalable particles with diameters that are generally 10 micrometers and smaller", and PM 2.5 is defined as "fine inhalable particles with diameters that are generally 2.5 micrometers and smaller"(USEPA, 2021) the PM reduction policies' prescribed in the 2017 Comprehensive Plan on Fine Dust Management (CPFDM) (Interagency coordination, 2019). To better prioritize PM reduction policies in the transportation sector, a thorough understanding of the PM emission sources is vital.

To better understand PM emission sources in transportation, different vehicle types and scales could be considered. Past findings imply that of all diesel vehicles, diesel trucks, in particular, contribute significantly to PM concentration levels (Hahn, 2020b). Though the 2020-2024 CPFDM bolstered regulations on diesel trucks, their effectiveness has yet been verified (Hahn et al., 2019; Hahn, 2020a; Hahn, 2020b). Additionally, gasoline tax subsidies provided to commercial diesel truck owners hinder efforts to lower the number of diesel vehicles, especially in the commercial freight industry in South Korea. As past studies have warranted a review and revision of measures that support diesel vehicle usage (Lee, 2018; Hahn et al., 2019), additional research that analyze PM emission by various vehicle types are needed.

Also, findings on PM emission by vehicle sizes have yielded conflicting results. Whereas Kim & Kang (2020) found that over 90 percent of medium to large trucks use diesel and emit more PM than other vehicle types, other studies found that small trucks emit more PM due to a significant portion of old vehicles operating for more than 10 years and their prevalent use for delivery services that accrue higher mileage (Lee, 2018; Seok et al, 2018). Adding to these complexities, the impact of diesel vehicles' PM emission on PM concentration has varied across the different city and regional scales due to varying population levels and density. Consequently, different administrative areas implement different PM emission reduction strategies as permitted by the Special Act on Air Quality Improvement for Atmospheric Control Area that came into law in 2020. As this law designates jurisdiction to specific administrative areas implement PM reduction strategies befitting their regional context, analysis of vehicle PM emission by regional scale and other characteristics is needed (Hahn, 2020a; Hahn, 2020b; Sung et al., 2020; Yoon, 2020b; Yoon et al., 2022).

This study will address these needs by analyzing the effect of diesel vehicle PM emission by type and size using two-way fixed effect model, then compare the relationships in cities of different scales. Results of this study can be applied to improve the effectiveness of PM reduction measures in the transportation sector by evaluating South Korea's 2020-2024 CPFDM.

3.2. Literature Review

3.2.1 Diesel vehicle contribution to PM

The Korean government issued the Special Plan on Fine Dust Management in 2016 to promote research on PM reduction policies, limitations, and improvements (Hwang, 2019). Additionally, the government has executed short-term special measures to limit the operation of tier-5 emission vehicles⑤ and implemented alternate no-driving system for public vehicles⑥ when PM concentration peaked between December 2019 and March 2020 (Interagency coordination, 2017; 2019).

⑤ The vehicle emission grade system is implemented by the Ministry of Environment. The emission grades range from tier 1 to 5, in which higher grades indicate higher emission potential. The evaluation standards for the five-tier system varies by vehicle types, including electric vehicles, gasoline vehicles, and diesel vehicles. More details about the vehicle emission grade system can be found on mecar.or.kr.

⑥ The alternate no-driving system regulates the number of operating vehicles by permitting vehicles with license plate numbers ending in odd numbers to operate on odd-numbered days and even numbers on even-numbered days. This measure was applied to public and governmental vehicles only (The Office for Government Policy Coordination Prime Minister's Secretariat, 2020).

Then, in 2019, the 2020-2024 CPFDM[7] was issued as a holistic set of measures, including those targeting the transportation sector, to reduce PM2.5 emission and manage risks arising from PM2.5 pollution.

Studies examining the relationship between diesel vehicles and PM have addressed pollutant emission from diesel vehicles (Oanh et al., 2010; Platt et al., 2017; Wang et al., 2019) and the impact of diesel vehicles on air pollution or PM concentration (Kim et al., 2021; Suleiman et al., 2019; Wihersaari et al., 2020). On associated policies, studies on regulation for diesel vehicle reduction (Kang & Kim 2015) demand for and purchasing decisions for electric vehicles (Kim et al., 2020; Seok et al., 2018) have been conducted.

Of these studies, many targeted diesel trucks due to its high contribution to overall PM pollution, which may be likely due to the high number of vehicles that were produced more than 10 years ago and their commercial purposes that accrue high mileage (Hahn et al., 2019). On trucks specifically, studies have examined associated trip activities (Kim et al., 2018), PM emission and reduction management (Lee, 2018; Hahn et al., 2019), transition to other transportation modes (Seok et al, 2018; Hahn et al., 2019; Hahn, 2020b), exhaust emission and travel factors (Hahn, 2020a; Hahn, 2021), and gasoline tax subsidy for truck owners (Hahn, 2020c). Hahn (2020c) assessed the relationship between vehicle inspection results and diesel truck characteristics, such as industry classification, registration site, model year, total mileage, existence of low emission device using the binomial logit model and suggested that vehicle emission management should

[7] The 2020-2024 CPFDM's plans for the transportation sector includes 1) reducing emissions from old, diesel vehicles and expanding the targets for driving restriction, 2) increasing the use of eco-friendly vehicles including gasoline-fueled cars and electric cars, 3) implementing the "Bonus-Malus System" (BMS), and strengthening control over fine dust emissions from vessels and construction machines (Interagency coordination,2019).

prioritize trucks and passenger vans over other vehicle types.

On the other hand, other studies have assessed PM pollution from a regional perspective since air pollutant emission scenarios differ by region. Lee (2018) focused on PM emission from small trucks and proposed plans better regulate them. Yoon (2020a) analyzed PM10 concentration level trends in 69 cities from 2010 to 2019 and projected 2025-levels to develop management measures appropriate for different regional characteristics. Hahn (2020c) also studied vehicle PM emissions, but distinguished the regions by city scale – small, medium, and large – and classified them as SMA or not to develop a more detailed PM management plan. As more studies addressing PM pollution from a regional perspective are needed, this study will assess the impact of PM2.5 emissions from vehicles on PM2.5 concentration level by vehicle type, size, in different regional scales.

3.2.2 PM concentration level determinants

Primary determinants of PM concentration level are climatic conditions, such as temperature and humidity, and emission of primary pollutants, such as nitrogen oxide (NOx) and sulfur oxide (SOx) that generate PM2.5 when released into the atmosphere from diesel combustion (Apostolopoulou et al., 2020; Kang et al., 2019; Park & Shin, 2017; Ramli et al., 2020; Saaroni et al., 2018). Park & Shin (2017) found that westerly wind direction ratio affects PM2.5 concentration level when controlling diesel consumption level, coal power transaction volume, domestic cement manufacturing index, and regional cement production index using a fixed effect model. Kang et al. (2019) applied machine learning methodology to assess the relationship between Korea’s PM pollution and concentration of air pollutants (e.g., NOx), climatic conditions (e.g., temperature, humidity, precipitation, wind direction), air pollutant emission (e.g., production process exhaust), and air quality in China (e.g., PM2.5 level). As a result, they found that China's air quality affected Korea's PM pollution while NOx and SOx emissions were primary emissions found domestically.

Other studies have incorporated spatial models to observe PM determinants within a regional context. For instance, Hao & Lio (2016) used spatial lag and error models to examine the effect of GDP per capita and industry and transport sectors on air quality across 73 cities in China and found that PM2.5 level and per capita GDP had an inverse-U relationship. Studies on PM determinants have been prolific in Korea and China, but direct comparison of the two countries' cases remains difficult due to discrepancy in the national statistical data. As such, this study will observe the effect of PM levels of the cities in China located near Korea and other factors from the transportation, industry, and energy sectors.

3.2.3 PM2.5 Policy Trend

The Korean government's plan to reduce PM2.5 includes 「PM2.5 management special measures」 established in June 2016, 「PM2.5 comprehensive management measures」 established in September 2017, and 「Emergency and regular PM2.5 management strengthening measures」 established in November 2018 (Interagency coordination, 2019). In addition, the 「Emergency and regular PM2.5 management」 is meaningful in that it has significantly strengthened emergency reduction measures in the event of high-concentration PM2.5 and regular reduction measures for PM2.5 emission sources such as diesel cars. Through these efforts, we aim to reduce PM2.5 emissions by 35.8% by 2022 compared to 2014 (Joo, 2018; Interagency coordination, 2019).

As for the regular reduction measures in the transportation sector, based on the reduction of PM2.5 emission from diesel cars, revitalizing the supply of eco-friendly cars, and strengthening transportation demand management proposed in「Comprehensive Measures for Management of PM2.5」, the reduction of diesel vehicles in the public sector and public transportation suppression of demand for new diesel vehicles, and expansion of support for scrapping old diesel freight vehicles were further suggested. Additional support for diesel truck scrapping was also suggested. In particular, in the case of expanding support for old diesel trucks, KRW 4 million will be provided for purchasing LPG 1-ton trucks after scrapping old diesel trucks, and medium and large trucks will also realize the current level of early scrapping subsidies to the level of used cars (Lee and Cho, 2017; Lee et al., 2018).

Discussions are underway around the world on reducing consumer preferences for diesel, given that the environmental cost of using diesel may be greater than that of gasoline. Given that the fuel price policy affects freight transportation methods and the entire automobile market, it is expected that it will be difficult to scrap the current pricing system favorable to diesel or switch from a large framework. However, as environmental damage caused by the use of diesel has been confirmed, consumers' preference for diesel vehicles has been lowered. With the development of the eco-friendly car, conditions for adjusting diesel prices have been set up compared to before. The OECD (2019) points out that many countries still have favorable tax and price policies that are favorable to diesel, but changes are emerging mainly in developed countries recently. However, despite the positive effects of environmental improvement, the market formed within the current price system and the existing economic entity should be approached step-by-step to adapt to the new market environment.

Table 3-1 Major contents of the road transportation sector of the comprehensive measures for PM2.5 management (2020-2024)

Major measures	Content	Detail
1) Acceleration of the elimination of old diesel cars	Expansion of early scrapping and conversion business of old diesel vehicles	○ Support for early scrapping to eliminate 80% or more of old diesel vehicles by 2024 (less than 490,000 vehicles by 2024) -Improvement of the current early scrap subsidy system to suppress the repurchase of new diesel vehicles after early scrap of diesel vehicles ○ Expand support for the elimination of old diesel vehicles adjusted to the low-income class and the sensitive class, such as old compact freight trucks and school vehicles for children ○ Expand support for low-emission measures, such as attaching a smoke reduction device (DPF) more than 80,000 units per year and reforming LPG engines when it is difficult to scrap a vehicle early due to lack of alternative models or the burden of new vehicle costs - Expand support for installation of devices such as parking AC/heater in freight trucks (more than 2,000 units annually) ○ Reorganization of acquisition tax and automobile tax (possession tax) to suppress re-entry and early exit of the old diesel car market - Adjust acquisition tax (4-7% of the current vehicle price) to twice the level of a gasoline vehicle when purchasing a used old diesel vehicle (Euro 5) - Reduce possession tax reduction rate for old vehicles exceeding a certain age among non-business cars, excluding freight trucks.
	Expansion of phased restrictions on operation and lead to the exit of public institutions	○ Restrictions on the operation of the emission rating system and phased expansion to strengthen the response to high concentrations and accelerate the exit of old diesel vehicles - Promote expansion of areas where regular operation of certain diesel vehicles is restricted from the metropolitan area to the whole country ○ Complete removal of old diesel vehicles from public institutions by 2022 - Scrapping of official diesel vehicles (below Euro5) that have passed the standard period, and the complete exit of old diesel vehicles (below Euro 3) from the public institution by 2022
2) Enhancing inspection and management of diesel vehicles		○ Promote appropriate follow-up management by blocking illegal inspections of diesel vehicles, expanding detailed inspections, and strengthening exhaust and idle control
3) Suppression of demand for new diesel vehicles	Adjustment of the relative price of transportation energy	○ Review measures to gradually adjust the relative price of gasoline : diesel : LPG to the level of environmentally developed countries such as the OECD (OCED gasoline and relative diesel price (second half of 2018) 100:93) ○Adjustment of the traffic energy environment tax distribution ratio Concentrated in the transportation and SOC Sector
	Strengthening the	○ Strengthen the exhaust standards for the next small and medium diesel vehicles (less than 3.5 tons in total weight) to the level equivalent to

	responsibility of manufacturers to produce diesel vehicles	gasoline cars following the EU's implementation period (likely around 2025). ○ Implementation of road emission standards for nitrogen oxides from small and medium diesel vehicles that have been strengthened to the same level as EU standards (0.114 g/km since 2020) ○ Implementation of restrictions on the use of new diesel vehicles for children's school and delivery in the air quality management district
4) Expansion of low-pollution vehicles	**Raising targets for low-pollution vehicles and expanding strategic support**	○ Promote the goal of distributing 850,000 electric vehicles and 150,000 hydrogen vehicles by 2024 ○ Implementation of the "low pollution vehicle supply target system" that mandates the manufacturer to sell a certain percentage of sales volume in low pollution vehicles ○ Gradually reduce subsidies for buying cars in phases and provide subsidies for vans and trucks in consideration of environmental improvement effects and price trends - Promotion of the distribution of low-pollution vehicles considering the conditions of each type of vehicle, such as cars, vans, and freight trucks • (Car) Support both electric and hydrogen vehicles until the point of securing competition with an internal combustion engine • (Van) Distribute electric buses for villages and rural areas and hydrogen-powered buses* for inter-city and express buses * (Inter-city bus) Demonstration projects in 2019 (7 cities, 35 units), full-scale supply from 2020 • (Freight) Focus on supplying electric trucks with a capacity of less than 1 ton and hydrogen trucks with a capacity of more than 1 ton
5) Promoting public transportation convenience and strengthening transportation demand management		○ Reduce the use of private cars and expand the use of alternative means of freight transportation through expanding public transportation, reducing the burden of transportation costs, and enhancing convenience

Resource: Interagency coordination (2019) comprehensive measures for PM2.5 management.

Description: The table summarizes measures related to this study, such as the elimination of diesel, suppression of demand for diesel cars, and expansion of the supply of low-pollution vehicles

3.2.4 Fixed effect panel models

Fixed effect panel models have been applied to studies of PM determinants (Park & Shin, 2017), changes in PM determinants over time (Kim, 2018), and the effect of the power sector on PM emission reduction (Kim et al., 2017a). Kim et al. (2020) further incorporated regional panel data to study electric vehicle purchasing decisions.

Fixed effect panel models contain error terms $e_{i,t}$, v_i, c_t to consider unobserved effects of changes in independent variables x and z, in observation i per change in time t, and in observation i itself. Error terms v_i and c_t both represent unobserved effects of changes in the observation and in time, respectively. Additionally, Hausman tests could be conducted to verify that the error term v_i and independent variables ($x_{i,t}$) are not correlated, and therefore do not cause endogeneity problems and compare the results of fixed and random effect models. To conduct a Hausman test, the difference in the models' coefficients ($\beta_{RE} - \beta_{FE}$) and the variance is needed. As shown in equation (1), the Hausman test statistic is the product of consistent and efficient coefficient estimates and variance and follows a chi-squared (x^2) distribution. In such cases, the null hypothesis would state that the difference in the matrices of the fixed and random effect model estimate variances are greater than zero with the random effect model estimates having a smaller variance, which conveys that the random effect model estimates would be more efficient than the fixed effect model estimates.

$$H = (\hat{\beta}_{FE} - \hat{\beta}_{RE})'(var\hat{\beta}_{FE} - var\hat{\beta}_{RE})^{-1}(\hat{\beta}_{FE} - \hat{\beta}_{RE}) \qquad (1)$$

If the null hypothesis is rejected, results could be interpreted so that the random effect model estimates are not consistent. In this case, the fixed effect model estimates can be selected over the random effect model estimates. Inversely, if the null hypothesis is not rejected, the random effect model estimates are efficient, and therefore should be selected.

This study observes PM levels in Korea's sixteen administrative areas, and there could be unobserved disturbances in each observation area and time t. For example, there could be unobserved characteristics from each area's economic sector activities, cultural values, regional customs, and lifestyle patterns. There also could be unobserved factors in the macroeconomic or socioeconomic context as time changes, all of which could influence PM emission and concentration levels.

If the fixed effect model is selected following the Hausman test, either the one-way fixed effect model with unobserved disturbances in either area or time (Equation 2) or the two-way fixed effect model with unobserved disturbances in both area and time (Equation 3) could be selected.

$$y_{i,t} = \alpha + \beta x_{i,t} + \gamma z_i + v_i + e_{i,t} \quad (2)$$

$$y_{i,t} = \alpha + \beta x_{i,t} + \gamma z_i + v_i + c_t + e_{i,t} \quad (3)$$

Since the objective of this study is to assess the relationship between the dependent and independent variables while controlling for both regional and time-related characteristics, the two-way fixed effect model was selected.

3.3. Research Method

3.3.1 Variable Selection and Description

The timeframe of this study is from 2015 to 2018, and the geographic scope encompasses sixteen administrative areas of South Korea, all except Sejong City due to lack of 2015 data. Detailed explanation of all variables and their sources are included in Table 3-2.

The dependent variable is the national PM2.5 concentration level (μg/m3), which is obtained from the monthly regional air quality data from the MOE's annual report. The primary explanatory variables are PM2.5 emission levels per vehicle type (passenger car, passenger van, trucks), which was derived using on-road air pollutant emission estimation methods from the An Analysis of the Power Market Impact of Fine Dust Emission Reduction Measures in the Power Generation Sector) (Kim et al., 2017b; Song et al., 2014). Detailed explanation of all variables and their sources are included in Table 3-2.

Table 3-2 Variable description and sources

	Variable Name			Unit	Variable Description	Source
Dependent Variable	ln_K_PMC		PM 2.5 Concentration Level in Korea	μg/m³	Ln(PM2.5 Concentration Level per city per month)	Air Korea (https://www.airkorea.or.kr/); NIER. Annual Report of Air Quality (2015-2018). Statistical Survey Report.
Explanatory Variable	ln_DCA		PM2.5 Emission by Vehicle Type	kg/km	Ln[(Daily average travel distance per city*30)*Monthly PM2.5 emission factor (=Number of diesel vehicles by type, size, and model year *diesel vehicle emission factor by vehicle type and size)/road-extension rate index]	MOLIT Statistics System (https://stat.molit.go.kr/); Korea Transportation Safety Corporation. 2019 Average Mileage of Automobile - 2018 Statistics - The Status of Automobile Registration by Ministry of Land, Infrastructure and Transport (2015-2018); NIER. 2015. Air Pollutant Emission Factor: Based on 2012 Air Pollutant Emission. Incheon: National institute of environmental research, 2015.
Control Variable	Domestic	COAL	Coal consumption for power generation	1,000 tons	Coal consumption for power generation (non-briquettes)	MOLIT Statistics System (https://stat.molit.go.kr/); Ministry of Trade, Industry, and Energy. Mineral production report (2015-2018). Statistical Survey Report.
		ln_MANUF	Manufacturing sector's production costs	1 million KRW	Ln(Production costs associated with regional sales, shipment, inventory change, sales and resales of good and services, and more)	MOLIT Statistics System (https://stat.molit.go.kr/); Statistics Korea. Mining and Manufacturing Sector Survey (2015-2018). Statistical Survey Report.
		NO2	Nitrogen dioxide pollution level	Parts per million (ppm)	Nitrogen dioxide pollution level measured by regional monitoring stations	Air Korea (https://www.airkorea.or.kr/); NIER. Annual Report of Air Quality (2015-2018).
	Foreign	CHINA_PM	Mean of PM2.5 concentration levels in Shandong, Hebei, and Jiangsu Provinces in China	μg/m³	[(PM2.5 level in Shandong/straight distance from Shandong to observed Korean city, 100km) + (PM2.5 level in Hebei/ straight distance from Hebei to observed Korean city, 100km) + (PM2.5 level in Jiangsu/straight distance from Jiangsu to observed Korean city, 100km)/3	Ministry of Ecology and Environment of the People's Republic of China (https://www.mee.gov.cn/)
		C_ATM	Temperature in China	℃	Monthly average temperature of Shandong, Hebei, and Jiangsu Provinces	National Bureau of Statistics of China (http://www.stats.gov.cn/)
		C_HMD	Humidity in China	%	Mean of Relative humidity levels in Shandong, Hebei, and Jiangsu Provinces	
	Climatic	WWR	Westerly wind direction ratio	Days/month	Regional ratios of days with westerly winds per month	Korea Meteorological Administration (https://www.weather.go.kr/).
		K_ATM	Temperature in Korea	℃	Mean of daily temperatures (recorded 8 times at 3, 6, 12, 15, 18, 21, 24 o'clock) in each Korean city	
		ln_K_RAIN	Precipitation level in Korea	mm	Regional precipitation levels	
	Regional	ln_K_AREA	Land area	km²	Total area of land uses categorized as residential, commercial, industrial, and green space	Air Korea (https://www.airkorea.or.kr/); Korea Land and Housing Corporation. Statistics of

					Urban Planning (2015-2018). Statistical Survey Report.
	ln_K_GRDP	GRDP	1 billion KRW	Ln(GRDP = Sum of market prices of all final goods and services)	Air Korea (https://www.airkorea.or.kr/); Statistic Korea. GRDP (2015-2018). Statistical Survey Report.
Dummy Variable	TYPE_CLASS	Categorical variable for vehicle type	NA	1: passenger cars, 2: passenger vans, 3: trucks	
	SIZE_CLASS	Categorical variable for vehicle size per type	NA	1: small, 2: medium, 3: large	
	CITY_CLASS	Dummy variable for regional scale classification	NA	1: Seoul, Busan, Incheon, Gwangju, Daejeon, and Ulsan, 0: All others	
	CITY_DUMMY	Dummy variable for each region	NA	Coded number of each administrative area (Seoul. Busan, Daegu, Incheon, Gwangju, Daejeon, Ulsan, Gyeonggi, Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Kyungbuk, Kyungnam, Jeju)	

To compute the vehicle PM2.5 emission levels, the following information were needed: 1) the average daily travel distance per region, 2) the number of registered diesel vehicles by type, size, and model year, 3) PM2.5 emission coefficient per vehicle type and size, and 4) the logarithm of the road-extension rate index. First, the Korean Transportation Safety Authority(2019)'s vehicle travel distance data was used to compute the total distance traveled by multiplying the average daily travel distance for each vehicle type by 30 days. Second, the Ministry of Land, Infrastructure, and Transport's registered vehicle data was used to derive the monthly count of vehicles by type, purpose (public, private, commercial), and model year per area. The model year is provided in all data from 1995 to 2018, and the emission level differs by model year. Third, PM2.5 emission (kg/km2) of diesel vehicles by type and size was calculated using the vehicle emission formula provided by NIER, which is k*C1*v^C2, where k is the ratio of PM2.5 to PM10 emitted from on-road vehicles, C1 and C2 are constants that vary by vehicle type, size, and model year provided by the NIER, and v is the average vehicle speed. For instance, for mid-size diesel passenger cars made after 2006, the PM2.5 emission coefficient would be k*0.0396*v^(-0.3420), where k is 0.92 and v could be assumed as 50km/h (Kim et al, 2017b). Details of emission coefficient computation method can be found in NIER's PM2.5 emission coefficient data files. Fourth, the regional road-extension rate ($km/\sqrt{area\ x\ population}$) was used as the denominator to account for regional characteristics such as the length of road networks (km), land area (km2), and populations (in 1,000 people).

Control variables include domestic coal sales volume, manufacturing production costs, and NOx pollution level for the power and industrial sectors.

Additionally, gross regional domestic product (GRDP) and land area were selected as regional variables, while national temperature, precipitation, westerly wind direction ratio, China's temperature and humidity were selected as climate-related variables. Also, the mean of PM2.5 levels in Shandong, Hebei, and Jiangsu Provinces was included as a variable related to China considering their positive correlation values (0.596, 0.556, 0.607, respectively) and in reference to Jin & Jin (2021). Here, the inverse distance (in 100km) between the Chinese provinces and the Korean administrative areas was multiplied to the mean PM2.5 level (Equation 4) in consideration of the inverse effects of the Chinese provincial PM2.5 level on Korean's regional PM2.5 level by distance.

$$PM_{2.5\ adj\ China\,(i)} = PM_{2.5\ China\,(i)} * \frac{1}{straight\ distace(100km)}$$

$;\ i =$ Hebei, Shandong, Jiangsu (4)

3.3.2 Estimation Model

Since this study uses panel data with both cross-sectional (regional) and time-series (year) characteristics, Pooled OLS model will likely violate assumptions on the error term. Instead, the fixed effect (FE) model that adjusts for heterogeneity among errors was used in combination with various tests for model selection. In detail, the study conducted the F-test to specify between Pooled OLS and the FE model, Breusch-Pagan's Lagrange Multiplier (LM) test for Pooled OLS and random effects (RE) model, and the Hausman test for FE and RE models.

Table 3-3 provides the result for model selection using F-test, LM test, and Hausman test. First, the F-statistic was 58.75, which was not statistically significant at $p<0.01$. The F-test result justified the rejection of the null hypothesis that Pooled OLS performs better than the FE model. As such, the FE model could be selected over the Pooled OLS model. Second, the LM test yielded χ^2 value of 550.34 that was not statistically significant at $p<0.01$. The LM test results indicated that the null hypothesis that the Pooled OLS performs better than the RE model could be rejected; therefore, the RE model could be selected over the Pooled OLS model. Third, the Hausman test resulted in χ^2 value of 72.03 that was not statistically significant at $p<0.01$. Based on this result, we could reject the null hypothesis that the RE model performs better than the FE model.

In summary, selection of the FE model and RE model over the Pooled OLS model through the F-test and LM test, respectively. The Hausman test results then confirm the selection of the FE model over the RE model. Conclusively, the FE model was the final model selection for this study's panel data with regional and year characteristics.

Table 3-3 Model selection test results

	F-test			LM test			Hausman test		
	P. Cars	P. Vans	Trucks	P. Cars	P. Vans	Trucks	P. Cars	P. Vans	Trucks
F-value	18.58***	18.80***	18.68***						
p-value	0.000	0.000	0.000						
F-test result	FE								
$Chibar^2$				1002.99***	1003.15***	1012.02***			
p-value				0.000	0.000	0.000			
LM test result				RE					
Chi^2							35.39**	40.77***	62.56***
p-value							0.047	0.010	0.000
Hausman test result							FE		
Final result	FE Model Selection								

The effect of diesel vehicle PM emission by type and size are analyzed by the following two estimation models (Equation 5 and 6) using two-way fixed effect model, then compare the relationships in cities of different scales. The regional dummy variable (CITY_DUMMY) is not included in Equation (5) to avoid redundancy with the interaction term that embeds a dummy variable for large and small to medium size cities (DCA*CITY_CLASS).

ln K_PMCi,t = β0 + β1DCAi,t + β2COALi,t + β3ln_MANUFi,t + β4NO2i,t + β5 ln_K_GRDPi,t + β6ln_K_AREAi,t + β7CHINA_PMi,t + β8WWRi,t + β9K_ATMi,t + β10ln_K_RAINi,t + β11C_ATMi,t + β12C_HMDi,t + ∑CITY_DUMMY + εi,t . (5)

(Classification by TYPE_CLASS and SIZE_CLASS)

ln K_PMCi,t = β0 + β1DCAi,t + β4COALi,t + β5ln_MANUFi,t + β6NO2i,t + β7 ln_K_GRDPi,t + β8ln_K_AREAi,t + β9CHINA_PMi,t + β10WWRi,t + β11K_ATMi,t + β12ln_K_RAINi,t + β13C_ATMi,t + β14C_HMDi,t + β2CITY_CLASSi,t + β3DCA*CITY_CLASSi,t + εi,t (Classification by TYPE_CLASS and SIZE_CLASS) (6)

where ln_K_PMC i,t is the logarithm of PM2.5 level in South Korea's administrative area i at time t; ln_DCAi,t is ththe logarithm of PM2.5 emission per vehicle type in area i at time t; COALi,t is the coal sales volume in area i at time t; ln_MANUFi,t is the manufacturing industry's production cost in area i at time t; NO2i,t is the nitrogen dioxide pollution level; ln_K_GRDPi,t is the logarithm of

GDRP of area I; ln_K_AREAi,t is the logarithm of the land area of area i; CHINA_PMi,t is the mean PM2.5 level of Shandong, Hebei, and Jiangsu Provinces; WWR i,t is the westerly wind direction ratio; K_ATM i,t is temperature in Korea; ln K_RAIN i,t is precipitation in Korea; C_ATM i,t is temperature in China; C_HMD i,t is humidity in China; TYPE_CLASS i,t is a categorical variable for vehicle type (1: passenger car; 2: passenger van; 3: trucks); SIZE_CLASS i,t is a categorical variable for vehicle size (1: small; 2: medium; 3: large); CITY_CLASS i,t is a dummy variable for dummy variable for large cities (1: Seoul, Busan, Daegu, Incheon, Gwangju, Daejeon, Ulsan; 0: otherwise); and CITY_DUMMY is a regional dummy variable.

In this study, the following three hypothesis will be tested: 1) PM emission from diesel trucks influence atmospheric PM concentration the most compared to diesel passenger cars and passenger vans; 2) PM emission from large-size diesel trucks influence atmospheric PM concentration more than small and medium diesel trucks; and 3) The effect of PM emission from diesel vehicles, all types and sizes, will differ between large and small to mid-size cities.

3.4. Results

3.4.1 Descriptive Statistics and Correlation Analysis

Table 3-4 shows the descriptive statistics of all variables. After removing three observations due to missing values, a total of 2,130 observations remained, of which there were 16 between-region observations and 48 within-region observations. PM2.5 concentration level (K_PMC) differed across regions and time, with the minimum of its overall value at 9μg/m3 and the maximum at 44μg/m3. PM2.5 emission per vehicle type (DCA) differed across region, with the minimum of the between value at 2,808,595 kg/km and the maximum is 27,500,000 kg/km. With the logarithm of PM2.5 emission per vehicle type (ln_DCA), the mean was 16.090 kg/km and the standard deviation was 1.119. Domestic coal sales volume (COAL) differed across regions and time, ranging between 10,000 tons and 34,000 tons with mean of 14,799 tons and standard deviation of 3.192. The nitrogen dioxide pollution level (NO2) ranges between 0ppm and 0.04ppm with mean 0.019 ppm. PM2.5 level in China's Shandong, Hebei, Jiangsu regions (CHINA_PM) had a mean of 0.054 μg/m3 and standard deviation of 0.021μg/m3, with the overall value ranging between 0.027 μg/m3 and 0.129 μg/m3.

Table 3-4 Descriptive statistics

Variable Name				Mean	Median	Std. Dev.	Minimum	Maximum
Dependent Variable		**K_PMC (μg/m³)**	Overall	24.563	24	6.484	9	44
			Between			5.493	12.5	34.062
			Within			3.470	13.876	37.730
		ln_K_PMC	Overall	3.163	3.178	.283	2.197	3.784
Explanatory Variable		**DCA (kg/km)**	Overall	19700000	10400000	36700000	431477.2	279000000
			Between			3619996	2808595	27500000
			Within			36600000	2497692	278000000
		ln_DCA	Overall	16.090	16.157	1.119	12.974	19.448
Control Variable	**Domestic**	**COAL (1,000 tons)**	Overall	14.799	16	3.192	10	34
			Between			2.931	10	18.380
			Within			1.109	8.945	35.361
		MANUF (1 million KRW)	Overall	58900000	28700000	57700000	908005	227000000
			Between			3820623	50400000	62900000
			Within			57600000	-3027461	223000000
		ln_MANUF	Overall	17.310	17.172	1.254	13.719	19.238
		NO2 (ppm)	Overall	.019	.019	.006	0	.04
			Between			0.004	0.011	0.027
			Within			0.005	0.003	0.033
	Foreign	**CHINA_PM (μg/m³)**	Overall	.050	.054	.021	.027	.129
			Between			0.021	.030	0.119
			Within			0.003	0.039	0.064
		C_ATM (℃)	Overall	15.703	16.6	9.553	-2.5	30.8
			Between			9.578	-2.1	29.075
			Within			0.827	9.441	22.142
		C_HMD (%)	Overall	61.357	67	13.789	31	88
			Between			12.837	37.142	81.846
			Within			5.427	28.669	94.993
	Climatic	**WWR (days/month)**	Overall	.688	.8	.358	0	1
			Between			0.209	0.143	0.970
			Within			0.292	0.205	1.544
		K_ATM (℃)	Overall	13.707	14.6	9.237	-5	29
			Between			9.144	-1.503	27.466
			Within			1.642	10.100	20.695
		K_RAIN (mm)	Overall	100.623	69.8	90.859	0	621
			Between			74.008	14.491	300.685
			Within			51.692	12.28	420.938
		ln_K_RAIN	Overall	4.218	4.259	.957	1.252	6.012
	Regional	**K_AREA (km²)**	Overall	1098.247	798	761.206	453.17	3376.01
			Between			24.80612	1050.572	1150.533
			Within			760.8694	427.7641	3415.165
		ln_K_AREA	Overall	6.824	6.682	.558	6.116	8.124
		K_GRDP (1 billion KRW)	Overall	113925.3	73648	121687.1	16947	479822
			Between			4458.418	103368.9	120727.9
			Within			121609.5	15762.25	475533.2
		ln_K_GRDP	Overall	11.276	11.207	.783	9.737	13.081
Dummy Variable		**TYPE_CLASS**	Overall	2	2	.816	1	3
			Between			0	2	2
			Within			0.816	1	3
		SIZE_CLASS	Overall	1.984	2	.810	1	3
			Between			0.116	1.757	2.229
			Within			0.802	0.754	3.226
		CITY_CLASS	Overall	0.472	0	.499	0	1
			Between			0.069	0.437	0.636
			Within			0.495	0.163	1.035

Among the climate variables, westerly wind direction ratio (WWR) had a mean value of 0.688 days/month with standard deviation 0.358. The average temperature in Korea (K_ATM) showed clear seasonal differences with minimum -5℃ and maximum 29℃. Likewise, temperature in the observed areas of China had a similar range of temperature between -2.5℃ and 30.8℃. Precipitation level in Korea (K_RAIN) varied across regions and time with mean 69.8 mm and the overall values ranging between 0 mm and 621 mm. Humidity level in China (C_HMD)'s overall values ranged between 31 percent and 88 percent. Among the regional variables, regional land area (K_AREA)'s overall values ranged between 453.17 km2 and 3,376.01 km2. The GRDP in Korea (K_GDRP) varied drastically with standard deviation of 121,609.5 billion KRW, which signifies a noticeable economic disparity across regions.

Table 3-5 shows the results of the Pearson correlation analysis of the dependent and independent variables. The correlation coefficient of the dependent variable (ln_K_PMC) and the logarithm of PM2.5 emission per vehicle type (ln_DCA) was 0.058 and statistically significant at $p<0.01$, indicating that the Korean PM2.5 concentration level and PM2.5 emission per vehicle type are positively correlated. Additionally, the correlation coefficient of the dependent variable (ln_K_PMC) and the logarithm of manufacturing sector's production costs (ln_MANUF) was 0.075 and statistically significant at $p<0.01$.

Table 3-5 Pearson correlation analysis

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. ln_K_PMC	1.000															
2. ln_DCA	0.058***	1.000														
3. COAL	0.156***	-0.194***	1.000													
4. ln_MANUF	0.075***	0.527***	-0.041*	1.000												
5. NO2	0.576***	0.284***	0.080***	0.235***	1.000											
6. CHINA_PM	0.546***	0.059***	0.070***	-0.053**	0.453***	1.000										
7. C_ATM	-0.560***	0.001	-0.029	0.013	-0.582***	-0.667***	1.000									
8. C_HMD	-0.312***	-0.037*	-0.101***	-0.033	-0.193***	-0.187***	0.276***	1.000								
9. WWR	0.339***	0.127***	0.040*	0.121***	0.393***	0.273***	-0.311***	-0.233***	1.000							
10. K_ATM	-0.650***	-0.071***	0.025	-0.041*	-0.634***	-0.679***	0.957***	0.344***	-0.360***	1.000						
11. ln_K_RAIN	-0.539***	-0.151***	-0.116***	-0.071***	-0.543***	-0.499***	0.622***	0.321***	-0.302***	0.675***	1.000					
12. ln_K_GRDP	0.049**	0.702***	-0.037*	0.611***	0.536***	-0.014	0.004	-0.018	0.235***	-0.054**	-0.126***	1.000				
13. ln_K_AREA	0.035	0.638***	-0.01	0.642***	0.036	-0.059***	0.011	-0.006	0.093***	-0.035	-0.027	0.547***	1.000			
14. TYPE_CLASS	0.000	-0.231***	-0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000		
15. SIZE_CLASS	0.007	-0.008	-0.002	-0.023	-0.003	-0.019	0.005	-0.021	0.023	0.002	-0.008	-0.002	0.028	0.026	1.000	
16. CITY_CLASS	-0.004	-0.201***	0.006	-0.127***	0.341***	0.014	-0.011	-0.001	0.024	0.034	-0.040*	-0.017	-0.597***	0	-0.027	1.000

1) This table represents pearson correlations among variables used in this study.
2) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).
3) Please refer to <Table 4-1> for variable definitions

Correlation coefficient between the dependent variable (ln_K_PMC) and control variables are as follows. With the average PM2.5 level in the observed Chinese regions (CHINA_PM), the correlation estimate was 0.546 and statistically significant at $p<0.01$. Those with temperature (C_ATM) and humidity (C_HMD) in China were -0.560 and -0.312, respectively, at $p<0.01$ confirming negatively correlation relationship among these factors. With Korea's temperature (K_ATM) and precipitation level (K_RAIN), the correlation coefficients were -0.650 and -0.539, respectively, at $p<0.01$ also confirming negative correlations. There was no statistically significant correlation between the dependent variable and the regional land area (ln_K_AREA). The correlation estimates between the dependent variable and PM2.5 emission per vehicle type (ln_DCA) and domestic coal sales volume (COAL) were -0.194 and statistically significant at $p<0.01$, confirming their positive correlation.

3.4.2 Hypothesis 1: PM Emission by Vehicle Type

Table 3-6 shows the regression results of PM2.5 concentration level and PM2.5 emission by diesel vehicle types, classified as passenger cars, passenger vans, and trucks. The estimation model was two-way FE model, controlling time and regional effects, with 710 observations. The regression coefficient of trucks was the highest at 0.073, followed by passenger vans with coefficient 0.066, then passenger cars with coefficient 0.061. These results imply that PM2.5 emission from all diesel vehicles are significantly associated with the national PM2.5 concentration level, with the highest impact from diesel trucks. The VIF among the independent variables were under 5.00 so there are no multicollinearity issues, and the model performance for all three models were about 0.43.

Table 3-6 Fixed effect model results for Hypothesis1

Dependent Variables: ln_K_PMC

TYPE_CLASS	P. Cars (TYPE_CLASS==1)	P. Vans (TYPE_CLASS==2)	Trucks (TYPE_CLASS==3)
Intercept	-1.193 (-0.26)	-2.764 (-0.60)	-2.549 (-0.55)
ln_DCA	0.061*** (-4.05)	0.066*** (-4.66)	0.073*** (-4.75)
COAL	0.005 (-1.3)	0.003 (-0.76)	-0.000 (-0.01)
ln_MANUF	-0.021 (-0.19)	-0.001 (-0.01)	0.027 (-0.25)
NO2	16.112*** (-6.73)	15.998*** (-6.71)	15.994*** (-6.7)
CHINA_PM	5.583* (-1.91)	5.926** (-2.04)	5.708** (-1.96)
C_ATM	-0.006 (-1.13)	-0.006 (-1.18)	-0.007 (-1.22)
C_HMD	-0.000 (-0.39)	-0.000 (-0.37)	-0.000 (-0.40)
WWR	0.018 (-1.13)	0.02 (-1.23)	0.018 (-1.16)
K_ATM	-0.021*** (-4.34)	-0.021*** (-4.46)	-0.021*** (-4.43)
ln_K_RAIN	-0.023** (-2.52)	-0.022** (-2.40)	-0.022** (-2.46)
ln_K_AREA	-0.517 (-0.95)	-0.431 (-0.79)	-0.437 (-0.80)
ln_K_GRDP	0.507** (-2.43)	0.560*** (-2.67)	0.507** (-2.45)
YEAR_MON & CITY EFFECT	included	included	included
MEAN VIF	4.81	4.95	4.92
No. of observations	710	710	710
R-square	0.429	0.433	0.434

1) This table presents results from Fixed effects model
2) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

In detail, the impact of PM2.5 emission from diesel passenger cars on the PM2.5 concentration level is statistically significant at $p<0.01$, with 0.061 increase in the PM2.5 concentration level as passenger car emission increases. NO2 pollution level also significantly affects PM2.5 concentration level at $p<0.01$ and is positively associated (16.112). PM2.5 levels in CHINA_PM was statistically significant at $p<0.1$ and is positively associated (5.583). K_ATM and ln_K_RAIN were statistically significant at $p<0.01$ and $p<0.05$, respectively, and are negatively associated with PM2.5 concentration level. Finally, ln_K_GDP is also statistically significant at $p<0.01$ and positively associated with the overall PM2.5 concentration level. Similarly, passenger vans' and trucks' PM2.5 emission had positive and statistically significant ($p<0.01$) impact on PM2.5 concentration level, with coefficients 0.066 and 0.073, respectively.

Conclusively, the first hypothesis of this study is not rejected, confirming that PM2.5 emission from diesel vehicles have statistically significant impact on Korea's PM2.5 concentration level with the greatest magnitude of impact from diesel trucks. This result may be attributed to the high number of old diesel trucks manufactured more than ten years ago, its relatively high emission factor, and the consistent increase in the number of diesel trucks from 2015 to 2018. This result echoes past suggestions that management of trucks and vans need to be prioritized (Hahn, 2020b) and implies that diesel vehicle management strategies need to center on diesel trucks first. For example, criteria for early diesel vehicle disposal incentives could be improved by primarily targeting trucks in its aim to reduce the total number of diesel vehicles to 490,000 vehicles by 2024. Additionally, though incentives for electric truck purchases and plans to distribute hydrogen vehicles are in place, distribution of low-pollution trucks in areas with particularly high truck traffic volume need to be promoted.

3.4.3 Hypothesis 2: PM Emission by Vehicle Type and Size

To test the second hypothesis of this study, each passenger cars, vans, and truck types were classified by small, medium, and large sizes, resulting in nine separate models. A detailed summary of regression results by vehicle type and size is presented in Table 3-7. For passenger cars, PM2.5 emission from small, medium, and large vehicles had statistically significant impact on Korea's PM2.5 concentration level at $p<0.05$ to $p<0.10$, with coefficients 0.045, 0.037, and 0.063, respectively. The model fitness for medium-size passenger cars was about 0.20 but that of small and large sizes were about 0.30. For passenger vans, both small and medium-size vehicles' PM2.5 emission had statistically significant and positive impact on the national PM2.5 concentration level, with coefficients 0.076 ($p<0.01$) and 0.043 ($p<0.05$). The model fitness of the small-size model was 0.277 and that of the medium-size model was 0.337. For trucks, PM2.5 emission from all vehicle types had statistically significant and positive effects on the national PM2.5 concentration level with coefficients 0.065 ($p<0.01$) for small-size, 0.048 ($p<0.10$) for medium-size, and 0.044 ($p<0.05$) for large-size. Model fitness for each vehicle size were about 0.277 for small-size, 0.301 for medium-size, and 0.332 for large-size. The mean VIF for all models did not exceed 10. Comparatively, the highest parameter estimates were large-size passenger cars (0.063), small-size passenger vans (0.076) and small-size trucks (0.065).

Table 3-7 Fixed effect model results for Hypothesis2

Dependent Variables: ln_K_PMC	P. Cars (TYPE_CLASS==1)			P. Vans (TYPE_CLASS==2)			Trucks (TYPE_CLASS==3)		
	Small	**Medium**	**Large**	**Small**	**Medium**	**Large**	**Small**	**Medium**	**Large**
Intercept	3.568***	3.396***	3.567***	3.796***	3.602***	3.684***	3.019***	4.802***	3.620***
	(-9.38)	(-9.91)	(-9.13)	(-9.51)	(-11.56)	(-10.00)	(-7.42)	(-10.25)	(-12.32)
ln_DCA	0.045**	0.037*	0.063**	0.076***	0.043**	0.039	0.065***	0.048*	0.044**
	(-2.08)	(-1.9)	(-2.26)	(-3.44)	(-2.05)	(-1.60)	(-2.95)	(-1.91)	(-2.26)
COAL	0.003	0.004	0.006	-0.007	0.009*	-0.012	0.004	-0.009	0.004
	(-0.35)	(-0.34)	(-0.8)	(-0.93)	(-1.69)	(-0.92)	(-0.34)	(-0.54)	(-0.59)
ln_MANUF	0.020*	0.014	0.029**	0.022**	0.033***	0.021**	0.028**	-0.007	0.016*
	(-1.97)	(-1.28)	(-2.51)	(-2.18)	(-2.97)	(-1.99)	(-2.4)	(-0.67)	(-1.68)
NO2	4.774	6.773*	6.389	10.210***	8.480**	4.145	12.212***	10.405***	2.649
	(-1.38)	(-1.8)	(-1.63)	(-2.9)	(-2.28)	(-0.93)	(-3.12)	(-2.66)	(-0.74)
CHINA_PM	4.197	0.81	-0.551	0.029	-0.209	0.374	1.806	-0.477	0.082
	(-1.45)	(-0.29)	(-0.19)	(-0.01)	(-0.07)	(-0.13)	(-0.65)	(-0.16)	(-0.03)
C_ATM	-0.026**	-0.001	-0.026*	-0.030*	-0.008	0.003	-0.004	-0.035**	-0.024**
	(-2.14)	(-0.10)	(-1.85)	(-1.78)	(-0.85)	(-0.21)	(-0.33)	(-2.29)	(-2.12)
C_HMD	0.001	0.001	0.001	0.001	0	-0.001	0.001	0.001	-0.002
	(-0.4)	(-0.4)	(-0.58)	(-0.34)	(-0.18)	(-0.54)	(-0.32)	(-0.7)	(-1.10)
WWR	0.114***	-0.001	0.092**	0.041	0.036	0.045	0.049	0.075**	0.025
	(-3.64)	(-0.03)	(-2.36)	(-1.33)	(-1.05)	(-1.27)	(-1.4)	(-2.23)	(-0.79)
K_ATM	-0.026***	-0.028***	-0.026***	-0.021***	-0.031***	-0.028***	-0.016**	-0.039***	-0.029***
	(-4.07)	(-4.36)	(-3.49)	(-3.03)	(-4.47)	(-4.14)	(-2.32)	(-5.48)	(-4.24)
ln_K_RAIN	-0.025	-0.001	-0.015	-0.01	0.008	-0.001	-0.001	-0.008	0.002
	(-1.31)	(-0.06)	(-0.80)	(-0.56)	(-0.43)	(-0.05)	(-0.03)	(-0.40)	(-0.12)
ln_K_AREA	-0.008	-0.013	-0.012	-0.024	-0.035	-0.033	0.015	-0.008	-0.049
	(-0.22)	(-0.38)	(-0.33)	(-0.64)	(-0.92)	(-0.77)	-0.41	(-0.20)	(-1.46)
ln_K_GRDP	-0.093***	-0.078***	-0.119***	-0.129***	-0.113***	-0.074**	-0.147***	-0.112***	-0.031
	(-3.51)	(-2.82)	(-3.09)	(-4.70)	(-3.74)	(-2.16)	(-4.68)	(-3.91)	(-1.21)
YEAR_MON & CITY EFFECT	included	included	included	included	included	included	included	included	included
MEAN VIF	5.48	4.99	4.58	5.18	5.06	5.09	5.65	4.37	5.73
No. of observations	241	252	217	249	235	226	227	244	239
R-square	0.305	0.210	0.295	0.277	0.337	0.210	0.277	0.301	0.330

1) This table presents results from Fixed effects model
2) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

In the large-size passenger car model, ln_MANUF had a statistically significant and positive impact on the PM2.5 concentration level at $p<0.05$. Similarly, NO2 had a statistically significant ($p<0.01$) and positive impact on PM2.5 concentration level. While K_ATM had a statistically significant ($p<0.05$) and negative effect on Korea's PM2.5 concentration level, C_ATM had no statistically significant impact. In the small-size passenger van model, ln_MANUF also had a statistically significant ($p<0.1$) and positive impact on PM2.5 concentration level, while K_ATM and C_ATM levels had statistically significant ($p<0.01$ and $p<0.05$, respectively) but negative effects on Korea's PM2.5 concentration level. Similarly, in the small-size truck model, ln_MANUF and NO2 pollution level had statistically significant ($p<0.05$ and $p<0.01$, respectively) and positive effects on the national PM2.5 concentration level, but K_ATM had a statistically significant ($p<0.05$) but negative effect while (C_ATM) had no statistically significant effect.

In all three models, the ln_K_GRDP had statistically significant ($p<0.01$) and negative effects on the national PM2.5 concentration level, which diverged from the findings presented in Table 3-8. This finding on the negative association between GRDP and PM2.5 concentration could suggest that the expansion of regional economic scale reduces PM2.5 concentration; however, this result may have arisen due to relatively small sample sizes of the vehicle classification groups and not accounting other factors commonly observed with GRDP, such as GDP per energy source and population change (Park, 2021).

On the other hand, PM2.5 levels in CHINA_PM is not statistically significant on Korea's PM2.5 concentration level in this analysis even though past studies on

Korea's PM2.5 determinants identified China's air quality as a contributor to Korea's PM2.5 levels (Kang et al., 2019; Park & Shin, 2017). As such, this study conducted additional analysis on the association between the dependent variable and factors related to China's air quality in subsection 4.5.

Conclusively, the second hypothesis of this study was rejected since small-size diesel trucks, not large-size diesel trucks, had the highest effect on PM2.5 concentration level. This result may be due to the higher prevalence of old vehicles among small diesel trucks than mid- to large diesel trucks and higher mileage of small diesel trucks that are more frequently used for commercial delivery services (Lee, 2018). Results of this study implies that measures targeting small trucks need to be expanded with early vehicle disposal and new vehicle purchase subsidies.

3.4.4. Hypothesis 3: PM Emission by Vehicle Type and Size in Different Regional Scales

Table 4-7 shows the regression results with the dummy variable for city scale, large and small to mid-size, since it influences how diesel vehicles' PM2.5 emission impacts PM2.5 concentration level. Of the sixteen administrative areas discussed in the methodology section, large cities include Seoul, Busan, Daegu, Gwangju, Daejeon, and Ulsan metropolitan cities and small to mid-size cities include the remaining ten regions. This dummy variable was included in the estimation models, which were classified by vehicle type and sizes. The overall model performance exceeded 0.60 and the mean VIF of the independent variables did not exceed 10.

Table 3-8 regression results for Hypothesis 3

Dependent Variables: ln_K_PMC	P. Cars (TYPE_CLASS==1)			P. Vans (TYPE_CLASS==2)			Trucks (TYPE_CLASS==3)		
	Small	**Medium**	**Large**	**Small**	**Medium**	**Large**	**Small**	**Medium**	**Large**
Intercept	3.859***	3.732***	3.978***	3.920***	3.921***	3.563***	3.651***	3.985***	3.495***
	(-13.92)	(-14.68)	(-11.88)	(-12.76)	(-14.66)	(-14.43)	(-15.13)	(-12.92)	(-13.23)
ln_DCA	-0.041	0.006	-0.022	-0.021	-0.037	-0.01	0.019	-0.028	-0.009
	(-1.64)	-0.28	(-0.80)	(-0.79)	(-1.57)	(-0.45)	-0.81	(-0.85)	(-0.32)
CITY_DUM	-0.609	-0.098	-1.055**	-1.060***	-0.522	-0.079	-0.288	-1.243**	-0.206
	(-1.61)	(-0.24)	(-2.15)	(-2.65)	(-1.24)	(-0.19)	(-0.66)	(-2.15)	(-0.45)
ln_DCA*CITY_DUM	0.032	0.002	0.062**	0.060**	0.03	0.001	0.018	0.071*	0.008
	(-1.34)	(-0.08)	(-2.07)	(-2.36)	(-1.14)	(-0.05)	(-0.65)	(-1.95)	(-0.26)
COAL	0.004	0.014***	0.009*	0.011*	0.008*	0.006	0.005	0.012***	0.015***
	(-0.8)	(-3.26)	(-1.68)	(-1.96)	(-1.68)	(-1.4)	(-1.08)	(-2.75)	(-3.87)
ln_MANUF	0.034**	0.012	0.031*	0.028*	0.026*	0.021	0.026*	0.018	0.026*
	(-2.33)	(-0.78)	(-1.83)	(-1.90)	(-1.95)	(-1.19)	(-1.66)	(-1.16)	(-1.93)
NO2	22.747***	28.343***	26.443***	32.113***	23.018***	24.587***	23.394***	32.680***	23.473***
	(-6.6)	(-7.31)	(-6.9)	(-8.54)	(-7.25)	(-5.49)	(-6.52)	(-9.37)	(-7.00)
CHINA_PM	2.743***	1.916**	2.355***	1.398**	2.914***	2.816***	3.347***	2.470***	1.741***
	(-2.66)	(-2.44)	(-3.32)	(-2.3)	(-3.02)	(-3.02)	(-2.92)	(-2.72)	(-3.66)
C_ATM	0.022***	0.026***	0.015***	0.017***	0.025***	0.022***	0.018***	0.023***	0.026***
	(-5.05)	(-7.04)	(-2.61)	(-4.05)	(-5.90)	(-4.51)	(-3.81)	(-4.86)	(-5.52)
C_HMD	-0.001	-0.001	-0.002**	-0.001	-0.001	-0.002*	-0.003***	-0.001	-0.000
	(-1.38)	(-0.83)	(-2.06)	(-1.27)	(-1.38)	(-1.93)	(-2.66)	(-1.24)	(-0.05)
WWR	0.095***	0.006	0.006	0.090***	0.003	0.025	0.077**	0.046	-0.020
	(-2.77)	(-0.16)	(-0.16)	(-2.65)	(-0.08)	(-0.68)	(-2.08)	(-1.23)	(-0.53)
K_ATM	-0.025***	-0.027***	-0.017**	-0.017***	-0.027***	-0.025***	-0.016***	-0.025***	-0.031***
	(-4.68)	(-5.68)	(-2.46)	(-3.11)	(-5.47)	(-3.94)	(-2.97)	(-4.25)	(-5.56)
ln_K_RAIN	-0.028*	-0.007	-0.013	-0.021	-0.015	-0.008	-0.03	0.009	-0.013
	(-1.79)	(-0.47)	(-0.78)	(-1.28)	(-0.98)	(-0.48)	(-1.54)	(-0.61)	(-1.01)
ln_K_AREA	0.046	0.072	0.066	0.067	0.089**	0.056	0.078	0.052	0.029
	(-0.79)	(-1.63)	(-1.43)	(-1.32)	(-2)	(-1.05)	(-1.5)	(-1.1)	(-0.59)
ln_K_GRDP	-0.126***	-0.190***	-0.180***	-0.187***	-0.162***	-0.136***	-0.205***	-0.173***	-0.133***
	(-4.37)	(-6.14)	(-4.83)	(-6.82)	(-5.13)	(-3.85)	(-6.33)	(-5.92)	(-4.92)
YEAR_MON EFFECT	included	included	included	included	included	included	included	included	included
MEAN VIF	8.70	8.94	7.82	8.65	8.97	7.80	8.82	7.09	7.65
No. of observations	241	252	217	249	235	226	227	244	239
R-square	0.648	0.642	0.601	0.606	0.663	0.627	0.626	0.639	0.657

1) ***, **, * denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

The regression analysis indicated that PM2.5 emission from large passenger cars in large cities has a statistically significant ($p<0.05$) and positive (0.062) impact on PM2.5 concentration at a greater magnitude than those in small to mid-size cities. The association between PM2.5 concentration level and PM2.5 emission from small and mid-size passenger cars in large cities were not statistically significant. As such, for passenger cars, those in large sizes in large cities had greater effects on PM2.5 concentration than those in small and mid-scale cities. Additionally, PM2.5 emission from small passenger vans in large cities had a statistically significant ($p<0.05$) and positive (0.060) effect on PM2.5 concentration, which is greater than those in small and mid-scale cities. On the other hand, the impact of PM2.5 emission from mid- and large size passenger vans were not statistically significant. So, passenger vans in small sizes in large cities has the greatest influence on the national PM2.5 concentration, which may be attributable to the increase in imported diesel passenger vans since 2014. Lastly, for trucks, PM2.5 emission from mid-size trucks in large cities had a statistically significant ($p<0.1$) and positive (0.071) impact on the national PM2.5 level, whereas those in small and mid-scale cities had smaller magnitude of impact and those of small and large sizes had no statistically significant effects. Therefore, trucks of medium size in large cities appeared to have the highest influence on the national PM2.5 concentration level.

The ln_K_GRDP had a statistically significant and negative impact on Korea's PM2.5 concentration level across all models. This result may be explained in the context of the environmental Kuznets curve, which explains the hypothesis that as an economy develops, environmental degradation would increase then decreases in an inverse-U shape (Kim and Kim, 2008; Dasgupta et al., 2002). Thus, even as GDP increases in large cities, its impact on PM2.5 concentration level could be negative.

Altogether, the regression results signify that the third hypothesis is not rejected since PM2.5 emission from large passenger cars, small passenger vans, and medium trucks in large cities had greater impact on Korea's PM2.5 concentration level than those in small and medium scale cities. This finding could be due to higher population levels and density in large cities that may cause higher traffic congestions, which reflects past findings the PM2.5 emissions are highest in the SMA (Jin & Jin, 2021).

Further, the results in Table 3-8 show that large passenger cars, small passenger vans, and medium trucks contribute to increasing the PM2.5 levels the most. These outcomes suggest that in large cities, medium trucks may influence PM2.5 concentration more than small trucks. These differing results from the previous implications that regional characteristics need to be incorporated in developing PM2.5 management plans (Hwang, 2019). Accordingly, PM2.5 abatement policies targeting diesel trucks should consider regulating mid-size trucks in large cities and small trucks in small to medium-scale cities.

4.4.5 Impact of China's PM on South Korea's PM

As indicated in subsection 4.3, an in-depth analysis on the effects of China's PM2.5 level on Korea's PM2.5 level was conducted using Pearson correlation test. As shown in Table 3-9, the correlation coefficients of Korea's PM2.5 level and CHINA_PM, an accumulation of PM2.5 concentration levels in Shandong, Hebei, and Jiangsu regions, is 0.546 and is statistically significant at $p<0.01$. Correlation coefficients with PM2.5 level in each region also exceed 0.5 (0.596 with Shandong's, 0.556 with Hebei's, and 0.607 with Jiangsu's) and are statistically significant at $p<0.01$.

Table 3-9 Pearson correlation analysis of Korean and Chinese PM2.5 levels

	1	**2**	**3**	**4**	**5**	**6**
1. ln_K_PMC	1.000					
2. ln_DCA	0.058***	1.000				
3. CHINA_PM	0.546***	0.059***	1.000			
4. Shandong_PM	0.596***	0.025	0.915***	1.000		
5. Hebei_PM	0.556***	0.093***	0.881***	0.899***	1.000	
6. Jiangsu_PM	0.607***	-0.033	0.857***	0.831***	0.752***	1.000

1) This table represents pearson correlations among variables used in this study.
2) ***,**,* denote significance at 1%, 5%, and 10% level, respectively (two-tailed).

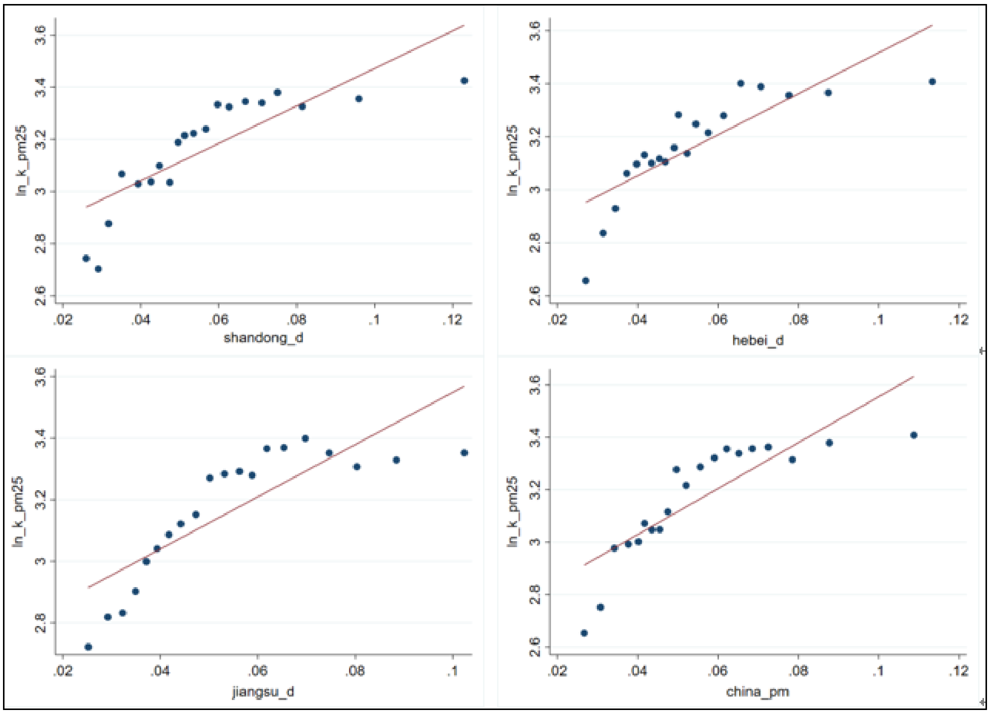


Figure 3-1 Scatterplot of PM2.5 correlation

Figure 3-1 shows the optimal linear line with correlation coefficients between the dependent variable, Korea's PM2.5 concentration level, and different independent variables for PM2.5 concentration levels in the observed Chinese regions. For all independent variables, positive linear lines are graphed, indicating that increase in PM2.5 levels in China are correlated with increase in PM2.5 levels in Korea. However, as shown in Table 3-8, these variables do not significantly affect PM2.5 concentration level in Korea, which may have resulted from detailed segmentation of vehicles by type and sizes. As stated previously, the sample vehicles were classified into three types, which were then divided by sizes, producing 9 models with about 250 samples each. Such compartmentalization aligns with this study's objectives, but may have yielded diverging results from studies that analyzed emissions from a wider range of vehicles, China's PM2.5 levels, and Korea's PM2.5 levels altogether.

3.5. Conclusion and Discussion

This study analyzed the impact of PM2.5 emission from diesel vehicles, by type and size, on Korea's PM2.5 concentration levels, and contextualized their relationship with different scales of the cities to account for regional characteristics. First, the study confirmed that PM2.5 emissions from all diesel vehicles observed – passenger cars, passenger vans, and trucks – had statistically significant impact on the national PM2.5 concentration levels, with the highest impact from diesel trucks. Second, considering vehicle size, PM2.5 emission from small diesel trucks had the largest positive impact on the dependent variable with coefficient 0.072 at $p<0.01$, which may be due to the large number of old vehicles in this category and its widespread use for deliveries that accrue high mileage (Lee, 2018). Third, PM2.5 emission from large passenger cars, small passenger vans, and medium trucks in large cities had a greater impact on the national PM2.5 concentration level than those in small to medium-scale cities, which may have been prompted by higher population levels that generate traffic congestion. This result also aligns with past findings of higher PM2.5 pollution around the Seoul Metropolitan Area that has the highest population density and levels of all administrative regions (Sung et al., 2020; Jin & Jin, 2021).

Translating these results to policy could include shifting the focus of diesel vehicle phase-out policies, such as early disposal subsidies and low-pollution vehicle schemes, to trucks since they influence PM2.5 pollution in Korea the most of all vehicle types. Short-term market strategies could be to increase the supply of vehicles that can replace diesel, which could be accompanied by long-term plans to develop and widely distribute non-PM2.5 emission trucks (Hahn 2020a). The second policy implication would be to establish detailed vehicle PM2.5 abatement programs for different vehicle types and sizes since some vehicles, have greater impact on increasing the national PM2.5 concentration level than others. Analysis from this suggest that small diesel trucks have the highest impact, possibly because of the high number of old vehicles aged 10 years or more in this category. As such, the appropriate PM2.5 reduction measure in transportation should prioritize small diesel trucks. Third, since the impact of PM2.5 emission from large passenger cars, small passenger vans, and small trucks on the national PM2.5 pollution levels is higher in large cities than in small to medium-scale cities, PM2.5 reduction policies need to cater to regional needs and characteristics. In addition to a central PM2.5 response strategies, regional implementation and monitoring plans may be necessary to effectively reduce PM2.5 emission from vehicles.

Though this study stands apart from previous studies on Korea's PM2.5 concentration determinants by analyzing the impact of vehicle PM2.5 emission by vehicle types and sizes and regional characteristics, it faced limitations in incorporating more detailed level of regional data. Due to data availability, the unit of all variables were limited to metropolitan cities and administrative areas. Provision of data at smaller geographic units, like country and district-level, from the National Statistical Office could provide more elaborate insight into the regional context of PM2.5 pollution in Korea.

Chapter 4. What are the main factors that interfere with the PM2.5 policy for diesel cars?

4.1. Study Background

The people of Korea are under great risk with continuous exposure to highly concentrated particulate matter (PM). PM concentration levels in Korea are one of the highest among OECD countries (2nd out of 34 countries) and became a major social and political issue by setting record high concentration rates in recent years. It has been a pressing environmental and health concern due to increasingly higher levels of particulate matters (PM10) and fine particulate matters (PM2.5). These PM pollutant concentrations are higher particularly during the winter season because PM pollutants are carried by the wind from China, where they are a byproduct of heat produced from coal-based power plants. Air circulation within the Korean Peninsula is slow during the winter and spring, which also contributes to increasing PM concentrations.

The Korean government is greatly concerned with how to resolve the problem and clean the atmosphere. However, the main causes of PM concentrations in Korea are still controversial. The media and general population still believe that pollution created in China that carries over to Korea is the main cause of increasing PM levels. However, a recent evaluation team from NASA, which visited Korea in 2016, discovered that that foreign sources account for only 48% of the pollution, whereas domestic sources account for 52% (Interagency coordination 2017).

Because of increase in foreign influence on PM concentration in Korea, Korean government set joint reduction targets for reducing air pollution as well as joint research and cooperation with China. South Korea proposed the exchange of information on air quality and relevant forecast technology, along with a joint study on soil pollution in mined areas. South Korea and China recently have agreed to set up a joint early warning system related to particulate matters (The Korea Times 2019).

Korea is a favorable market for diesel engine vehicles. The tax rate on diesel fuel is relatively low compared to gasoline because diesel engine vehicles are more efficient than gasoline engine vehicles. It is well recognized that diesel engines produce significant amounts of PM compared to gasoline engines. In the Seoul Metropolitan Areas (SMA) in Korea, where a large number of diesel engine vehicles are registered and operated, diesel engine vehicles are responsible for 23% of the total PM emissions. Other sources in SMA include construction machinery and logistics, 16%, industrial sites, 14%, air conditioning and heating, 12%, organic solvent, 10%, and power plants, 9% (Kwang 2018). Nationally, 38% of PM emissions are sourced from industrial sites, 16% from construction machinery and logistics, 15% from power plants, 11% from diesel-engine vehicles, 5% from air conditioning and heating and 5% from dust scattering (Kwang 2018). Foreign sources include China and North Korea which account for, on average, 30% to 50% of PM emissions annually (Interagency coordination 2017).

The Korean government announced ‘The 2nd Atmospheric Environment Comprehensive Plan’ in April 2016 and ‘The detailed plan for implementation of special measures for PM’ in 2017. These plans were prepared through interagency coordination to prevent the problems brought by PM. According to the detailed plans, 87% of the budget geared towards the PM problem is concentrated in the transportation sector and 79% of the transportation sector budget is now assigned for green vehicle supply and infrastructure expansion (Interagency coordination 2017, Park et al. 2018). However, the diesel policy plan has not been promoted sufficiently due to conflicts of interest among the ministries and disparities in their positions regarding the decision.

There are policy inconsistencies among the ministries in Korea, including the Ministry of Environment (MOE), the Ministry of Trade, Industry and Energy (MOTIE) and the Ministry of Strategy and Finance (MOSF), as revealed in their directives to control diesel engine vehicles. The MOE believes that diesel engine vehicles are the major source of the concentration of PM and they are trying to promote more restrictive regulations. However, the MOTIE is cautiously approaching new diesel engine vehicle regulations by considering their effect on the automotive and oil-refinery industries. The MOE also has a conflict with the MOSF with respect to diesel tax regulation. The MOE insists that the tax on diesel should be raised. However, the MOSF is resisting an increase, anticipating possible serious criticism from the working class population, which is highly dependent on diesel engine vehicles and fuel. In October 2017, the MOCIE and the MOE organized a "Ministerial Policy Council" to enhance mutual understanding and strengthen cooperation. However, control measures that were developed have not been implemented effectively due to continual disagreement and conflicts of interest among the ministries.

Understanding the thoughts and perspectives of policy makers on environmental problems is important. It is necessary for the government to identify ways to pursue common goals and to minimize conflicts among ministries in order to enhance policy coherence and efficiency. This understanding will ultimately alleviate public anxiety in an era of continually increasing PM emission and concentration.

The objective of this study is to address current PM problems in Korea and classify the specialists' (government officials and researchers) opinion with respect to the policies and management direction related to PM policy for diesel fuels and vehicles. The Q-methodology and systems thinking approaches are employed to analyze the specialists' subjectivity, perceptions and their causal relationship for PM policy for diesel fuels and vehicles. These methods are helpful in categorizing the specialists' interests and in understanding the differences between their positions. A series of interviews with the specialists from various government institutions were conducted for the analysis. These specialists are highly involved in promoting government policies. It is important to gather their perceptions and opinions in order to understand the direction of government policy on diesel fuel and their efforts in improving the PM problem.

4.2. Literature Review

4.2.1 The Perception of Particulate Matters

The Korean public was surprised by the recent government announcement that PM concentration has improved compared to PM levels in the 1990s (Kim 2017). The public is still suspect of the countermeasures used by the government to alleviate the PM problem. In fact, 75% of citizens are dissatisfied with such measures and still have great concerns about the PM problem (Realmeter 2016). Some of the public do not perceive the serious risk of PM, and such ill-informed perceptions mean that information on PM concentration and its risk to public health is not being properly provided to the general public (Kim 2017).

The MOE (2015) amended the ‘Comprehensive Second Air Quality Improvement Plan (2016 -2025)’ to improve emissions and lessen PM concentrations. With this plan 1) the consumption tax is reduced on new vehicle purchases after the discarding of an older vehicle, 2) stricter emission standards are implemented for coal-fired power plants, and 3) the PM forecasting system will be improved (Kim 2016). Additionally, the government established a ‘Detailed Implementation Plan for the Special Measures for PM Management’ to expand the use of eco-friendly vehicles and infrastructure. According to the detailed implementation plan, 87% of the budget is concentrated in the transportation sector, 79% of which is budgeted for the supply of greener cars and infrastructure.

There are a number of studies on the perception of air pollution; however, only a few explore the perception of PM after the more recent acknowledgement of its seriousness and the need for it to be managed by various stakeholders. Most of the studies target citizens and primarily focus on risk perception and behavioral changes caused by PM emissions. In general, the perception of PM influences individual decision-making and behavior (Gany et al. 2016; Kim et al. 2016; Cho et al. 2018). More specifically, Cho et al. (2018) identified the relationship between the perceptions of PM and behavioral change among people involved in leisure activities. They found that the level of PM concentration influenced people’s attitudes and behavior patterns. In a study focused on a specific group, Gany et al. (2016) measured taxi drivers' knowledge, attitudes, and opinions about PM in New York City by comparing their direct measures of exposure. According to the study, 56 of 100 drivers thought they were more exposed than nondrivers and 81 drivers believed that PM increases their health risks. Park et al. (2018) studied the relationships between risk perception and the knowledge of university students about PM using Pearson's correlation analysis. They discovered that there is a significant positive relationship between PM risk perception and health-promoting behaviors. In a study for perception classification, Kim et al. (2016) classified the perception of the general public based on their perceptions about the causes of PM, its current status, health effects and solutions through a cluster analysis. They showed characteristic differences for risk perception, policy participation, and information understanding about PM. On the other hand, there is a difference in the perception of citizens and specialists on PM. For example, the government insists that the concentration of PM is improving whereas citizens continue to feel that PM problems are getting worse. The public's perceptions are important in the process of securing justification for the enforcement of PM policies (Gross 1994; Kim et al. 2016a). Kim et al. (2016b) examined the difference between the general public and specialists using a psychological model with cognitive structure analysis. Their results suggest that differences originated from the lack of communication among decision-making bodies and citizens that caused a failure to comprehend the core of the problem and that created more confusion. Therefore, specialists' roles are important because their opinions dictate the direction of policy. Spruijt et al. (2016) classified four roles of PM policy using Q-methodology and discovered the differences by type in the science-policy interface. The differences in specialists' advice come from different views on issues and/or positions (Spruijt et al. 2016). Various views are needed to make the right policy decisions, but it is necessary to understand and coordinate the positions and opinions of the specialists in order to implement effective policies. Therefore, this study aims to classify the perceptions of specialists and analyze their characteristics on PM policy.

4.2.2 Q-methodology for Environmental Studies

Q-methodology was developed by William Stephenson in 1935 and is frequently used in psychology and the social sciences. Q-methodology is a research method used for systematic study of people's subjective viewpoints using correlation and factor analysis (Kim 2008, Korean Society for the Scientific Study of Subjectivity 2014). This is an ideal method to derive common viewpoints by type or group of the subject through statistical methods (Brown 1980; Baek and Lee 2011). Categorizing people's subjectivity helps to understand their common interests and the differences among their positions (Jung 2000).

In-depth interviews, survey analysis, the hierarchical process and the Delphi methods are more commonly practiced methods in analyzing subjective interpretations of social phenomena. However, Q-methodology can supplement the limitations of subjectivity research with its qualitative and quantitative features in analyzing subjective viewpoints. Q-methodology involves technique and method in the form of factor analysis that is used to analyze the data. Unlike normal factor analysis, which involves finding correlations between variables across a sample of subjects, Q-methodology observes the correlations between subjects across a sample of variables (Brown 1993).

The data for Q factor analysis come from a series of "Q sorts" performed by one or more subjects. Most typically in Q-methodology, a subject is presented with a set of statements about some topic according to "condition of instruction", and is asked to rank-order them (usually from "agree" to "disagree") (Brown 1993). This is an operation refer to as Q-sorting and it is subject to factor analysis. The resulting factor indicate segments of subjectivity which exist.

The Q-methodology deals with inter-individual differences and the significance of a Q sample within an individual rather than differences among individuals. It is primarily used to describe the subjective opinions of various stakeholders on social phenomena or problems. It can also be used to prove a hypothesis through inductive and deductive logic (Gil et al. 2010).

Another advantage using this method is that it does not require a large sample size. The researchers can concentrate with relevant samples for the study given limited time and budget (Kim 2010). Sala et al. (2015) used Q-methodology to investigate the attitudes towards urban air pollution. Lim (2015) analyzed the perspective of stakeholders for biofuel policy in Korea using Q-methodology. Oh et al. (2016) examined the level of recognition in the establishment renewable energy policy in Korea using Q-methodology.

4.2.3 System Thinking

System Thinking is a methodology established by Jay W. Forrester at the MIT School of Business in 1961. This method is used to explain and predict the long-term, non-linear behavior of the system over time, and to understand the cause of the dynamic change of the system (Richardson, 2012). System thinking is a way of thinking that can efficiently develop the system by understanding the overall flow of the system based on the facts and finding the feedback loop in the causal relation of variables in the system (Kim et al. 1999).

Since system thinking deals with the essence of the whole system flow, it can identify the problems that affect the system change and present a long-term strategy accordingly, and can help organize the existing knowledge to understand the problem (Kim et al. 1999). In addition, systematic thinking explains the cause-and-effect relationship between variables using a feedback loop, providing insights that cannot be shown by statistical studies that analyze the relationship between existing dependent variables and independent variables (Lee and Chung, 2012). On the other hand, in the analysis of causal loop, it is essential to find a feedback structure that fits the subject of research, and it is relatively insignificant to judge the strength and rigidity of individual causal relationships (Kim et al. 2018).

In order to apply systematic thinking, the following steps were carried out. First, individual causal loop diagram were generated for each of the four types derived from the Q methodology. The variables included in individual causal loop diagram were set as keywords included in the main statement (Z score> 1) that determines personality / characteristics of each type. Second, by creating integrated causal maps, we derive fundamental problems (variables) that have a common effect on the system of four individual causal maps. The correlation between the variables in the causal map was visualized using positive sign (+) and negative sign (-) and arrows using Vensim PLE. In addition, in the cause-and-effect relationship, the system can be developed efficiently by finding the B (balanced loop) and R (reinforced loop) feedback loops at the center of the interval between the balanced loop and the reinforced loop. The reinforced loop is a structure that has self-reinforcing characteristics that continuously increase or decrease with each turn. The balance loop is a self-reinforcing structure in which the characteristic changes in the opposite direction to the previous property of self-stabilizing or selfbalancing (Sterman 1989).

There are only a few studies that employed the system thinking method. Kim et al. (2018) investigated the system thinking for walking and health improvement of Seoul citizens by a system accident. In this paper, it is suggested that the increase in the use of public transport reduce the air pollution, such as particulate matter, and finally strengthen the public transport policy, which will eventually affect the walking of the citizens. On the other hand, Hosseinabad and Moraga (2017) used system thinking method to investigate the variables (root variables) that cause pollution in Mexico and used simulation models to evaluate the best applicable policy and prepare an effective policy that can reduce air pollution in Mexico City.

In this study, system thinking was applied to identify the causal variables that have different characteristics according to the type of dynamic feedback perspective and to derive fundamental problems (variables) that have common effects on each type, and to improve the efficiency of the policy.

4.3. Research Method

Because of possible disparities and inconsistencies of the specialists' interests and perceptions, it is important to understand the differences between their positions and how their opinions can be reflected in policy decisions. This study uses Q-methodology, as it can provide the quantitative results of the differences of perceptions (viewpoints) by the group of samples (specialists). The study group consists of PM policy specialists, and their perception types are categorized by the following four steps:

1) Making Q-statements with representative questionnaires related to the PM policy;
2) Determining P-Samples, that is, respondents who are PM policy specialists;
3) Sorting Q-samples depending on the level of agreement; and
4) Analyzing the results using a Q-sorting process.

This study also implements the systems thinking method in order to investigate the causal relationship by perception types. Since systems thinking addresses the flow of overall systems, it can identify the fundamental problems that affect system transformations and can present a long-term strategy (Kim et al., 1999). The systems thinking method is processed using the following two steps:

1) Create individual causal loop diagrams after defining major variables based on the characteristics of each type. The correlation between variables in a causal loop diagram is illustrated using positive and negative signs and arrows using the Vensim Personal Learning Edition (VPLE) method. Additionally, balanced loop (B) and reinforced loop (R) are displayed at the center of the interval.
2) Create an integrated causal loop diagram by combining individual causal loop diagrams and identify factors from different perceptions and address countermeasures for policy.

The overall research design for this study using Q-methodology and the systems thinking method is presented.

4.3.1 Classification of Perception by Q-Method

1) Q-sample: Q-statements

The Q-statements are prepared by gathering the specialists' perceptions on PM policies from news articles, research papers, and policy reports. More detailed and in-depth Q-statements are prepared through four interviews with the government administrators who are in charge of PM mitigation and diesel engine vehicle policies. The Q-statement preparation interviews were conducted from April 3 to May 16, 2018, with open questionnaires about the countermeasures related to diesel engine vehicles and PM mitigation. There were 36 Q-statements that were initially prepared. However, after in-depth interviews and a preliminary investigation of the prepared questionnaires, 8 statements were removed, and 28 statements were finally prepared for the survey. The final Q-statements and their related categories are listed in Table 4-1.

Table 4-1 Q-statements and categories

No.	Statement	Categories
1	There is concern about the public rejection of policies as a result of a rise in the diesel tax	Cognitive difference characteristics and causes
2	Skepticism of the PM reduction effect due to increasing the diesel tax.	
3	I believe that legal grounds for PM reduction have been established.	
4	Education for PM risk is needed for public officials in charge of the "PM management comprehensive measures."	
5	There is concern about the economic ripple effect caused by diesel policy.	
6	Collaboration among ministries is closely linked.	
7	Driving restrictions such as the prohibited entrance of old diesel cars to the 4 main gates in Seoul can cause confusion among the public.	
8	The role of the control tower in the Office of Government Policy Coordination needs to be strengthened.	Mediation of the recognition difference
9	Policy councils are effective for interministerial policy making and implementation.	
10	I strongly support the expansion of eco-friendly cars.	
11	Regulation of diesel cars should be pursued considering the	

	economies and status of the people.	
12	PM control is important not only from the efforts of the government but also with the cooperation of citizens.	
13	It is more appropriate to present the quantity of eco-friendly cars to the MOTIE rather than the MOE.	
14	There is a position in favor of regulation of diesel cars.	
15	Friction does not always exist, but coordination between ministries is difficult.	Thinking about the difference in recognition
16	Expect more effective policies will be pursued when the Special Committee on PM launches under the Office of the Prime Minister (February 2019).	
17	Consultations between ministries can be held as often as necessary.	
18	Consultations between ministries are needed first when a ministry announces its decisions to the press.	
19	Each ministry has a responsibility and is engaged in consultation with other ministries.	
20	There is always potential conflicts between ministries in policy implementation.	
21	Effective measures will come out through the ‘PM measures committee' where citizens participate.	
22	Restrictions on the operation of old vehicles will bring positive results in a reduction of PM.	Policy direction
23	The government’s financial support is needed to encourage the purchase of LPG trucks.	
24	It is necessary to adjust the ratio of the transportation tax expenditure with the review of the diesel tax increase. (*Transportation Tax: Earmarked tax created to secure funds for the expansion of social overhead capital (SOC))	
25	It is inevitable that diesel prices will rise.	
26	It is imperative to establish a guideline that suggests the role of citizens in reducing PM.	
27	Increasing the diesel tax should be treated with caution because it affects the general public.	
28	It is necessary to expand the budget for the remodeling of older vehicles with LPG engines, the installation of exhaust gas reduction devices, and early termination of unused vehicles.	

2) P-samples: Determining the respondent

P-samples are the survey participants. In general, 30 to 50 respondents are an appropriate sample size in the Q-methodology since the main ideas and opinions are revealed from closely related specialists involved in policy decisions (Kim 2008). The P-samples in this study consist of 38 specialists who are affiliated with the research institutions and ministries of Korea. Table 4-2 presents affiliated institutions and ministries of the specialists and their job titles.

Table 4-2 Affiliated Institutions of the specialists and job title

No.	Affiliated Institution (Job title)	Gender	Age	Years of Career
1	Ministry of Trade, Industry and Energy (deputy director)	F	36	3
2	Korea Energy Economics Institute (Head Researcher)	M	43	2
3	Korea Institute for Industrial Economics and Trade (Senior Research Fellow)	M	58	16
4	Korea Institute for Industrial Economics and Trade (Head Researcher)	F	35	1
5	Korea Institute for Industrial Economics and Trade (Research Fellow)	F	36	7
6	Korea Institute for Industrial Economics and Trade (Research Fellow)	M	46	16
7	Korea Institute of Construction Technology (Senior Researcher)	M	41	14
8	Korea Institute of Construction Technology (Chief Researcher)	M	32	1
9	Korea Institute of Construction Technology (Chief Researcher)	M	32	4
10	Korea Institute of Construction Technology (Chief Researcher)	M	32	6
11	Korea Institute of Energy Research (Head Researcher)	M	50	12
12	Ministry of Economy and Finance (deputy director)	M	55	17
13	Ministry of Economy and Finance (deputy director)	M	43	12
14	Ministry of Economy and Finance (deputy director)	M	46	13
15	Korea Institute of Public Finance (Head Researcher)	F	57	15

16	Korea Research Institute for Local Administration (Research Fellow)	F	39	4
17	National Assembly Budget Office (Deputy Director-General for Tax Analysis)	F	48	24
18	National Assembly Budget Office (Director General for Tax Analysis)	F	42	4
19	National Assembly Budget Office (Director General for Tax Analysis)	M	45	13
20	Ministry of Land, Infrastructure, and Transport (Deputy director)	M	55	28
21	Ministry of Environment (Deputy director)	M	35	5
22	Ministry of Environment (Deputy director)	M	41	3
23	Ministry of Environment (Deputy director)	M	40	7
24	Korea Forest Service (Deputy director)	M	35	2
25	Korea Research Institute for Human Settlements (Head Researcher)	M	39	4
26	Korea Research Institute for Human Settlements (Head Researcher)	M	35	6
27	Korea Research Institute for Human Settlements (Head Researcher)	M	28	2
28	The Korea Transport Institute (Head Researcher)	M	34	5
29	The Korea Transport Institute (Chief Researcher)	M	36	5
30	The Korea Transport Institute (Head Researcher)	F	39	4
31	The Korea Transport Institute (Head Researcher)	M	37	2
32	Korea Environment Institute (Head Researcher)	M	42	4
33	Korea Environment Institute (Head Researcher)	M	57	14
34	Korea Environment Institute (Head Researcher)	M	39	5
35	Korea Environment Institute (Senior Research Fellow)	M	37	4
36	Korea Environment Institute (Researcher)	F	27	2
37	Korea Environment Institute (Researcher)	F	48	20
38	Korea Environment Institute (Researcher)	F	39	1

Among the 38 interviewed specialists, 9 specialists are affiliated with the government (3 from MOE, 1 from MOTIE, 3 from MOEF, 1 from MOLIT, and 1 from the Korea Forest Service (KFS)), 26 specialists are affiliated with government-funded research institutions (1 from the Korea Energy Economics Institute (KEEI), 4 from the Korea Institute for Industrial Economics and Trade (KIET), 4 from the Korea Institute of Construction Technology (KICT), 1 from the Korea Institute of Energy Research (KIER), 1 from the Korea Institute of Public Finance (KIPF), 1 from the Korea Research Institute for Local Administration (KRILA), 3 from the Korea Research Institute for Human Settlement (KRIHS), 4 from the Korea Transport Institute (KOTI), 7 from the Korea Environment Institute (KEI)), and 3 specialists who are affiliated with the National Assembly Budget Office (NABO).

3) ***Q-sorting: Placing the statement based on the level of agreement***

The survey for Q-sorting was conducted by personal visits to the specialists from May 2018 to January 2019. The Q-statement cards were distributed to the P-samples, and they were divided into three groups (disagree, neutral and agree) after a full understanding the Q-sorting method. The Q-statement cards were then placed in the Q-sort table, as shown in Figure 4-3. They were ranked in each group based on the degree of agreements (from strongly disagree (+1) to strongly agree (+9)). One of the main features of Q-methodology is to distribute the sample depending on the significance of the relative meaning (Kim 2008). Therefore, Q-samples are placed by the distribution according to personal preferences.

4.4. Results

This study performed the principal component factor analysis using the PQMethod 2.35 program based on the data from the Q-sorting. The varimax rotation was performed to optimize the variance. The P-samples were the variables, and the Q-statements were the samples in the Q-factor analysis. In this analysis, differences of age or gender were not important. The Q-factor analysis interpreted the number of opinions and what implication the respondents opinions had towards the problem. This study also used the varimax rotation method, which is a deterministic rotation, to maximize the distance between factors, and which shows how the specialists' perceptions can be categorized.

5.4.1 Overview of the Results

To extract the factors from the data set, the eigenvalues are the most commonly used criterion. Eigenvalues are indicative of a factor's statistical strength and explanatory power that keep the factors with an eigenvalue of 1 or more (Watts and Stenner, 2012). The distribution of eigenvalues is derived with the mean of 0 and the standard deviation of 2.357. The Q-factor is classified into four types, and Table 4-4 summarizes eigenvalues and accumulated explanatory variables (in percentage) for each type. The eigenvalues of each type have an independent explanatory power of 1 or more, and they are based on the Kaiser-Guttman criterion. The total accumulated explanatory variable for the four types is 56%. However, the Q-methodology is not intended for generalization and not significantly affected by the cumulative explanatory variance (Kim 2008).

Table 4-3 Eigenvalues and explanatory variable by types

Category	Type 1	Type 2	Type 3	Type 4
Eigenvalues	10.3421	5.1208	3.0547	2.6501
Accumulated Explanatory Variable (%)	27	41	49	56

Among 38 respondents, 33 showed significant results. The number of specialists per type is shown in Table 4-4.

Table 4-4 Factor characteristics

Category	Type 1	Type 2	Type 3	Type 4
No. of Defining Variables	13	9	6	5
Average Relative Coefficient	0.800	0.800	0.800	0.800
Composite Reliability	0.981	0.973	0.960	0.952
S.E. of Factor Z-Scores	0.137	0.164	0.200	0.218

The correlation coefficient among four types are presented in Table 4-5. The correlation coefficient between all types are positive, where type 1 and type 4 have the highest correlation coefficient of 0.4816. Table 4-7 shows the factors of Q-sort values affecting each type of statements.

Table 4-5 Correlation coefficient between four types

	Type 1	Type 2	Type 3	Type 4
Type 1	1.0000			
Type 2	0.2546	1.0000		
Type 3	0.2905	0.4198*	1.0000	
Type 4	0.4816*	0.3990*	0.2825	1.0000

* correlation is significance at P < .05

Table 4-6. Factor Q-sort values for each statement

No.	Statements	Types			
		1	2	3	4
1	There is concern about the public rejection of policies as a	3	3	0	2
2	Skepticism of the PM reduction effect due to increasing the	-4	2	-1	3
3	I believe that legal grounds for PM reduction have been	0	-3	-3	-3
4	Education for PM risk is needed for public officials in charge of the "PM management comprehensive measures."	-2	-2	-2	0
5	There is concern about the economic ripple effect caused	-2	1	-3	-2

6	Collaboration among ministries is closely linked.	-3	-4	-4	-4
7	Driving restrictions such as the prohibited entrance of old diesel cars to the 4 main gates in Seoul can cause confusion	0	1	-2	0
8	The role of the control tower in the Office of Government Policy Coordination needs to be strengthened.	-1	0	2	3
9	Policy councils are effective for interministerial policy making and implementation.	0	-1	-1	-2
10	I strongly support the expansion of eco-friendly cars.	4	2	4	4
11	Regulation of diesel cars should be pursued considering the economies and status of the people.	-1	1	-1	1
12	PM control is important not only from the efforts of the government but also with the cooperation of citizens.	3	0	2	4
13	It is more appropriate to present the quantity of eco-friendly cars to the MOTIE rather than the MOE.	-2	-1	3	-3
14	There is a position in favor of regulation of diesel cars.	4	-2	1	2
15	Friction does not always exist, but coordination between ministries is difficult.	2	2	3	-1
16	Expect more effective policies will be pursued when the Special Committee on PM launches under the Office of the Prime Minister (February 2019).	-3	0	0	1
17	Consultations between ministries can be held as often as necessary.	-1	1	0	-1
18	Consultations between ministries are needed first when a ministry announces its decisions to the press.	1	4	1	2
19	Each ministry has a responsibility and is engaged in consultation with other ministries.	-4	-2	0	-4
20	There is always potential conflicts between ministries in policy implementation.	2	2	2	-1
21	Effective measures will come out through the 'PM	-3	-3	-2	-1
22	Restrictions on the operation of old vehicles will bring positive results in a reduction of PM.	2	-3	-1	-2
23	The government's financial support is needed to encourage the purchase of LPG trucks.	-1	-1	3	-3
24	It is necessary to adjust the ratio of the transportation tax expenditure with the review of the diesel tax increase. (*Transportation Tax: Earmarked tax created to secure	1	3	1	1
25	It is inevitable that diesel prices will rise.	3	-4	-4	0
26	It is imperative to establish a guideline that suggests the role of citizens in reducing PM.	1	-1	-3	3
27	Increasing the diesel tax should be treated with caution because it affects the general public.	1	4	1	1
28	It is necessary to expand the budget for the remodeling of older vehicles with LPG engines, the installation of exhaust gas reduction devices, and early termination of unused	0	0	4	0

4.4.2 The Classification of Perception Types

This study classified the four types based on the results of factor analysis of the specialists' perception on diesel policy in Korea. Statements with high standard scores (Z score > +1) and low standard scores (Z score < -1) are divided for each type. The characteristics of each type are identified by the level of agreement (from weak to strong). Items with high standard scores (+1) and low standard scores (-1) are the criteria by which the type can be explained. Therefore, each type is determined according to the characteristics of statements with a difference in standard score (Z score) of ±1 or more. The results of classification are presented in Table 4-6, and the representative statements of each types and their Q-sort values and standardized scores are presented in Table 4-7.

Table 4-7 Classification of perception types of the specialists

No.	Institutions	Positions	Type 1				Type 2				Type 3				Type 4			
			Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
1	MOTIE	Deputy Director					-0.138	**0.7656**	0.2987	-0.1								
2	KEEI	Head Researcher									-0.068	0.3091	**0.7581**	0.1912				
3	KIET	Senior Research Fellow	**0.6382**	0.2304	-0.142	0.2885												
4	KIET	Head Researcher	**0.7603**	-0.223	0.1882	-0.045												
5	KIET	Research Fellow	**0.5703**	0.2314	0.1351	0.2041												
6	KIET	Research Fellow	**0.4719**	0.4529	-0.102	-0.222												
7	KICT	Senior Researcher													0.2107	0.398	0.2186	**0.65**
8	KICT	Chief Researcher									-0.046	0.3715	**0.6841**	-0.049				
9	KICT	Chief Researcher					0.1384	**0.61**	-0.009	0.2474								
10	KICT	Chief Researcher									0.2698	0.0248	**0.6656**	0.3106				
11	KIER	Head Researcher					0.0871	**0.6408**	0.0577	0.5524								
12	MOEF	Deputy Director					0.0184	**0.7018**	0.3577	0.3093								
13	MOEF	Deputy Director	**0.5697**	0.2962	-0.089	-0.093												
14	MOEF	Deputy Director									0.246	0.358	**0.6698**	-0.032				
15	KIPF	Head Researcher					0.4972	**0.5982**	0.1606	0.0718								
16	KRILA	Research Fellow					-0.067	**0.795**	0.057	0.1864								
17	NABO	Deputy Director	**0.512**	-0.413	-0.09	0.1081												
18	NABO	Director General	**0.5063**	0.4522	0.2106	0.1857												
19	NABO	Director General													0.2096	0.2903	0.0282	**0.5838**
20	MLIT	Deputy Director									-0.198	0.2331	**0.2825**	0.1372				
21	MOE	Deputy Director	**0.5626**	-0.231	0.1003	0.4044												
22	MOE	Deputy Director	**0.5671**	0.0212	-0.215	0.3975												
23	MOE	Deputy Director									0.135	0.0732	**0.5872**	-0.382				
24	KFS	Deputy Director					0.0505	**0.7709**	0.1697	0.3954								

25	KRIHS	Head Researcher					0.2008	**0.8353**	0.0562	-0.002								
26	KRIHS	Head Researcher	**0.6978**	-0.113	0.2185	0.1978												
27	KOTI	Head Researcher													0.3104	0.3042	-0.171	**0.5836**
28	KOTI	Head Researcher	**0.7043**	0.177	-0.054	-0.009												
29	KOTI	Chief Researcher													-0.062	0.0545	0.2097	**0.4718**
30	KOTI	Head Researcher	**0.4782**	0.1447	0.1628	-0.032												
31	KOTI	Head Researcher													0.2766	-0.109	0.0752	**0.7489**
32	KEI	Head Researcher					-0.140	**0.2271**	0.0352	0.2121								
33	KEI	Head Researcher	**0.6739**	-0.042	0.2515	0.2805												
34	KEI	Head Researcher									0.3196	-0.22	**0.6724**	0.2236				
35	KEI	Senior Research Fellow	**0.6288**	-0.355	0.5013	0.2979												
36	KEI	Research Fellow	**0.462**	0.1764	-0.005	0.3999												
37	KEI	Research Fellow	**0.7083**	-6E-04	0.0379	0.128												
38	KEI	Research Fellow					0.3704	**0.6939**	0.0921	-0.07								

Table 4-8 Representative statements of each types.

Type 1			Type 2			Type3			Type 4		
Statement Number	**Q-Sort Value**	**Standardized score (Z score)**	**Statement Number**	**Q-Sort Value**	**Standardized score (Z score)**	**Statement Number**	**Q-Sort Value**	**Standardized score (Z score)**	**Statement Number**	**Q-Sort Value**	**Standardized score (Z score)**
14	4	1.53	**27**	4	1.85*	**28**	4	1.56*	**12**	4	1.77
25	3	1.47*	**18**		1.44*	**23**	3	1.47*	**26**	3	1.45*
12		1.17	**14**	-2	-1.06*	**7**	-2	-1.06*	**8**		1.4
16	-3	-1.14*	**22**	-3	-1.2	**5**	-3	-1.42	**13**	-3	-1.27
2	-4	-1.85*				**26**		-1.53*			

1) Advocacy Type for a Diesel Regulation (Type 1)

Advocacy type for diesel regulation is shared by 13 specialists and explained 27% of the total variance. Type 1 argues that the diesel regulation policy is necessary because it is helpful to reduce PM. This is supported by a score of +4, which was given to statement (14), and -4 was given to statement (2). Type 1 also provides -3 to statement (16). According to the survey, for reasons of statement selection, Type 1 is not favorable in the role and function of the Office of the Prime Minister (OPM) for policy related to PM. However, 'Special Measures Committee for PM' operated under the OPM.

On the other hand, Type 1 gives +3 to statement (12). Type 1 considers that citizen participation and cooperation should be coordinated in relation to the diesel regulation policy.

2) Passive Type for a Diesel Regulation (Type 2)

Passive Type for Diesel Regulation was shared by 9 specialists and explained 13% of the total variance. Type 2 does not support the diesel regulation policy. They do not expect any effect from the diesel regulation policy and have little motivation to improve the policy. This is supported by the result of a score of -3 to statement (22) and -2 to statement (14). Type 2 also provides +4 to statement (27) and statement (18). Compared to Type 1, Type 2 is cautious about the process and results of the policy.

3) Government Budget Support Type (Type 3)

Government budget support type was shared by 6 specialists and explained 8% of the total variance. Type 3 argues that the government budget should be supported in order for the diesel policy to be effective. This is supported by the result with a score of +4 in the statement (28) and +3 in the statement (23). Type 3 also provides -3 to the statement (26). Type 3 shows a favorable position for citizen participation in reducing PM. They argued that the ministries must produce results in the short-term when the public is involved in the reduction of PM, and there is a possibility that there will be short-sighted measures. Moreover, they tend to think that it is more important to play a role in the industrial area rather than in residential areas to be effective in reducing PM.

4) *Sensitive Response type for Public Opinion (Type 4)*

Sensitive Response type for Public Opinion was shared by 5 specialists and explained 7% of the total variance. Type 4 considers citizen cooperation to be most important, and it is necessary to establish a guideline that suggests the citizenry's role in reducing PM. This is supported by the result with a score of +4 in the statement (12). Type 4 also provides -3 to statement (13). They argue that the ratio of work should be coordinated by the MOE since PM should be examined in terms of environmental regulation and protection rather than industry.

On the other hand, as shown in Table 4-9, all four types did not strongly agree with statement (6) that "Collaboration among ministries is closely linked.”

Table 4-9 Views shared among specialists

Statements	Category	Type 1	Type 2	Type 3	Type 4
6. Collaboration among ministries is closely linked.	Q sort value	-3	-4	-4	-4
	Z score	-1.38	-1.68	-1.67	-1.95

The main characteristics and characteristics comparison of the four types are summarized in Tables 4-10 and 4-11, respectively.

Table 4-10 The characteristics by type

Type	Main Characteristics	Specialists' occupation
Type 1 Advocacy Type for Diesel Regulation	- argues that the diesel regulation policy is necessary because it is helpful to reduce PM. - does not expect anything from the role of Office of the Prime Minister. - thinks that citizen participation and cooperation needs leaders	Public official 4, Researcher 9
Type 2 Passive Type for Diesel Regulation	- does not support the diesel regulation policy. - does not expect any effect from the diesel regulation policy and has a low will to improve the policy. - is cautious about policy implementation process and results	Public official 3, Researcher 6
Type 3 Government Budget Support Type	- argues that the government budget should be supported in order for the diesel policy to be effective. - Citizen participation causes the ministry to make short-term and short-sighted measures.	Public official 2, Researcher 4
Type 4 Sensitive Response type for Public Opinion	- considers citizen participation and cooperation the most important factor - believes that it is necessary to strengthen the functions of Office of the Prime Minister and to organize the roles of ministries.	Public official 1, Researcher 4

Table 4-11 The Comparison of main characteristics by types

Support for the expansion of eco-friendly cars (All types)						
Division (Statement)			Diesel Regulation			
			Yes			No
Expectations for policy effectiveness through diesel tax increase			Yes		No	
			Type 1	Type 3	Type 4	Type 2
Concern about the citizen's repulsion by diesel tax increase		(1)	O (+3)	Δ (0)	O (+2)	O (+3)
Citizen	Coordination	(12)	O (+3)	O (+2)	O (+4)	Δ (0)
	Participation	(21)	X (-3)	X (-2)	X (-1)	X (-3)
Government budget support		(23)	X (-1)	O (+3)	X (-3)	X (-1)
Expectation for role of the Office of the Prime Minister		(8)	X (-1)	O (+2)	O (+3)	Δ (0)
Responsibility of the ministries		(19)	X (-4)	Δ (0)	X (-4)	X (-2)
Suitability for role of the ministries		(13)	X (-2)	O (+3)	X (-3)	X (-1)
Close consultation of the ministries		(6)	X (-3)	X (-4)	X (-4)	X (-4)
Legal grounds of PM policy		(3)	Δ (0)	X (-3)	X (-3)	X (-3)

Note: O (Agree) , Δ (Neutral), X (Disagree)

4.4.3 Classification Analysis by System Thinking

To observe the effects and causal relationships among the types, this study employed a systems thinking approach and illustrated it with causal loop diagrams. The causal loop diagrams consist of the variables from the characteristics of each type. It is necessary to consider the cause and result because it is the process of understanding how they can influence one another within a whole system.

1) Individual Causal Loop Diagram

The individual causal loop diagram for type 1 is illustrated in Figure 4-1. It shows the characteristics of type 1 in relation to the cause and result for the diesel policy. According to the causal loop diagram 1, Type 1 believes that the diesel tax increase can have an influence in decreasing PM due to a decrease in the number of diesel cars. The decrease of PM will therefore negatively influence policy rejection by the public and positively support diesel tax policy. Type 1 have confidence in the diesel tax enforcement policy and believe it will be more effective in reducing PM even though there are concern about the citizenry's potential rejection of it and of the conflicts between ministries.

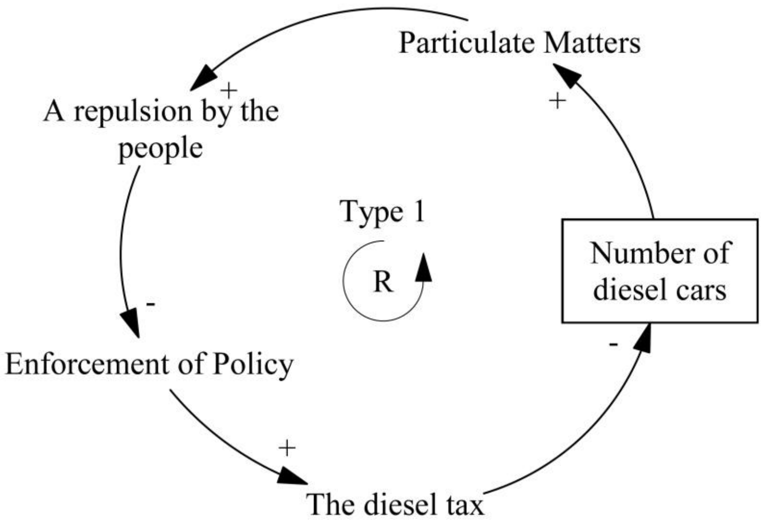


Figure 4-1 The individual causal loop diagram for type 1

On the other hand, type 2 is defensive in promoting diesel tax policy because of its possible effect on the economy and that they believe may therefore intensify people's rejection of it. The individual causal loop diagram for type 2 is illustrated in Figure 4-2. Type 2 have less confidence in raising the diesel tax and they are more concerned with the minimal effect of diesel policy and the higher possibilities of rejection by the public. Therefore, they have low motivation to improve diesel tax-related policy even though they have low satisfaction with the current policy including the role between ministries, government budget support and civil participation.

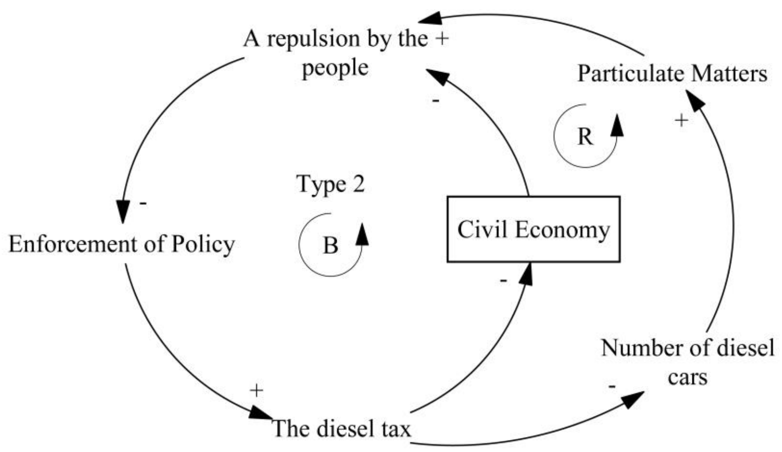


Figure 4-2 The individual causal loop diagram for type 2

Type 3 emphasizes the necessity in expansion of government budget support. Type 3 expects that the government budget will enrich policy enforcement and believes that it will bring positive policy results. The individual causal loop diagram for type 3 is illustrated in Figure 4-3.

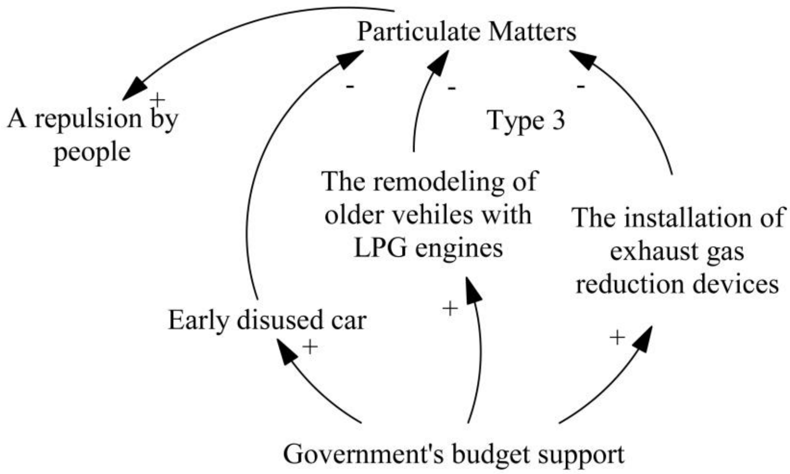


Figure 4-3 The individual causal loop diagram for type 3

Type 4 highlights the importance of civil cooperation and participation in reducing PM. However, they are concerned with the rapid commencement of a new diesel policy due to active civil participation that may cause policy failure. This policy failure finally could lead to public rejection. The individual causal loop diagram for type 4 is illustrated in Figure 4-4.

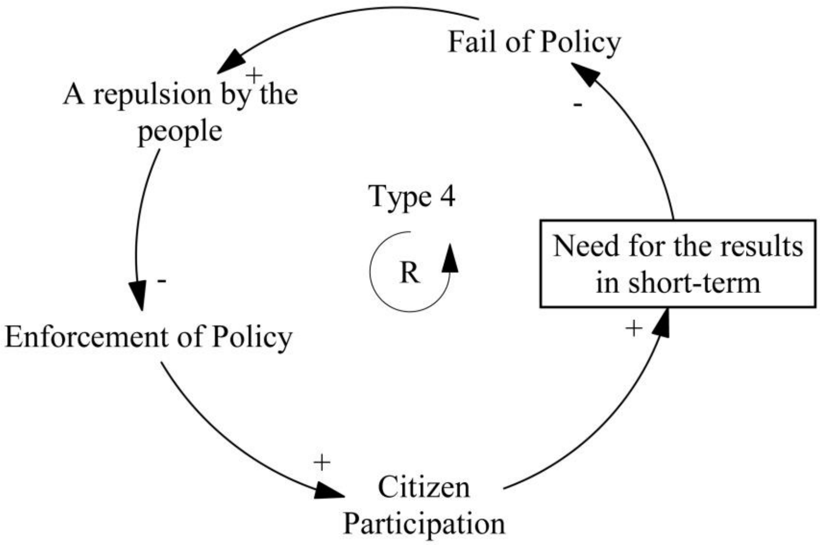


Figure 4-4 The individual causal loop diagram for type 4

2) Integrated Causal Loop Diagram

The integrated causal loop diagram is illustrated in Figure 4-5. The variables that clearly effect promoting the policy are the government budget, civil participation, and civil economy. In particular, the major variables of Type 1, 2, and 4 are connected to the 'rejection by the people' variable. This means that there is a concern about possible negative public opinion that could influence the delay in policy implementation. This proves that the government is highly concerned with public opinion in their policy-making. Therefore, the government concentrates on short-term measures and successes from their policies, even though it is important and more responsible for them to consider mid- to long-term strategies and measures.

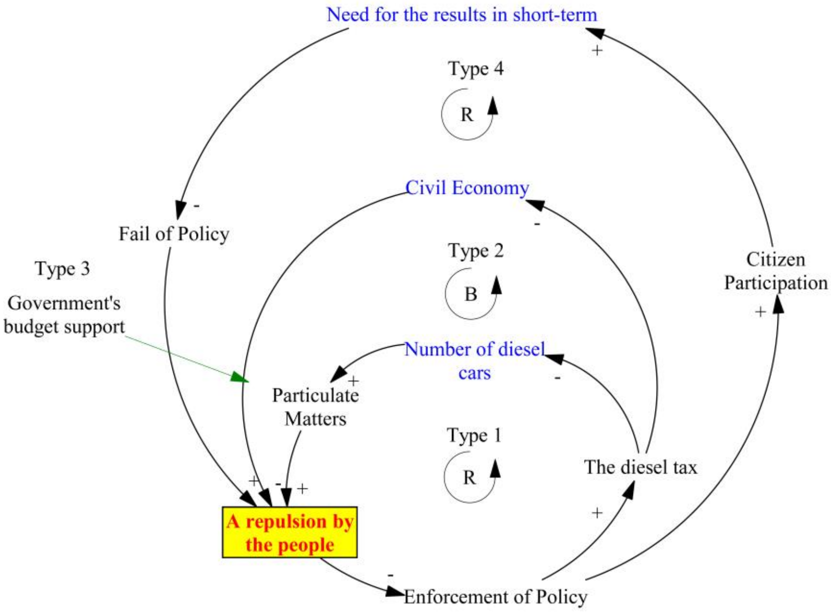


Figure 4-5 The integrated causal loop diagram

4.5. Conclusion and Discussion

This study prepared questionnaires (28 Q-statements) for 38 specialists who work closely on PM-related policies at four ministries (MOTIE, MOEF, MOLIT, MOE, and KFS) and seven research institutions (KEEI, KIET, KIER, KRILA, NABO, KRIHS, and KOTI). Specialists are classified according to their level of understanding for diesel policy and their individual perceptions of it rather than being classified by departmental characteristics. The specialists' perceptions for diesel policy are classified by four types using Q-methodology: advocacy type for a diesel regulation (type 1), passive type for diesel regulation (type 2), government budget support type (type 3), and sensitive response type for public opinion(type 4).

Based on the results from Q-methodology and systems thinking analysis, the main reasons for ineffective diesel policy are dysfunction in the ministries, lack of conveying relevant information to the stakeholders, and uncertainty regarding citizen participation. There are deep concerns about the public's potential rejection of policy, which has caused major delays in implementation. Therefore, the following recommendations and implications need to be considered in the implementation of government policies. First, it is necessary to find a group that can play an intermediary role among the four types. Type 3 is an optimal group to act as a mediator because they not only emphasize the pros and cons of the policy and mostly accept the need for improvements but also positively evaluate the policy effects. After choosing a group that can act as a mediator, one needs to get feedback on whether one wishes to have citizenship participation and what type of funding one will support. For example, Type 1 and Type 4 are considered necessary for citizen participation in PM reduction, but for Type 2 and Type 3, it is considered unnecessary. Additionally, Type 3 actively demands government funding, while Type 2 and Type 4 do not require government budgets to be funded. From these various opinions and causal relationships, selecting a group that can play a mediator role can be an important step to prevent conflicts among the different group interests.

Second, functions and roles of the ministries need to be reconsidered in order to enhance the understanding and arrangements among ministries. All four types did not strongly agree on statement (6) that "Collaboration among ministries is closely linked." Moreover, most types of specialists are confused about the roles of other departments. For example, Type 1 does not expect anything from the function and role of the OPM, whereas Type 3 and Type 4 argue that the role of the OPM should be further strengthened. In addition, Types 1, 2 and 4 took an opposing position in statement (13): “It is more appropriate to present the quantity of eco-friendly cars to the MOTIE rather than the MOE.” Therefore, more sound and enduring cooperation among the stakeholders is needed. Better understanding of the roles and functions among ministries needs to be considered and redefined.

Considering the urgency of particulate matter problem in Korea, solving the domestic problem only will not resolve the ongoing trend of PM concentration. Since international source accounts for over 48% of PM concentration in Korea, it is important to understand more scientific identification and cooperation on air pollution interactions among Northeast Asian countries. A concrete action plan to the trilateral talks among the environmental ministers of Korea, China and Japan is needed in establishing a trilateral treaty to fight for the particulate matter pollution in Northeast Asia countries. In an effort to move forward, the South Korean government signed with China, Japan, Mongolia, Russia and North Korea on Northeast Asia Clean Air Partnership (NEACAP) in Oct. 2018. With this partnership, they anticipated to establish an achievable model that would create a reduction convention with participated countries.

For the success of this partnership, a stable environmental cooperation platform needs to be established with a representative cooperation program between participated countries. In addition, since major metropolitan areas suffer most from PM concentration problems, cross-cooperation network for air-environmental platform need to be established between metropolitan municipalities.

This paper clarified that the Chapter 4 of this research paper includes the ‘Specialist perception on particulate matter policy in Korea: causal relationship analysis with Q-methodology and system thinking’ published in The Annuals of Regional Science in July 2019.

Reference: Lee, H., Chang, I., & Kim, B. H. (2019). Specialist perception on particulate matter policy in Korea: causal relationship analysis with Q-methodology and system thinking. *The Annals of Regional Science*, *63*, 341-373.

Chapter 5. What is the monetary value of the decrease in the probability of death by PM2.5?

5.1. Study Background

PM2.5 has been observed since 2015, and the average concentration in 2015 steadily decreased from $26\mu g/m^3$ to $18\mu g/m^3$ last year (Interagency coordination, 2017; 2019). Since 2020, when COVID-19 began, the average concentration decline has increased. However, the concentration of PM2.5 in Korea is three times higher than the World Health Organization (WTO) recommendation, which is $5\mu g/m^3$ (OECD, 2016).

Researchers at George Washington University in the U.S. and the University of British Columbia in Canada estimated that 1.8 million of the world's population would die excessively due to PM2.5 in 2019. This indicates that about 31,586 out of 51.78 million Korean population will die prematurely due to PM2.5. The Korea Disease Control and Prevention Agency suggested 2275 deaths from short-term exposure to PM2.5 in 2019 and 23,053 deaths from long-term exposure in 2019 (KDCA, 2022).⑧

To reduce the damage caused by PM2.5, it is necessary to quantify the damage and develop a plan for cooperation between countries to reduce PM2.5. One of the alternatives is to allocate the cost of PM2.5 reduction among countries. The EU agreed on reducing PM2.5 obligations through the Gothenburg Protocol, and an economic analysis study was used to form a consensus on detailed implementation content. Even though the EU and OECD have been preparing internal and external cooperation measures based on the economic analysis results of PM2.5 (OECD, 2016), r

⑧.Short-term and long-term exposure are classified according to the disease name.

esearch on the economic evaluation of PM2.5 is insufficient in Korea (Hwang, 2018). In particular, as citizens' interest in the effects of PM2.5 increases, economic evaluation research related to health effects is more important. Therefore, multilateral research on the value of PM2.5 reduction and socioeconomic effects through PM2.5 reduction needs to be conducted (Hwang, 2018). Despite the importance of research on population groups, economic research on PM2.5 reduction is very insufficient in Korea (Ann et al., 2016; Hwang & Son, 2020). In order to monetize the value of health damage, cost-of-illness (COI), the value of statistical life (VSL), and the value of life years (VOLY) are selectively utilized. Among these, the estimation of damage cost through the value of statistical life (VSL), which means the willingness to pay (WTP) to avoid the risk of premature death, helps prepare the foundation for policy evaluation (Ann et al., 2016; Bae, 2016; OECD, 2016; Hwang & Son, 2020)

Economic analysis of PM2.5 is an important process for joint cooperation with neighboring countries or local governments. By quantifying damage caused by PM2.5 and distributing the PM2.5 reduction costs to regions or countries that generate PM2.5, it can contribute to cooperation between local governments or countries (Yoon et al., 2022). This study aims to estimate the value of statistical life about the decrease in the probability of death due to PM2.5. The results of this study can be used not only as fundamental data to quantify citizenship to reduce PM2.5 damage and prepare policies, but also as a basis for establishing PM2.5 management plans for each local government and region in Korea.

5.2. Literature Review

In the health economics field, considering the characteristics that PM2.5 problems form a close relationship with health and health problems, the effect of air pollution mainly caused by PM2.5 on health is evaluated as an economical cost (Eom et al., 2019; Xu & Shan, 2018; Lee et al., 2021; Bayat et al., 2019). Although the spatial scope of these studies differs in Europe, the U.S., and China, many value of statistical life (VSL) methods are applied, which are widely applied mainly in evaluating the value of environmental goods (OECD, 2016). In other words, it measures the change in the level of welfare that increases as the level of pollution generated by PM2.5 improve. Specifically, Zhang et al.(2008) estimated the economic cost of the harmful effects of PM2.5 on health by using China as a spatial scope shows that economic costs are intertwined with regional characteristics.

The WTO reported that one out of every nine deaths was related to air pollution (WHO, 2016), and international cooperation for PM is desperately needed to improve the quality of life and reduce the financial burden. In addition, the Organization for Economic Cooperation and Development (OECD) estimated that the number of premature deaths from PM had already exceeded 3 million in 2010, with the number of deaths expected to reach 6 million to 9 million per year by 2060. Assessment of health effects from PM is crucial because it can lead to the assessment of related policies only when it is linked to calculating social costs through estimating damage costs (OECD, 2016).

Korean Government is necessary to quantify the damage and develop a plan for cooperation between countries to reduce PM2.5. Such plan help to allocate the cost of PM2.5 reduction among countries. The EU agreed on reducing PM2.5 obligations through the Gothenburg Protocol, and an economic analysis study was used to form a consensus on detailed implementation content.

The EU and OECD have been preparing internal and external cooperation measures based on the economic analysis results of PM2.5 (OECD, 2016; EPA Homepage), but research on the economic evaluation of PM2.5 is insufficient in Korea (Hwang, 2018). In particular, as citizens' interest in the effects of PM2.5 increases, economic evaluation research related to health effects is more important. Therefore, multilateral research on the value of PM2.5 reduction and socioeconomic effects through PM2.5 reduction needs to be conducted (Hwang, 2018).

The contingent valuation method (CVM) is widely used to evaluate the economic value of air quality improvement or reduced health damage through the estimation of people's willingness to pay(WTP) or willingness to accept (WTA) in nonmarket for clean air, health status, and human life. Methods for estimating the willingness to pay (WTP) are largely divided into the revealed preference method and the stated preference method (Kim et al., 2015). The revealed preference method requires market data related to mortality reduction, and market data can be used to estimate the amounts of payments made to reduce mortality. On the other hand, the stated preference method is convenient because researchers can estimate the willingness to pay for mortality reductions through surveys assuming certain conditions and specifying research phenomena more accurately than the revealed preference method (Lee et al., 2016). The stated preference method can be largely divided into the Contingent Valuation Method and the Conjoint Method, and the National Oceanic and Atmospheric Administration (NOAA) suggests that the value of a good can be measured through a contingent valuation method, provided that reasonable virtual scenario designs and the processes are properly controlled.

Many researchers in China and Korea have been studying the causes of PM occurrence, human health factors, and policies to reduce PM. Previous studies have demonstrated that PM causes damage to public health and ultimately leads to social externalities. The study for CVM focuses on people's WTP for air pollution reduction or health risk reduction (Pu et al., 2019; Freeman et al., 2019; Dong et al., 2018; Tan et al., 2014). The studies in China were conducted not only on a national and urban scale but also on a regional scale to seek joint regional cooperation in controlling air pollution. On the regional scale, Jing-Jin-Ji (Beijing and its surrounding areas) is frequently studied due to its heavy pollution problems. Wei and Wu (2016) estimated that the mean WTP in Jing-Jin-Ji to reduce 80% of severe PM2.5 polluting days accounted for 602CNY/year, approximately 1% of GRDP, far exceeding that in Sweden. The mean WTP in Beijing (Yin et al., 2018) based on a random forest model to reduce health and mood impact due to PM2.5 was 1388.4 CNY/year and 897.7/year, respectively, total accounting for 2.2% of the 2015 Beijing GDP. This indicated that people in Beijing attached high importance to reducing the health risks of PM2.5.

On the other hand, when taking a look at previous studies that estimated the health benefits of PM2.5 emissions reduction, Yin et al. (2017) transferred VSL2012 from VSL1999 with a 0.8 value of income elasticity recommended by the OECD. They estimated that the total costs of health risk due to PM2.5 was US$2.53 billion with VSL within a year, accounting for 0.9% of the 2013 regional GDP in Beijing. Yang et al.(2018) showed that the average economic loss from health impact due to PM2.5 was around 1% VSL of the total GDP in 190 Chinese cities from 2014 to 2016. Meanwhile, they pointed out that economic loss in the Jing-jin-ji region was higher than the average value. However, these two papers just applied WTP values from previous research to their VSL estimation without conducting WTP research alone. Cho(2003) measured the social welfare effects of reducing premature mortality from improved air pollution. They identified the relationship between the death of chronic respiratory disease in Korea and the concentration of air pollutants in each region through the model of Lave and Seskin (1973). Cho (2003) suggested that people would pay an average of WTP 2,100 KRW per month to reduce the number of premature deaths from five per 1,000 to zero per 1,000, and the value of human life was estimated to be around 5 million KRW in this paper. Shin (2007) used the Conjoint Method to estimate the statistical value of human life to reduce premature mortality by type. The attributes associated with the type of premature death risk were defined as the cause of death, the spontaneity of death, the time of death, the size of the reduction of the risk of death, and the statistical human life values of one type of early mortality reduction were estimated by combining each attribute. In the Shin (2007) study, the statistical human life value of each type of early mortality rate is presented as at least 1.1 billion to 1.8 billion. Choi and Lee (2015) analyzed the effect of changes in PM2.5 emissions on changes in the probability of hospital visits and hospitalizations due to respiratory diseases using the Probit and Tobit models. The analysis results suggest that a 1% change in PM2.5 emissions increases the probability of hospitalization due to respiratory diseases from 0.755% to 1.216%, and the probability of hospitalization increases from 0.150% to 0.197%. In addition, the KRW unit benefit of PM2.5 emission was estimated, and the health benefit of reducing 1 ton of PM2.5 emission was claimed to be KRW 214 million.

On the other hand, when the health effects of air pollutants lead to death, a number of previous studies have used the value of statistical life or the value of statistical life year to estimate the socioeconomic loss. The value of statistical life refers to the value given in advance to avoid the death of one unspecified person in our society. It is not an evaluation of an individual's life's value but a value derived from the willingness to pay for a small change in the probability of death. In other words, it is an ex-ante choice of the WTP for a slight change in the death probability under the premise of uncertainty about who will die. The concept of the value of statistical life year is similar to the value of statistical life. However, it is different in that it is the value that society endows on reducing the risk of premature death in advance and derives values for a specific period.

The estimated range of the value of statistical life in studies related to PM mortality varies significantly from $200,000 to $30 million (Ann et al., 2016). Yang et al. (2018) showed that the average economic loss from health impact due to PM2.5 was around 1% VSL of the total GDP in 190 Chinese cities from 2014 to 2016. Ann et al. (2016) derived the respondent's willingness to pay (WTP) for a policy scenario that reduces the possibility of death from air pollution by 0.0001 using a Contingent Valuation Method. As a result of applying the single bounded spike model, the annual willingness to pay (WTP) to reduce the possibility of death due to air pollution by 0.0001 was estimated to be KRW 10,141. Based on this, the statistical life value when no discount rate was applied was calculated to be about KRW 1.014 billion, and the statistical life value derived by applying a 10-year payment period and a social discount rate of 5.5% was estimated to be about 806 million

Meanwhile, they pointed out that economic loss in Jing-jin-ji region was higher than the average value. Cho (2003) suggested that people would pay an average of WTP 2,100 KRW per month to reduce the number of premature deaths from five per 1,000 to zero per 1,000, and the value of human life was estimated to be around KRW 5 million in this paper. Shin (2007) used the Conjoint Method to estimate the statistical value of human life for the reduction of premature mortality by type. The attributes associated with the type of premature death risk were defined as the cause of death, the spontaneity of death, the time of death, the size of the reduction of the risk of death, and the statistical human life values of one type of early mortality reduction were estimated by combining each attribute. In the Shin (2007) study, the statistical human life value of each type of early mortality rate is presented as at least 1.1 billion to 1.8 billion.

This study aims to estimate the willingness to pay (WTP) and the value of statistical life (VSL) for the Reduction of Mortality by PM2.5 Improvement. This study can be used as essential data for international cooperation for PM2.5 reduction.

Table 5-1 List of contingent valuation method research results related to air pollution (2000-2020)

Reference	Evaluation target	**Details of the evaluation target**	**Estimated value (presented value in research)**	Evaluation standard year	**Statistical population**	Number of samples
Kim et al, 2019	Economic value of resolving the PM2.5 problem in Seoul and the metropolitan area	Additional willingness to pay (entire samples) for green electricity usage fees to improve PM2.5 problems in Seoul and the metropolitan area	Month 3,993 won/household	2017	Households in the metropolitan area with children aged from 0 to 18	171
Ann et al., (2016)	16 cities across the county	Reduced deaths due to air pollution by 1/10,000 (from about 4 in 10,000 to 3 in 10,000 after 10 years)	Month 845 won/person (Annual KRW 10,141.3)	2016	Adult men and women from 20 to 65 in their age	1,000
			Month 84,500,000 won/person (VSL)			
Kim & Seo (2010)	Value of atmospheric environment in Seoul	Willingness to pay for atmospheric environment quality improvement (median value), pay in taxes	Month 3,532 won/person	2009	Seoul citizens	200
Seo et al., (2010)	Economic value of Seoul atmospheric environment quality improvement	Willingness to pay for atmospheric environment quality improvement (multiple linear regression model)	Month 302 won/person	2009	Seoul citizens	200

Kim et al. (2003)	Risk due to air pollution	Willingness to pay for environmental pollution risk reduction (10 per 1000 people risk reduced to 5 per 1000 people)	Year 14,700 won/person	2002	Seoul citizens	600
	Risk due to air pollution	Willingness to pay for environmental pollution risk reduction (10 per 1000 people risk reduced to 5 per 1000 people)	Year 10,700 won/person	2002	Seoul citizens	600
Yoo et al. (2003)	Seoul air quality	Benefits of reducing death risk, disease risk, dust damage, and visibility damage (changed from current to best attribute level) due to air quality improvement	Month 55,139 won/household	2002	Seoul citizens	654
Jo (2003)	Air pollution across the country	Amount of willingness to pay to reduce the premature mortality rate of patients with respiratory diseases caused by air pollution by 0.5%	Month 2,132 won/person	2002	Internet users across the country	245
Park (2002)	Impact of air pollution on health	Amount of willingness to pay for health improvement (zero experience of eye irritation) due to air quality improvement	Month 2,703 won/person	2002	Residents of Seoul, Incheon, and Gyeonggi-do	1850
	Impact of air pollution on health	Amount of willingness to pay for health improvement (zero experience of dyspnea) due to air quality improvement	Month 28,543 won/person	2002	Residents of Seoul, Incheon, and Gyeonggi-do	1850
	Impact of air pollution on health	Amount of willingness to pay for health improvement (zero experience of esthma) due to air quality improvement	Month 89,923 won/person	2002	Residents of Seoul, Incheon, and Gyeonggi-do	1850

Reference: Environmental Valuation System (EVIS) homepage.

5.3. Research Method

The value of Statistical Life (VSL) corresponds to the amount of money an individual is willing to pay to avoid a critical risk. It is also the amount members of society are willing to pay together (WTP) to reduce the average number of deaths. This study sets deriving the respondents' willingness to pay for reducing death from PM2.5 as a target good and applies the contingent valuation method (CVM), which is one of the stated preference approaches in order to estimate the non-market value of the environment. The flow of research is as follows (Table 5-2).

Table 5-2 Flowchart of research

Set up the CVM Virtual market
• Set up value evaluation target: Reduction of mortality rate through reduction of PM2.5 • Selection of payment method: Payment cycle (annual), payment period (10 years) • Selection of willingness to pay induction method: Double bounded dichotomous choice
↓
CVM survey and sample design
• Survey composition through previous studies • Review the survey through a preliminary survey and design the scope of the suggested amount of money • Survey target setting: Sample design by population proportion, gender, and age ratio
↓
Estimate WTP and VSL function
• Understand the characteristics of samples and summarize the questionnaire • Derivation of descriptive statistics and response results of the CV questionnaire • WTP function estimation for benefit estimates: Identification and processing of Protest Responses for WTP • Sample WTP measurements and annual total benefit estimates • VSL estimation

Annotation: Restated by referring to the report of the KDI public and private infrastructure investment management center & Korea environmental and resource economics review

Table 5-3 Research phase and performance of each phase

Phase	Detailed procedures
Previous research	• Understand the purpose of valuation, previous studies on similar cases, and issue points
Set research scope	• Design the target population, type, and characteristics of the sample
Select valuation techniques and research methods	• Select CVM based on previous studies • Select from in-person interview, mail, phone calls, or internet survey
Design survey	• Selection of payment method and period • Survey composition: Write a preliminary questionnaire for the main survey • Method to induce the willingness to pay: dichotomous choice • Questionnaire design: Set up CVM hypothetical scenario and suggest WTP questions
	• Preliminary survey for the validation of the survey • Bid design
Sample design and main survey performance	• Select sampling method (population proportion, gender, age ratio sample design)
Estimate WTP and VSL function	• WTP sample average and medium estimation • Analysis of the 'Yes/No' ratio and refusal response of the willingness to pay according to the bid price • WTP and VSL estimation • Social・economical characteristics analysis
Aggregate and write a report	• Aggregation of population WTP and estimation of VSL from sample WTP estimates

Annotation: Restated by referring to the report of the KDI public and private infrastructure investment management center & Korea environmental and resource economics review

5.3.1 Research Survey Design

1) Selection of payment method and period

The payment method must consider the actual situation in order for respondents to express their willingness to pay for the virtual market clearly. The 'traffic energy environment tax' was considered as the payment method by referring to the results derived from the preliminary survey. However, as there was an opinion on adjusting the annual expenditure restructuring of the 'traffic energy environment tax,' it was not applied in this survey to avoid related issues or controversy. The payment method was set to be paid annually for the next 10 years, referring to previous studies. On the other hand, before presenting the willingness to pay questionnaire, it was explicitly stated that it would cost a lot to implement the policy, that it would be difficult to carry out if not many people were willing to pay, and that respondents' income would be limited and should be spent for various purposes.

2) Survey composition

The survey can be largely divided into a survey of interest and awareness of the PM2.5, a survey to derive the willingness to pay, and a survey of socioeconomic information. The CV scenarios are written to help understand the values and characteristics of non-market services through the virtual market. The questionnaire should be simplified to clarify the questions' contents for the respondents' convenience. In addition, the response types should be mutually exclusive and cover all possibilities (KDI Public and Private Infrastructure Investment Management Center & Korea Environmental and Resource Economics

Review, 2012). The composition of the survey of this study is shown in Table 5-4.

Table 5-4 Survey composition

Category	Main questions by component
Purpose	• Estimation of the value of statistical life (VSL) according to the decrease in the probability of death due to the PM2.5
Preliminary questionnaire	• Overall interest in environmental pollution • Interest and awareness of PM2.5 • Interests and awareness of government policies • Awareness of socio-economic damage caused by PM2.5 • Awareness of the effects on health caused by PM2.5
VSL questionnaire	• Question about the value of statistical life: How much additional amount per year would you be willing to pay for 10 years to reduce the chance of excess deaths from PM2.5?
Characteristics of respondents	• Question about the health status and health care of respondents • Question about respondents' efforts to take care of their health • Socio-economic characteristics of the respondent, such as age, gender, family size, education level, income, and occupational questions.

3) Method of inducing the willingness to pay

Methods to induce the maximum willingness to pay for a product or service include bidding games, open-ended questions, payment cards, and dichotomous choice questions. However, the choice of method of inducing the willingness to pay must be taken into serious and careful consideration as the estimate of WTP can be measured differently depending on the willingness to pay method. Generally, it is suggested that the payment card and dichotomous choice methods are complementary to other methods.

Table 5-5 General methods for WTP in CVM

Methods to induce WTP	Content
Bidding game	This is a format commonly used in early CVM studies. It is a method of repeatedly bidding to give respondents a specific starting bid price and to converge the respondent's true willingness to pay (WTP) by repeating the process of raising or lowering it. There are concerns such as the convenience of starting point and convenience of 'yes-yes' remarks.
Open ended	This is a method to directly determine the maximum willingness to pay for non-market goods. Generally, because there is no purchase experience for non-market goods and it is unfamiliar, the non-response rate may be high, zero value or outliers may come out a lot.
Payment card	This is a method of giving supplementary data that divides a certain range of amounts into several intervals. Mark v was given for the amount you are willing to pay with certainty, and x for the amount respondents are not willing to pay with certainty. Therefore, there are concerns about strategic expediency.
Dichotomous choice	This is a method of randomly distributing the selected amount of money among respondents and then answering "yes" and "io" whether they are willing to bid a certain price and pay. Single bounded dichotomous choice and double bounded dichotomous choice depend on how many times they are asked.

Reference: KDI Public and Private Infrastructure Investment Management Center & Korea Environmental and Resource Economics Review, 2012

4) Setting hypothetical scenarios and presenting WTP questionnaire

According to previous studies, a research team at George Washington University in the U.S. and the University of British Columbia in Canada estimated that 1.8 million people worldwide would die excessively from PM2.5 in 2019. This means that 61 out of 100,000 people worldwide have a chance of excess death. In the survey of this study, information such as domestic and foreign health damages caused by PM2.5, especially the excess number of deaths, was provided before presenting a hypothetical market to derive the willingness to pay. In that way, respondents could more clearly recognize and respond to the current situation. Then, the survey emphasized that the effect can vary depending on the policy measures and asked how much additional amount per year respondents would be willing to pay for the next 10 years to reduce the probability of death due to PM2.5 by 1/10,000 (1 person per 10,000 people) in all age groups through the PM2.5 seasonal management system. In addition, the survey recognized respondents that their income is limited, and that income should be spent for various purposes.

5) Preliminary survey for validation of survey

This study conducted a Pre-Test through population proportional allocation on 50 ordinary citizens between the ages of 20 and 64 nationwide. According to KDI Public and Private Infrastructure Investment Management Center & Korea Environmental and Resource Economics Review (2012), the preliminary survey sample of 25 to 100 people is appropriate. In order to set the bid scope of the survey, respondents were asked open-ended questions about their willingness to pay for hypothetical situations in the preliminary survey. Moreover, based on the amount the 50 respondents were willing to pay in the preliminary survey, the mean and median values, to minimize the impact of excessively large WTP responses of the survey results, were carefully inspected. Finally, the first bid price of this survey was set as a total of five, from KRW 10,000 to KRW 60,000. Moreover, based on the bid price, this study allocated the entire respondents into 5 groups by dividing them into gender and age group proportions.

6) Bid design

The double bounded dichotomous choice that this study adopted offers a doubled amount if the response is “yes” to the first bid presented to the survey respondent and offers a half amount if the response is “no.” Adopting the double bounded dichotomous choice can be an option to increase the efficiency of WTP function estimation. However, since this study samples 1,000 people, adopting the single bounded dichotomous choice can be a more appropriate approach. Although the double bounded dichotomous choice has the advantage of improving the inefficiency of the single bounded model, such as the 1.5 bounded model, the double bounded dichotomous choice was adopted considering that both single bounded models and double bounded models can be estimated.

The WTP sample average or median value derived from the dichotomous choice is derived from the coefficient estimates of the dichotomous choice model. The distribution of the offered amount is important as it affects the variance of the coefficient estimates, that is, efficiency (KDI Public and Private Infrastructure Investment Management Center & Korea Environmental and Resource Economics Review, 2012). This study derived and utilized the first bid (KRW 10,000, KRW 15,000, KRW 45,000, KRW 60,000) within the range of 15% to 85% of the WRP distribution obtained by the preliminary survey.

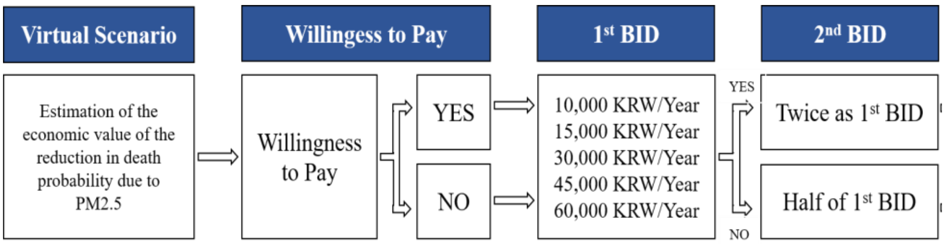


Figure 5-1 Procedure of estimation WTP

7) Sample design and main survey performance

The survey for this study was conducted online by commissioning Embrain. The population of this research survey is households in 16 cities and provinces excluding Jeju Island. The sampling method is proportional to population, gender, and age ratio. The total number of respondents is 1000, and the total age range is from 20 to 65 years old. According to Lee & Yim (2006), regarding the minimum number of questionnaires for CVM, it is suggested that only a sample of about 400 samples can almost accurately identify the overall opinions when the entire population is more than 1 million people. In addition, 1000 respondents who would have reviewed the previous studies are judged to be a sufficient number of participants to obtain results from this study.

5.3.2 WTP and VSL function estimation model

1) Estimation of Willing to Pay (WTP)

The approach used to estimate the WTP function is the method proposed by Cameron & James (1987), which directly presents the WTP function of respondents without passing through the utility function of individuals. Even after respondents set up a hypothetical situation, the maximum willingness to pay (WTP), which allows respondents to enjoy the same utility as before, can be expressed as Equation (1) below.

$$u_j(y_j - WTP, w_j, z=1) + e_{ij} = u_j(y_j, w_j, z=0) + e_{0j} \quad (1)$$

WTP can represent the Compensating Variation (CV), which is the maximum willingness to pay that respondents are willing to pay to reduce the mortality rate due to PM2.5 without changing respondents' utility level as an expenditure difference function).

$$WTP_j = e\,(w_j, z=0, v_j) - e(w_j, z=1, v_j) = X_j^{'}\beta + \eta_j \quad (2)$$

$e(\bullet, z=i)i=0$ represents the minimum expenditure required by individuals to achieve a certain level of utility in each situation related to weather conditions. If respondent j responded 'yes' to the bid price, A means that the WTP is greater than the bid price. Therefore, the probability of responding 'yes' can be expressed as follows.

$$\begin{aligned}\Pr(yes) &= \Pr(WTP_j > A_j) \\ &= \Pr(X_j^{\cdot}\beta + \eta_j > A_j) = \Pr(X_j^{\cdot}\beta - A_j > \eta_j)\end{aligned} \quad (3)$$

The simplest form of the expenditure difference function represented by Equation (2) can be expressed as Equation (4).

$$WTP_j = \beta_j + \eta_j = \mu + \eta_j \quad (4)$$

μ indicates the average WTP, and Equation (3) can be simplified into the following Equation (5).

$$\Pr(yes) = \Pr((\mu - A_j)/\sigma > e_j) \quad (5)$$

Therefore, the mean and median values of WTP can be obtained using the coefficient estimate of the probability density function for the estimation of WTP as follows.

$$WTP = \frac{\widehat{\mu/\sigma}}{\widehat{1/\sigma}} = \hat{\mu} = WTP^{*} \quad (6)$$

5.3.3. Hicks' the compensating variation (CV) and equivalent variation (EV) [9]

The compensating variation (CV) and equivalent variation (EV) devised by Hicks have the advantage of overcoming the theoretical problem of consumer surplus (CS) to accurately estimate the welfare effect of price changes. Using the concept of Hicks' compensation surplus (CS) can be expressed as shown in model 7 below.

$$CS = E(p, q0 : U0, Q, T) – E(P, qi : U0, Q, T) \qquad (7)$$

P: Price vector of market goods
q0: Initial level of environmental quality
qi: Changed environmental quality
U0: Initial level of utility
Q: Vector of other public goods assumed to be changed
T: Variable vector reflecting participants' preferences

In equation (8), the value of the first expenditure function is Y0. In other words, it is the current income and the minimum expenditure level to obtain the utility of U0 at the first environmental quality level q0 while other conditions are constant. The value of the second expenditure function is Yi, which is the minimum expenditure level that can maintain the first utility level when only the environmental quality changes to qi while other conditions are constant. At this time, Hicks' compensation surplus (CS), according to changes in environmental quality, is defined as the difference between Y0 and Yi.

Willing (1976) finds that the model (7) can be expressed in the form equivalent to the income compensation function, and when the willingness to pay is used as a

[9] Hicks' compensating variation and equivalent variation was extracted from Hyungbaek Lim and Sungwoo Lee (2014).

measure of benefit, the income compensation function is usually regarded as the willingness to pay which is same as model (8).WTP(qi)= $f(P, qi, Q, Y0, T)$ ----(8)

Y0 : Current income

Compensating variable (CV) is a measure of how much welfare has increased in the criteria for post-policy improvement, given that a policy has brought about an increase in welfare. In other words, it is possible to estimate how much income should be deducted to return to the welfare level before improvement in a state where the premature mortality rate decreases due to the reduction of PM2.5, and the amount of income deduction at this time is the size of the welfare increase. This also means the amount of willingness to pay (WTP) to reach a new level of utility, which is a decrease in the premature mortality rate due to the improvement of PM2.5. Meanwhile, the equivalent variable (EV) refers to an increase in income standard, that is, welfare, required in a state where the premature mortality rate is not reduced due to PM2.5 reduction to reduce the premature mortality rate by reducing PM2.5 through policy. In other words, the equivalent variation (EV) is the minimum amount of compensation or willingness to Accept (WTA) that is acceptable instead of reducing the premature mortality rate due to PM2.5. Estimating welfare changes through compensating variable (CV) and equivalent variable (EV) is appropriate when the output of a good or service changes continuously, which changes the price of the good and allows consumers to freely choose the amount of consumption. The sizes of the two values are the same. Therefore, this study questions how much welfare increases when the premature mortality rate decreases (based on post-mortem) due to PM2.5 reduction and derives the willingness to pay (WTP) to reach the utility level of premature mortality rate reduction. Therefore, estimating welfare through compensating variable (CV) is appropriate.

5.3.4 Estimation of Value of Statistical Life (VSL)

The value of statistical life is defined as the willingness to pay (WTP) for the reduction in the risk of premature death (ΔP) divided by the reduction in the risk of death (ΔP), ($\frac{WTP}{\Delta P}$).

$$VSL = \frac{WTP}{\Delta P} \quad (1)$$

For example, If the mortality rate per 100,000 population decreases by one due to the PM2.5 seasonal management policy, the risk of death will be 1 per 100,000. If individuals are willing to pay KRW 1,000 on average, the value of statistical life will be KRW 100 million (=1/1/100,000) (Youngchul Shin, 2008).

5.4. Results

5.4.1 Socioeconomic characteristics of respondents

The subjects of this study were set in their 20s and 60s in Korea. In the case of gender and residential areas, respondents were selected in consideration of the actual Korean gender structure and regional distribution. In addition, in the case of age, it was organized to form an equal distribution for each class. 50% of the household owners and members were also selected. Moreover, the number of family members[10] is the highest in the order of 4, 3, 2, 1, 5, and 6. Regarding

[10] Based on the 2021 census in Korea, the total number of households (20-64 years old) was 16,375,327, followed by single-person households (5,287,302), two-person households (3,852,414), three-person households (3,478,897), four-person households (2,962,151), five-person households

educational background, the response is different based on the head of the household and the whole. However, the ranking of each educational background is the same (in order of bachelor's degree, high school graduation, associate's degree, current in graduate school, current in 4-year university, middle school graduation, elementary school graduation) (Table 5-6).

Table 5-6 Socio-economic characteristics of respondents1

Items	Category	Freq.	%	Total
Gender (Q1)	1 (Male)	584	50.78	1,150 (100.00)
	2 (Female)	566	49.22	
Age (Q2)	1 (20’s)	237	20.61	1,150 (100.00)
	2 (30’s)	228	19.83	
	3 (40’s)	221	19.22	
	4 (50’s)	232	20.17	
	5 (60’s)	232	20.17	
Province (Q37)	1 (Seoul)	331	28.78	1,150 (100.00)
	2 (Busan)	85	7.39	
	3 (Daegu)	54	4.70	
	4 (Incheon)	69	6.00	
	5 (Gwangju)	35	3.04	
	6 (Daejeon)	31	2.70	
	7 (Ulsan)	16	1.39	
	8 (Gyeonggi)	296	25.74	
	9 (Gangwon)	22	1.91	
	10 (North Chungcheong)	29	2.52	
	11 (South Chungcheong)	38	3.30	
	12 (North Jeolla)	28	2.43	
	13 (South Jeolla)	25	2.17	
	14 (North Gyeongsang)	44	3.83	
	15 (South Gyeongsang)	36	3.13	
	16 (Jeju)	6	0.52	
	17 (Sejong)	5	0.43	
Number of family members	1person	151	13.13	1,150 (100.00)
	2people	240	20.87	

(658,854), and six-person households (110,291) in order. Therefore, this study may have limitations in securing representation because the results of the characteristics of the number of household members in the survey sample have errors compared to the population and housing census.

(Q38)	3people	289	25.13	
	4 people	386	33.57	
	5 people	76	6.61	
	6 people	8	0.70	
Education (Q39)	1 (Elementary school graduation)	2	0.17	1,150 (100.00)
	2 (Middle school graduation)	5	0.43	
	3 (High school graduation)	218	18.96	
	4 (Associate's degree)	178	15.48	
	5 (Current in 4-year university)	60	5.22	
	6 (Bachelor's degree)	570	49.57	
	7 (Current in graduate school)	117	10.17	
Houseowner (Q40)	1 (Houseowner)	574	49.91	1,150 (100.00)
	2 (Not houseowner)	576	50.09	
Houseowner's education(Q41)	1 (Elementary school graduation)	11		1,150 (100.00)
	2 (Middle school graduation)	20	3.47	
	3 (High school graduation)	176	30.56	
	4 (Associate's degree)	77	13.37	
	5 (Current in 4-year university)	23	3.99	
	6 (Bachelor's degree)	214	37.15	
	7 (Current in graduate school)	55	9.55	

In terms of job and property, general office workers account for the most significant proportion of respondents (34.35%), followed by housewives and students (22.61%), production and service workers (14.78%), other (13.13%), professional (10.75%), agriculture, livestock and fisheries, and food nutrition-related jobs (0.5% respectively). The average monthly income intervals are less than KRW 1 million to more than KRW 7 million, with the proportion of income earners over KRW 7 million the highest (21.04%), followed by less than KRW 5 million (16.52%), less than KRW 4 million (15.91%), and less than KRW 3 million (14.17%). The monthly expenditure intervals are from less than KRW 500,000 to KRW 4 million, and the proportion of more than 4 million (16.43%), less than 2.5 million (14.35%), and less than 2 million (13.48%) are relatively higher than that of other expenditure levels. In addition, the ownership of the house consisted of self-ownership, lump-sum housing lease, and monthly rent, and the ratio of self-ownership (66.43%) is the highest, with lump-sum housing lease (19.74%) and monthly rent (13.13%). Furthermore, the most house type is an apartment (67.91%). In addition, about three-quarters of the respondents are not engaged in medical and health-related jobs. Finally, the fact that about 85% of the questionnaire difficulty items are composed of 'moderate' and 'easy' shows the appropriateness of the questionnaire design (Table 5-7).

Table 5-7 Socio-economic characteristics of respondents2

Items	Category	Freq.	%	Total
Jobs (Q42)	1(Senior management)	42	3.65	1,150 (100.00)
	2 (Agriculture, livestock, and fisheries)	4	0.35	
	3 (Production and service)	170	14.78	
	4 (General office workers)	395	34.35	
	5 (Food nutrition)	4	0.35	
	6 (Housewives and students)	260	22.61	
	7 (Profession)	124	10.78	
	8 (Other)	151	13.13	
Average monthly income (Q43)	1 (Less than KRW 1 million)	37	3.22	1,150 (100.00)
	2 (Less than KRW 2 million)	75	6.52	
	3 (Less than KRW 3 million)	163	14.17	
	4 (Less than KRW 4 million)	183	15.91	
	5 (Less than KRW 5 million)	190	16.52	
	6 (Less than KRW 6 million)	149	12.96	
	7 (Less than KRW 7 million)	111	9.65	
	8 (More than KRW 7 million)	242	21.04	
Monthly expenditure (Q44)	1 (Less than fifty thousand)	29	2.52	1,150 (100.00)
	2 (Less than KRW 1 million)	135	11.74	
	3 (Less than KRW 1.5 million)	147	12.78	
	4 (Less than KRW 2 million)	155	13.48	
	5 (Less than KRW 2.5 million)	165	14.35	
	6 (Less than KRW 3 million)	124	10.78	
	7 (Less than KRW 3.5 million)	90	7.83	
	8 (Less than KRW 4 million)	116	10.09	
	9 (More than KRW 4 million)	189	16.43	

Ownership of the house (Q45)	1 (Self-ownership)	764	66.43	1,150 (100.00)
	2 (Lump-sum housing lease)	227	19.74	
	3 (Monthly rent)	151	13.13	
	4 (Other)	8	0.70	
House type (Q46)	1 (Single house)	323	28.09	1,150 (100.00)
	2 (Apartment)	781	67.91	
	3 (Studio)	41	3.57	
	4 (Other)	5	0.43	
Engaged in medical and health-related jobs (Q47)	1 (Yes)	297	25.83	1,150 (100.00)
	2 (No)	853	74.17	
Questionnaire difficulty (Q48)	2 (Hard)	79	6.87	1,150 (100.00)
	3 (Moderate)	500	43.48	
	4 (Easy)	474	41.22	
	5 (Very easy)	97	8.43	

5.4.2 Descriptive statistics for questionnaires

1) Interest and awareness of PM2.5

Respondents aged 43.7 on average have a moderate interest in environmental pollution and PM2.5 and recognize that the air quality environment level and PM2.5 concentration are generally bad. On the other hand, some respondents responded that they are not interested in PM2.5 for reasons such as not feeling uncomfortable with more critical issues such as COVID-19 and already having easy access to information. Meanwhile, respondents mainly take information about PM2.5 through TV (35.32%), mobile (29.27%), and Internet (29.27%), and on the Internet, they answered that they mainly obtained information from portals. However, the recognition rate of the PM2.5 season management system is low (2.56), which is related to the relatively low rate of referring to government ministries (13.53%) in taking PM2.5 information. Nevertheless, respondents generally agreed with the harmfulness of PM2.5 and responded that they are aware of the socio-economic damage and are concerned about their health (Table 5-8).

Table 5-8 Descriptive statistics for questionnaires

Items		**mean**	**sd**	**min**	**p50**	**max**
Age	Age	43.75652	13.33161	20	43	64
Interest and Awareness of PM2.5	Interest in environmental pollution	3.765217	.7478479	1	4	5
	Awareness of Air quality level	2.289565	.7301625	1	2	5
	Subjective level of PM2.5	2.161739	.6503106	1	2	5
	Interest Level of PM2.5	3.682609	.7878274	1	4	5
	The reason why not interested	2	.8485281	1	2	4
	PM Information Access Route: TV (%)	.7513043				
	PM Information Access Route: Mobile app (%)	.6226087				
	PM Information Access Route: Internet (%)	.6226087				
	PM Information Access Route: Newspaper (%)	.0278261				
	PM Information Access Route: Radio	.0547826				

	(%)					
	PM Information Access Route: Friends (%)	.0373913				
	PM Information Access Route: other (%)	.0104348				
	PM Information Access Route through the internet: Government website (%)	.2402235				
	PM Information Access Route through the internet: Publication (%)	.2918994				
	PM Information Access Route through the internet: Portal (%)	.9315643				
	PM Information Access Route through the internet: Social media (%)	.2918994				
	PM Information Access Route through the internet: other (%)	.0195531				
Interest and Awareness of PM2.5 Policy	Awareness level of Seasonal Management	2.561739	.9564569	1	3	5
	PM2.5 interest level	3.624348	.7725255	1	4	5
Awareness and approval level for Socio-Economic Damage	Awareness level of socioeconomic effects of PM2.5	3.2	.8175618	1	3	5
	Approval rate of PM2.5 risk factors	4.304348	.6473339	1	4	5
	Concern level of health effect of PM2.5	4.009565	.6886464	1	4	5

Table 5-9 Response result of information access route

Category	Content	Frequency	Percentage (%)
Information Access Route (Q10: Multiple responses allowed)	TV	864	35.32
	Mobile	716	29.27
	Internet	716	29.27
	Newspaper	32	1.31
	Radio	63	2.28
	Friends	43	1.76
	Other	12	0.49
Total		2,446	100.00

Table 5-10 Response result of information access route through the internet

Category	Content	Frequency	Percentage (%)
Information Access Route through the internet (Q11: Multiple responses allowed)	Government	172	13.53
	Publication	209	16.44
	Portal	667	52.48
	Social media	209	16.44
	Other	14	1.10
Total		1,271	100.00

Table 5-11 Response result of reasons for indifference to PM2.5

Category	Content	Frequency	Percentage (%)
Reasons for indifference to PM2.5	1 (Didn't feel discomfort)	26	34.21
	2 (Easy access to information)	25	32.89
	3 (Issues such as Covid-19)	24	31.58
	4 (Other: Got used to it)	1	1.32
Total		76	100.00

Table 5-12 Response result of disease caused by PM2.5

Category	Content	Frequency	Percentage (%)
Disease caused by PM2.5	1 (Respiratory disease)	959	83.39
	2 (Cardiovascular disease)	98	8.52
	3 (Cerebrovascular disease)	71	6.17
	4 (High blood pressure)	3	0.26
	5 (Depression)	18	1.57
	6 (Other: Eye disease)	1	0.09
Total		1,150	100.00

2) Respondent's health status and level of health management

Before measuring WTP and VSL, respondents' current subjective/objective health status, another basis for value measurement, was checked. Respondents generally had an average level of health status but responded that their health status would deteriorate in the next ten years. In the case of diseases, the highest percentage of respondents said they were not diagnosed with a disease. However, the proportion of diseases related to high blood pressure (14.12%), respiratory (10.19%), and skin (9.64%) is high (Table 5-13).

Table 5-13 Respond results of health status and level of health management

variable		N	mean	sd	min	p50	max
Self-rated health	Self-rated health)	1150	3.157391	.7046484	1	3	5
Expected health after 10 years	Self-rated health after 10 years)	1150	2.796522	.7626999	1	3	5
Diagnosed disease	Liver disease (%)	1150	.0343769				
	Thyroid (%)	1150	.0478821				

	High blood pressure (%)	1150	.1411909
	Osteoarthritis (%)	1150	.0208717
	Stroke (%)	1150	.0073665
	Diabetes (%)	1150	.0478821
	Digestive disease (%)	1150	.0859423
	Renal failure (%)	1150	.0055249
	Myocardial infarction (%)	1150	.0085942
	Cancer (%)	1150	.0331492
	Dyslipidemia (%)	1150	.0546347
	Skin disease (%)	1150	.0963781
	Respiratory disease (%)	1150	.101903
	Other (%)	1150	.0079804
	None (%)	1150	.3063229

The respondents generally have moderate (3.6) health management through exercise (36.04%), health supplements (22.81%), and diet control (25.23%).

Table 5-14 Response Results for health management

Items		N	mean	sd	min	p50	max
Level of health management efforts	Level of health management	1150	3.592174	.7391393	1	4	5
Status of health management efforts	Status of health management efforts	1150	1.165217	.3715382	1	1	2
Health management method	Diet (%)	1150	.2523158				
	Exercise (%)	1150	.3603882				
	Smoke-free (%)	1150	.0613145				
	Alcohol-free (%)	1150	.094839				
	Supplement (%)	1150	.2280547				
	Other (%)	1150	.0030878				

Table 5-15 Response Result of Health management method

Category	**Content**	**Frequency**	**Percentage (%)**
Health management method (Q23: Multiple responses allowed)	Diet	572	25.23
	Exercise	817	36.04
	Smoke-free	139	6.13
	Alcohol-free	215	9.48
	Supplement	517	22.81
	Other	7	0.31
Total		1,629	100.00

5.4.3. Results of Willing to Pay

1) Process of the protest responses for WTP: Understanding of the protest responses for WTP

When conducting the CVM survey, respondents were asked why they were not willing to pay additionally. Responses indicating that they were unwilling to pay such as 'I already pay enough taxes', 'The government is already investing a lot of money in this field', and 'I am not given information to make a decision,' ‘Additional tax will not be used for the project', etc., are regarded as refuse to pay and are excluded from the CVM analysis. In this study, of the 284 respondents who refused to pay, 121 samples were classified as resisting payment. The statement of “I cannot afford to pay.” Or, “The health effects of PM2.5 are not my concern” were classified as payment resistance and excluded from the sample.

Among the total 1,150 respondents, 284 respondents, which is approximately 25% of the total, showed the protest responses for WTP for PM2.5 reduction policies and projects. Bias may occur if the price of willingness to pay is estimated by excluding samples of protest responses for WTP. Accordingly, this study classified rejection responses for WTP based on the protest responses for WTP classification criteria presented by Kim and Oh (2011) and excluded samples of protest responses for WTP. Of the 284 respondents who showed rejection responses for WTP, 121 samples were classified as protest responses for WTP. The survey was conducted by adding the following questions to understand the sample of protest responses for WTP. This study classified the questions “can't afford to pay" or "health effects caused by PM2.5 are not of my interest" as protest responses for WTP and excluded them from the sample (Table 5-16).

Table 5-16. Reasons for the absence of willingness to pay questions

Content	WTP	Freq.
Can't afford to pay financially (Solvency)	X	112
Health effects caused by PM2.5 are not of my interest. (No additional utility)	X	9
Can't understand due to the insufficient explanation and examples.	O	17
Don't know how much to pay. (Uncertainty)	O	35
Don't think the PM2.5 season management system will be effective. (Distrust)	O	34
The government is already spending a lot of money on PM2.5 management. (Fairness)	O	51
Other (Answers may vary)	O	26
Total	-	284

On the other hand, 199 respondents were willing to pay less than the offered price through the survey. Respondents with less amount than the first offered bid price were classified as protest responses for WTP and excluded from the analysis based on "the offered price is too high," which is one of the response criteria for protest responses for WTP presented by Kim and Oh (2011).

2) Result of the willingness to pay questions

This study analyzes a total of 830 questionnaire responses, excluding 320 samples classified as protest responses for WTP, to reduce the bias of estimating the amount of WTP. This study conducted a double bounded dichotomous choice questionnaire to estimate the amount of WTP. Moreover, this study divided each first offered amount into a total of 5 groups and distributed it to respondents in proportion to the population. Table 5-17 shows the ratio of YES or NO responses by the first offered bid price.

Table 5-17 Results of responses for willingness to pay questions

1st Bid (KRW)	Samples	Willing to pay(Q27)	
		Yes	No
10,000	228	134 (58.77%)	94 (41.23%)
15,000	228	133 (53.88%)	95 (41.67%)
30,000	229	133 (58.08%)	96 (41.92%)
45,000	235	141 (60.00%)	94 (40.00%)
60,000	230	126 (54.78%)	104 (45.22%)
Total	1,150	667	483

Respondents respond to the first offered bid price and respond to the next question based on the result of the first bid price. If they agree with the first bid price, it doubles in the next question. If they disagree, the price is halved. In Table 5-18, The ’Y’ and ‘N’ indicate the presence of a willingness to pay about the first bid price. The highest approval rate was shown in the KRW 45,000 group. In comparison, the lowest approval rate was shown in the KRW 60,000 group. The same tendency was shown in the second offered price. When the doubled amount of the first bid price was offered, the KRW 10,000 group showed the highest approval rate. In comparison, the KRW 45,000 group showed the lowest approval rate. The results of more opposed responses in the KRW 45,000 group than in the KRW 60,000 group require additional analysis. Taken together, the approval rate of WTP at KRW 45,000 is generally high, but the tendency to oppose WTP seems to increase as the price goes up. In general, the higher the first offered bid price is, the lower or no willingness to pay for the PM2.5 reduction. This indirectly indicates that this survey reflects the reasonable decision-making of the survey respondents.

Table 5-19 shows the results of respondents' responses to the first offered bid price that was first presented through the survey. In the case of this study, which adopted a double bounded dichotomous choice method, four combinations of responses were derived in the table below by asking for the willingness to pay twice in a row. When examining the distribution of the four responses combination, the lower sample size with 'Yes (y)' to the willingness to pay and the higher sample size with 'No (n)' were found when the higher first offered bid price was given. This indicates that the higher the offered price, the lower or non-willing to pay for the measure. Moreover, it indirectly shows that this survey reflects the reasonable decision-making of the survey respondents.

Table 5-18. Result of response by bid amount

1st Bid (KRW)	y-y	y-n	n-y	n-n	Total
10,000	60	58	11	44	173
15,000	73	45	6	42	166
30,000	46	49	16	53	164
45,000	81	2	27	60	170
60,000	28	47	26	56	157
Total	288	201	86	255	830

1) First (Yes)/(No): Yes/No Groups in First bid (Q27)
2) Second (Yes)/(No): Higher bid suggestion (Double: Q29) or Lower bid suggestion (Half: Q31)

On the other hand, the response distribution was examined by changing the survey data designed as a double bounded dichotomous choice (DBDC) into a single bounded dichotomous choice (SBDC) for ease of analysis. Considering only the willingness to pay for the first offered bid price when converting to SBDC, the higher the offered bid price, the lower the probability of willingness to pay.

Table 5-19 Results of WTP responses for 1st BID

1st Bid (KRW)	No	Yes	Total
10,000	55 (31.79%)	118 (68.21%)	173
15,000	48 (28.92%)	118 (71.08%)	166
30,000	69 (42.07%)	95 (57.93%)	164
45,000	87 (51.18%)	83 (48.82%)	170
60,000	82 (52.23%)	75 (47.77%)	157
Total	341	489	830

3) Analysis of the correlation between the willingness to pay and the socioeconomic characteristics of the respondent

This study analyzes the single-bound dichotomous choice (SBDC) and a double-bound dichotomous choice (DBDC) for estimating the WTP factors. The analysis results are shown in Table 5-20 below.

First, Model 1-1 in a single-bounded dichotomous choice model shows the WTP value of SBDC when there is no explanatory variable, while Model 1-2 shows a coefficient value when considering the explanatory variable. The control variables of the model are the Y/N response of WTP to the first offered bid price. The explanatory variables include Gender (gender), Age_grp, Seoul Metropolitan Area (SMA), average monthly income of all households (Hinc), number of PM2.5 access routes (Info_PM25), recognition of PM2.5 seasonal management (Pol_PM25), Med_exp, diagnosed disease (DHeed), and health care amount.

Table 5-20 Detailed description of Socio-economic variable

Category		Description
Socio-economic variable	Gender	Gender of respondents (Male=0, Female=1)
	Age_grp	Age of respondents (20~29=1, 30~39=2, 40~49=3, 50~59=4, above 60=5)
	SMA	Residing area of respondents (Non-metropolitan area=0, Metropolitan area=1)
	Total monthly average income of households (HHinc)	① Less than KRW 1 million ② Less than KRW 1-2 million ③ Less than KRW 2-3 million ④ Less than KRW 3-4 million ⑤ Less than KRW 4-5 million ⑥ Less than KRW 5-6 million ⑦ Less than KRW 6-7 million ⑧ More than KRW 7 million
	Number of PM2.5 information access route (Info_PM25)	① Number of PM2.5 Information access route: 1 ② Number of PM2.5 Information access route: 2 ③ Number of PM2.5 Information access route: 3

	Level of awareness of PM2.5 high concentration season management system (Pol_PM25)	① I don’t know at all ② I don’t know (have heard of it) ③ Neutral (know the concept) ④ I know (know concepts and key initiatives) ⑤ I know very well
	Having a family member or relative with experience in the medial health profession (Med_exp)	① Yes, ② No
	Diagnosed disease (Reldis_ord)	① Not diagnosed with any disease ② Diagnosed with disease ③ Diagnosed with brain disease ④ Diagnosed with myocardial infarction and angina pectoris ⑤ Diagnosed with respiratory disease
	Status of health management (Phlth_eff)	① Yes, ② No

As a result of the analysis, five of the nine explanatory variables secured statistical significance, and the null hypothesis that the regression coefficient of all explanatory variables was 0 at the 1% significance level in the likelihood ratio test (LRchi2) was rejected, judging that the estimated result was significant. Pol_PM25 (level of awareness of PM2.5 season management system) and the offered bid price (bid) showed significant results at a significant level of 1%, and age (Age_grp), number of PM2.5 access routes (Info_PM25), and degree of health care effort (Phlth_eff) showed significant results at a significant level of 10%. On the other hand, gender (Gender), metropolitan area (SMA), average monthly income of the entire household (HHinc), Med_exp, and diagnosed disease (Reldis_ord) did not secure statistical significance. In the case of the bid variable, which refers to the offered bid price, the regression coefficient was analyzed to have a negative (-) value, which means that the higher the presented amount, the lower the respondent's probability of willingness to pay, indicating that the results of this survey reflect the survey respondents' reasonable decision.

Table 5-21. Result of single bound dichotomous choice (SBDC)

Variable	Model 1-1				Model 1-2			
	Coefficient		S.E.	P	Coefficient		S.E.	p
Constant	0.6371	***	0.0892	0	-0.5606	**	0.2569	0.029
Gender					-0.0075		0.0911	0.935
Age_grp					0.0595	*	0.0333	0.074
SMA					-0.0501		0.0943	0.595
HHinc					0.0263		0.0227	0.248
Info_PM25					0.1069	*	0.0591	0.07
Pol_PM25					0.1646	***	0.0498	0.001
Med_exp					0.0851		0.1024	0.406
Reldis_ord					0.0178		0.0333	0.593
Phlth_eff					0.2472	*	0.1403	0.078
Bid	-0.1285	***	0.024	0	-0.1359	***	0.0244	0
N	830				830			
LL	-547.5862				-530.2355			
LR chi2	28.92 ***				63.62 ***			
Pseudo R2	0.0257				0.0566			

Annotation: *, **, *** indicates a statistically significant p-value ($p<0.1$, $p<0.05$, $p<0.01$)

Analyzing the significant variables, it was found that the higher the age group, the higher the willingness to pay. Moreover, the higher the number of PM2.5 access routes, the higher the willingness to pay. The higher number of PM2.5 access routes can be understood as a high level of interest in PM2.5 concentration, which can be accepted as reflecting reasonable decision-making by survey respondents. Furthermore, it was confirmed that the more aware the concept of the PM2.5 seasonal management system is, the higher the willingness to pay.

Next, in the double-bounded dichotomous choice model, the control variable is expressed based on the Y/N of willingness to pay the first and second offered bid price. Model 2-1 did not set the bid variable as an explanatory variable based on the study of Lopez-Feldman, A. (2012). The control variable was constructed using the results of the willingness to pay for each offered bid price from the first and second offered bid prices. Model 2-2 is a model considering the explanatory variable, and the model's fitness can be determined through the Wald chi2 test. As a result of the test, the null hypothesis that all explanatory variables have a regression coefficient of 0 is rejected at the 1% significance level, indicating that the estimated result of the second model is also significant.

The explanatory variables were the same as the SBDC model presented earlier, and as a result of the analysis, three of the nine explanatory variables secured statistical significance. The degree of awareness of the PM2.5 season management system (Pol_PM25) showed significant results at the significance level of 1%. In comparison, the average monthly income of the entire household (HHinc) showed significant results at the significance level of 5%. In addition, Info_PM25 (number of PM2.5 access routes) showed significant results at a significance level of 10%. On the other hand, in the DBDC model considering explanatory variables, gender (Gender), age (Age_grp), metropolitan area (SMA), medical health worker (Med_exp), disease diagnosis (Reldis_ord), and level of health management effort (Phlth_eff) did not secure significance.

Analyzing the significant variables, it was found that the higher the average monthly income of the entire household, the higher the willingness to pay. In addition, the higher the number of PM2.5 access routes and the better the concept of the PM2.5 seasonal management system, the higher the willingness to pay was found in SBDC.

Table 5-22. Result of double bound dichotomous choice (DBDC)

Variable	Model 2-1				Model 2-2			
	Coefficient		S.E.	P	Coefficient		S.E.	p
Constant	4.1700	***	0.2510	0	-2.9022	**	1.3763	0.035
Gender					0.3434		0.4969	0.49
Age_grp					0.0383		0.1818	0.833
SMA					-0.5720		0.513	0.265
HHinc					0.2728	**	0.1252	0.029
Info_PM25					0.6184	*	0.3204	0.054
Pol_PM25					1.1070	***	0.2753	0
Med_exp					0.6771		0.5581	0.225
Reldis_ord					0.2087		0.183	0.254
Phlth_eff					1.0500		0.783	0.18
N	830				830			
LL	-1178.799				-1156.9029			
Wald chi2	.				41.45 ***			

Annotation: *, **, *** indicates a statistically significant p-value (p<0.1, p<0.05, p<0.01)

Table 5-23 compares the SBDC and DBDC models when the explanatory variables are considered. Log likelihood (LL) statistics are the sum of the predicted values and the probabilities of actual observations. The larger the value, the more unexplained observations exist. Furthermore, the suitability of the model was determined based on Log Likelihood (LL).

Some studies have analyzed the internal consistency problem of double bounded dichotomous choice questions with a single bounded dichotomous choice questions model. However, most of them were conducted without a description of the statistical verification procedure. This study selected a model based on the LL value. The LL value of SBDC is -530.2355, and the LL value of DBDC is -

1156.9029.

This study estimated the economic value of the reduction in death probability due to PM2.5 based on the measured values of the DBDC model. The average amount of willingness to pay per household estimated in the DBDC model with no control variables was KRW 41,700 per year (Table 5-24). Further, the DBDC model with control variables was KRW 41,643 per year. Therefore, there was no significant difference between the two models. The economic value of the PM2.5 reduction measures estimated by multiplying the DBDC model with control variables by the total number of Korean households (16,375,327) in the 2021 census is about KRW 681.9 billion (KRW 681,900,000,000) per year. According to the Department of Environment’s office for Planning and Finance (2022), the government's budget for PM2.5 management in Korea amounts to about KRW 18 trillion annually from 2021 to 2025. In addition, the economic value of the additional amount that can be paid to reduce PM2.5 accounts for 24.84 percent of the government's annual budget.

Table 5-23. Model Comparison of SBDC and DBDC

Variable	**Model 1-2**				**Model 2-2**			
	Coefficient		**S.E.**	**P**	**Coefficient**		**S.E.**	**p**
Constant	-0.5606	**	0.2569	0.029	-2.9022	**	1.3763	0.035
Gender	-0.0075		0.0911	0.935	0.3434		0.4969	0.49
Age_grp	0.0595	*	0.0333	0.074	0.0383		0.1818	0.833
SMA	-0.0501		0.0943	0.595	-0.5720		0.513	0.265
HHinc	0.0263		0.0227	0.248	0.2728	**	0.1252	0.029
Info_PM25	0.1069	*	0.0591	0.07	0.6184	*	0.3204	0.054
Pol_PM25	0.1646	***	0.0498	0.001	1.1070	***	0.2753	0
Med_exp	0.0851		0.1024	0.406	0.6771		0.5581	0.225
Reldis_ord	0.0178		0.0333	0.593	0.2087		0.183	0.254
Phlth_eff	0.2472	*	0.1403	0.078	1.0500		0.783	0.18
Bid	-0.1359	***	0.0244	0				
N	830				830			
LL	-530.2355				-1156.9029			

LR chi2	63.62 ***	-
Wald chi2	-	41.45 ***
Pseudo R2	0.0566	-

Annotation: *, **, *** indicates a statistically significant p-value (p<0.1, p<0.05, p<0.01)

In the SBDC and DBDC analysis results, it is possible to compare variables that have secured statistical significance (Table 5-23), and this study estimated WTP for each DBDC group.

According to the results of the double bound dichotomous choice model including covariates, the average willingness to pay is KRW 41,643 (KRW 3,470 per month) per year, and the average willingness to pay is KRW 22,397 (KRW 1,866 per month) per year excluding respondents with resistance to pay.

Table 3-24. Amount of WTP based on the double bounded dichotomous choice

Model	Mean WTP (Excluding Protest Responses)	Mean WTP (Including Protest Responses)
with no control variables	41,700 KRW/year	22,973KRW/year
with control variables	41,643 KRW/year	22,397KRW/year

As a result of estimating the additional amount of willingness to pay through the values measured in the model, the average monthly household income was derived, as shown in Table 5-25. Households with an average monthly household income of less than KRW 4 million are willing to pay an additional WTP of about KRW 30,000 to KRW 37,000 annually, and households with an average monthly household income of more than KRW 4 million are willing to pay an additional WTP of about KRW 40,000 to KRW 48,000. The higher the average monthly household income, the more additional WTP was paid to reduce PM2.5. Furthermore, the point where the difference value changed from negative (-) to positive (+) in Mean WTP was ‘KRW 5 million to 6 million’.

Table 5-25. WTP based on the average monthly household income

Group	Mean WTP	Difference
Overall	41,643	-
① Less than KRW 1-2 million	29,440	-12,203
② Less than KRW 1-2 million	32,169	-9,474
③ Less than KRW 2-3 million	34,897	-6,746
④ Less than KRW 3-4 million	37,626	-4,017
⑤ Less than KRW 4-5 million	40,354	-1,289
⑥ Less than KRW 5-6 million	43,082	1,439
⑦ Less than KRW 6-7 million	45,811	4,168
⑧ More than KRW 7 million	48,539	6,896

As the number of PM2.5 information access routes such as TV, mobile, Internet, paper newspaper, radio, and friends increased, WTP also increased. The WTP of respondents with one PM2.5 information access route was KRW 34,288, the WTP of respondents with two PM2.5 information access routes was KRW 40,473, and the WTP of respondents with more than three PM2.5 information access routes was KRW 46,657.

Table 5-26. WTP according to the number of PM2.5 information access routes

Group	Mean WTP	Difference
Overall	41,643	-
1 source	34,288	-7,355
2 sources	40,473	-1,170
3 and more sources	46,657	5,014

In addition, the respondent who responded, 'I don't know at all' about the PM2.5 high concentration seasonal management system suggested a WTP of 23,316 won, and the respondent who responded, 'I know' suggested a WTP of KRW 56,528. Respondents who said 'I know very well' suggested a WTP of KRW 67,598, indicating that the higher the interest in the policy, the higher the WTP.

Table 5-27. WTP according to the level of awareness of high concentration seasonal management system

Group	Mean WTP	Difference
Overall	41,643	-
I don’t know at all	23,316	-18,327
I don’t know	34,387	-7,256
Neutral	45,457	3,814
I know	56,528	14,885
I know very well	67,598	25,955

5.4.4. Results of Value of Statistical Life (VSL)

1) Estimation of value of statistical life (VSL)

Researchers at George Washington University and the University of British Columbia in Canada estimated that 1.8 million people die early worldwide due to ultrafine dust in 2019 (Southerland et al., 2022). As of 2019, about 60 out of every 100,000 people have the potential of excess deaths due to PM2.5, meaning that the reduction in the risk of premature death is 60 per 100,000.

$$\text{VSL} = \frac{WTP}{\frac{60}{100{,}000}} \qquad (2)$$

The probability of death due to PM2.5 before policy improvement is 60/100,000 per year, and the expected probability of death after policy improvement is 50/100,000 per year.

2) Calculation of willingness to pay (WTP) and value of statistical life for reduction in the risk of premature death (ΔP)

This study conducted a survey to derive the willingness to pay for the reduction in the risk of premature death due to PM2.5. Respondents suggested an additional amount that they are willing to pay annually for 10 years to reduce the possibility of excess death due to PM2.5. The average amount of willingness to pay for the survey respondents is KRW 41,64. The sample size used for the value of statistical life estimation is 830, excluding 320 samples classified as protest zero.

$$\mathrm{VSL} = \frac{\frac{41{,}643}{10}}{10{,}0000} \qquad (3)$$

If the value of statistical life value ($\frac{WTP}{\triangle P}$) is calculated using the reduction in the risk of premature death (ΔP) calculated in this study and the willingness to pay (WTP) calculated through the survey, it is derived as KRW 4.16430 billion.

$$\mathrm{VSL} = \frac{41{,}643\mathrm{KRW}}{\frac{10}{100000}} = 416{,}430{,}000\mathrm{KRW} \quad (4)$$

Table 5-28 shows the WTP and VSL values considering the payment deadline (10 years).

Table 5-28 Result of Annual WTP and VSL

Estimation(KRW)	Annual WTP	Total WTP considering payment term (10 years)	VSL
Excluding Protest Responses	41,643	416,430 (=41,643*10)	4,164,300,000
Including Protest Responses	22,397	223,970 (=22,397*10)	2,239,700,000

5.5. Conclusion and Discussion

This study derives the respondents' willingness to pay (WTP) for a policy scenario that reduces the possibility of death due to air pollution by 0.0001 using the contingent valuation methods. According to the results of the double-bound dichotomous choice model, including covariates, the average willingness to pay is KRW 41,643 (KRW 3,470 per month) per year, which is similar to the value estimated in the relatively recent studies by Kim et al. (2019) and Kwon and Seo (2010). Meanwhile, if respondents who refused to pay were included, the average willingness to pay is KRW 22,397 (KRW 1,866 per month) per year, excluding respondents with resistance to pay.

The economic value of the PM2.5 mortality reduction of 1/10,000 is about KRW 894.0 billion (KRW 894,000,907,100) per year. According to the Department of Environment's Office for Planning and Finance (2022), the government's budget for PM2.5 management in Korea amounts to about KRW 18 trillion annually from 2021 to 2025. In addition, the economic value of the additional amount that can be paid to reduce PM2.5 accounts for 24.84 percent of the government's annual budget. Finally, the value of statistical life value is calculated as KRW 0.4164 billion, and the value of statistical life derived by applying the ten years payment period was estimated to be about KRW 4.1643 billion. The result of this study can be used as fundamental data to quantify citizenship to reduce PM2.5 damage and prepare policies. Further, it can be used as a scientific basis for establishing PM2.5 management measures for each local government and region in Korea.

On the other hand, Hwang et al. (2018) suggested that the average annual willingness to pay for PM2.5 concentration improvement in Seoul was KRW

138,107. They also suggested that an average annual health impact improvement benefit of about KRW 413.9 billion would be made when PM2.5 concentration is improved by 2025 by 10 ppm. There may be differences in willingness to pay due to the improvement of PM2.5 in each region, and it is necessary to investigate the cause of such differences in the future.

Based on the 2021 census in Korea, the total number of households (20-64 years old) was 16,375,327, followed by single-person households (5,287,302), two-person households (3,852,414), three-person households (3,478,897), four-person households (2,962,151), five-person households (658,854), and six-person households (110,291) in order. Therefore, this study may have limitations in securing representation because the results of the characteristics of the number of household members in the survey sample have errors compared to the population and housing census. Therefore, for the results of CVM research to be validated and used in the policy, additional research must be continuously conducted by supplementing these limitations. Therefore, it is necessary to more accurately identify the position or level of the WTP value derived from this study in the WTP value presented in CVM studies conducted domestically and internationally by conducting a comparative study focusing on PM2.5 studies using the contingent valuation Method in the future.

Furthermore, it can help identify socioeconomic factors that affect WTP, which conducted meta-analysis research focusing on PM2.5 research applying the contingent valuation Method. The analysis results on the social welfare effects followed by policy improvement derived in this study can be used as cost-benefit analysis data for PM2.5 policies or technologies.

Chapter 6. Conclusions

6.1. Summary of Findings and Implications

Among the factors that generate PM2.5, PM2.5 from roads in the transportation sector is a pollutant that can easily be exposed to citizens and cause health risks. It enters the lungs through breathing and negatively affects human diseases and deaths. Although it is relatively difficult to secure data on mobile pollutant sources by city, county, and district compared to point pollutant sources, it is crucial to provide evidence or validity for policy alternatives by conducting an empirical analysis of PM2.5 research focusing on diesel vehicles. This study aims to determine whether the PM2.5 generation from diesel vehicles in the transportation sector affects the mortality rate of diseases and to identify the social welfare effects of PM policy improvement by reviewing policy implementation directions to reduce PM2.5.

In the Chapter2, this study aims to analyze the effect of PM2.5 emissions from diesel vehicles on the mortality rate from local respiratory and other cardiovascular disease, and to investigate the relationship that affects them. This study applies a special panel model that considers spatial adjacency between regions by utilizing the metropolitan area's borough, city, and district data from 2015 to 2019. The main results of this study are as follows.

First, it was confirmed that PM2.5 emissions from diesel vehicles had a positive (+) effect on the mortality rate due to the respiratory system. However, in the mortality rate from other cardiovascular disease, PM2.5 emissions from diesel vehicles did not significantly affect the mortality rate. Second, SO2 was found to have an interregional effect on the mortality rate from other cardiovascular disease. SO_2 is a secondary product of PM2.5 and a major pollutant generated by diesel cars, and SO_2 generated in the area affects the mortality rate from other cardiovascular disease in the nearby area, and SO_2 in the nearby area also affects the dependent variables in the area. Third, as a result of examining the difference between the non-metropolitan area and the metropolitan area, it was found that the non-metropolitan area is relatively more affected by the mortality rate from the respiratory system than the metropolitan area when the PM2.5 emission of diesel vehicles increases. This is thought to be attributable to the difference in infrastructure between non-metropolitan and metropolitan areas, and since various factors can affect mortality rate due to the respiratory system, it is necessary to examine regional differences in the future by considering medical and environmental infrastructure.

This study examines the difference between the spatial correlation of the econometric model for PM2.5 emissions from diesel vehicles on the mortality rate from local respiratory and other cardiovascular disease. The differentiation and significance of this study are as follows. First, the possibility of underestimating or overestimating the estimated value was prevented by considering spatial autocorrelation. In addition, the Inverse Distance Weighting (IDW) method, which is suitable for continuous data and can be applied when the closer the distance between regions is, the more likely it is to interact or affect each other, was selected. Furthermore, the IDW method was found to be appropriate for analyzing the effects of PM2.5 emissions from diesel vehicles on the mortality rate from local respiratory and other cardiovascular disease.

Second, this study calculated PM2.5 emissions of diesel vehicles using the National Clean Air Policy Support System (CAPSS) method of calculating air pollutant emissions from mobile road sources and used them as the main variable of the model. The study results showed that the variable of PM2.5 emissions of diesel vehicles had a significant effect on the mortality rate from the respiratory tract. Third, it was found that the higher the temperature and humidity, the more impact it has on the mortality rate of local respiratory and other cardiovascular disease. Furthermore, in the case of SO2, only the mortality rate of other cardiovascular disease was found to have a significant positive effect.

This study suggests that the SO2 generated in the area affects other cardiovascular disease mortality rate of the nearby area, and SO2 in the neighboring area also affects the dependent variable. This was not found in the general econometric model that did not consider spatial correlation. It was confirmed that the characteristics became clear when constructing the spatial weight matrix through the IDW method. Fourth, to consider meteorological factors in China, monthly average data of temperature, relative humidity, and precipitation levels in Shandong, Hebei, and Jiangsu Provinces in China were considered. Consideration of foreign variables is important in PM2.5-related studies, and studies between neighboring countries also need to be conducted in the future. Fifth, it was found that the respiratory mortality rate in non-metropolitan areas was relatively more affected by PM2.5 emissions from diesel vehicles than in metropolitan areas. The need for additional research on the reason for regional differences has been raised. Suppose further research confirms that the non-metropolitan area is relatively more affected by the PM2.5 emissions of diesel cars. In that case, short-term measures to install PM2.5 shelters in the non-metropolitan area will be needed to protect citizens' health from PM2.5.

In the Chapter 3, this study empirically analyzes the effect of PM2.5 emissions of diesel vehicles by vehicle type (passage, vanishing, cargo) and size (small, medium, and large) on PM2.5 concentrations in Korea, and identifies whether there are differences in results depending on large and small cities. The analysis results are as follows. First, the amount of PM2.5 generated by diesel cars, vans, and trucks all had a significant effect on the concentration of fine dust in Korea, of which trucks had the greatest impact. Second, it was found that the amount of PM2.5 generated by small cargo trucks (0.072) among cargo trucks had the greatest influence on the dependent variable. This result is believed to be due to the fact that small trucks are the mostly older than 10 years compared to medium and large trucks. In particular, small trucks for business use have a higher mileage than cars due to the large number of delivery and delivery vehicles (Kyujin Lee, 2018). Third, PM2.5 generation of large passenger vehicles, small van, and medium-sized cargo trucks in large cities was found to have a greater impact on the concentration of PM2.5 in Korea than in small and medium-sized cities. This is seen as a result of the fact that large cities, including the metropolitan area, often cause traffic jams due to dense populations, and reflects the reality that high-concentration fine dust occurs around the metropolitan area (Seonyong Sung et al., 2020; Jingyu Jeong and Jangik Jin, 2021).

The implications of the research results are as follows. First, as PM2.5 generation of trucks among diesel vehicles has a greater impact on the concentration of PM2.5 in Korea, it is considered necessary to improve and implement the system centered on trucks in diesel vehicle measures such as early disposal and low-pollution vehicle operation. In particular, it is necessary to expand the supply of fuel vehicles that can replace diesel vehicles in the short-term in the truck market, and to combine strategies to supply PM2.5-free trucks in the mid-to-long-term (Hhan, 2020). Second, considering the size of each car type, PM2.5 generation of small trucks has a greater influence on Korea's PM2.5 concentration, so detailed measures should be prepared according to the type and size of PM2.5 measures, especially for small trucks with many old vehicles. Third, the PM2.5 generation of large passenger vehicles, small vans, and small trucks has a greater influence on Korea's PM2.5 in large cities, proving the importance of regional customized PM2.5 reduction measures, and it is urgent for the government to prepare and evaluate PM2.5 management measures for each local government. This study has its significance in that it derived and analyzed representative variables by sector through previous studies and examined Korea's policy directions. In particular, it can be emphasized that PM2.5 generation of diesel cars on PM2.5 in Korea by subdividing into vehicle types (passage, van, cargo) and size (small, medium, and large).

In the Chapter 4, the objective of this study is to address current PM policy in Korea and classify the specialists' (government officials and researchers) opinions with respect to the policies and management direction related to PM policy for diesel fuels and vehicles. Specialists in Korea are highly involved in promoting government policies, so it is valuable to gather their opinions and comments about diesel fuel policy direction and management. This study employed Q-methodology and a system thinking approach to analyze the specialists' subjectivity and their causal relationship to PM policy. These methods are helpful in categorizing the specialists' interests and understanding the differences among their positions. A series of interviews with specialists from various government institutions was conducted for the analysis. The results show that there is dysfunction in the ministries, an absence of effective systems to convey relevant information, and uncertainty regarding citizen participation. Therefore, a better understanding of the roles and functions of ministries needs to be considered and redefined.

Based on the empirical analysis results of this thesis, the following policy approach can be suggested. Regarding the analysis results of domestic factors, it is necessary to continuously improve the policy responses of each government department related to diesel automobiles and manufacturing production. In addition, clearer discussions between ministries and cooperation to promote coexistence are required. For example, it is essential to conduct a sophisticated analysis of how effectively projects such as scrapping old diesel cars will reduce PM2.5. It is also necessary to discuss how many old diesel cars should be scrapped to maximize the effect of reducing the concentration of PM2.5 at the minimum scrapping cost. This discussion can also be applied to the high-concentration PM2.5 emergency reduction measures specified in the PM2.5 Act. Furthermore, an in-depth discussion is required on the level to which the measures to reduce PM2.5 at workplaces must be taken at a time when both economic feasibility and PM2.5 reduction are considered. In addition, as shown in the analysis results related to the model considering the spatial lag effect of the dependent variable, the indirect effect was generally larger than the direct effect, suggesting that research between local governments or countries effectively reduces PM2.5.

In the Chapter 5, the study derives the respondents' willingness to pay (WTP) for a policy scenario that reduces the possibility of death due to air pollution by 0.0001 using the contingent valuation methods. The willingness to pay (WTP) that reduces the possibility of death due to PM2.5 by 0.0001 is KRW 41,643 per year. The value of statistical life value is calculated as KRW 0.4164 billion, and the value of statistical life derived by applying the 10 years payment period was estimated to be about KRW 4.1643 billion. There may be differences in the amount of willingness to pay for PM2.5 in the future, and it is necessary to investigate the cause of such differences.

In this chapter, the derived statistical life value (VSL) is compared with the results of existing domestic and international conditional valuation studies to observe changes in people's utility for reducing early mortality rates of fine dust. If the location of utility for reducing early mortality rates due to fine dust is observed through domestic and foreign research comparisons, it is expected to be used as basic data for justification for domestic fine dust countermeasures and health protection.

6.2. Limitations of the Studies and Future Research

This study is significant in that it calculates the data of PM2.5 on city, country, and district scale from the transportation sector, which is highly harmful in terms of public health, and analyzes health effects and social welfare effects of policy improvement by applying various empirical analysis methods to provide a basis for future PM2.5 reduction policies. However, this paper has several limitations, and it should be supplemented through continuous research in the future. First, in the Spatial Durbin Model analysis, the mortality rate of respiratory diseases in the region decreased as the temperature increased. In contrast, the mortality rate of respiratory diseases in the region increased as the temperature in the neighboring region increased, indicating inconsistency. This is believed to be a limitation of being unable to closely examine monthly data by applying annual data. It is necessary to investigate the cause through further research accurately. In addition, some parts of the results table could be clearer to explain logically, which may be a matter of data reliability or may mean additional variables should be considered. Therefore, further analysis is needed in the future by securing data on not only prevalence but also mortality variables. Second, there is a limit to the timeliness of policy issues. Chapter 3 deals with specific issues on the difference in PM2.5 emissions according to the scale and size of diesel vehicles. Chapter 4 discusses overall issues related to diesel vehicles, such as issues related to policy implementation conflicts between ministries and issues related to fuel taxes on trucks. Moreover, chapter 4 presents factors that hinder policy implementation. However, the purchase and usage rates of diesel vehicles, which had been steadily increasing before the COVID-19 pandemic, fell sharply. On the other hand, the demand for electric vehicles increased rapidly, naturally reaching the middle ground on existing policy issues, and some improvements have been made. The implications presented in this paper suggest a policy plan to supplement the government's countermeasures against PM2.5 reduction. In future studies, it is expected that research will be conducted to prepare alternatives to overcome PM2.5 management policies by local governments, considering new issues regarding electric and hydrogen vehicles. Third, Chapter 5 focuses on PM2.5 research using the Contingent Valuation Method to accurately identify the location or level of the WTP value of the study derived from the WTP value presented in the CVM study conducted domestically and internationally. Furthermore, the socioeconomic factors affecting WTP can be understood through comparative or meta-regression studies, and the value of statistical life is derived by using the Contingent Valuation Method. It is also expected that the results derived from this study can be used as main data for cost-benefit analysis of PM2.5 policy or technology.

Bibliography

Ann, S. E., Bae, H. J., Kwok, S. Y., Yim, Y. H., Kim, M. H., & Oh, S. Y. (2016) Assessment of Human Health Effects of Air-Pollution Using Cohort DB and Estimation of Associated Economic Costs in Korea (II). Korea Environment Institution. Project Report, 2016, 1-165.

Ann, S. J. (2014). Impact of particulate matter on health. Journal of the Korean Medical Association, 57(9), 763-768.

Anselin, L. (1988). Spatial Econometrics: Methods and Models. Springer, Dordrecht.

Anselin, L. (2005). Exploring spatial data with GeoDaTM: a workbook. Center for spatially integrated social science, 165-223.

Anselin, L., Le Gallo, J., & Jayet, H. (2008). Spatial panel econometrics. In The econometrics of panel data (pp. 625-660). Springer, Berlin, Heidelberg.

Atkinson, R. W., Analitis, A., Samoli, E., Fuller, G. W., Green, D. C., Mudway, I. S., ... & Kelly, F. J. (2016). Short-term exposure to traffic-related air pollution and daily mortality in London, UK. Journal of exposure science & environmental epidemiology, 26(2), 125-132.

Bae, H. J. (2016) The Health Impacts and Benefits of Cardiovascular and Respiratory Hospitalization Attributed to PM2.5. Korean Association of Applied Economics 18(3): 125-139.

Baek, P.G., & Lee, H.S. (2011) The meaning of ‘Subjectivity' researches in HRD: Focusing on Q methodology. The Adult and Continuing Education of Korea 14(1): 1-37. (in Korean)

Bayat, R., Ashrafi, K., Motlagh, M. S., Hassanvand, M. S., Daroudi, R., Fink, G., & Künzli, N. (2019). Health impact and related cost of ambient air pollution in Tehran. Environmental research, 176, 108547.

Brown, S.R. (1980) Political subjectivity: applications of methodology in political science. New Haven and London: Yale University Press.

Brown, S.R. (1993) A primer on Q methodology. Operant Subjectivity, 16, 91-138.

Brugge, D., Durant, J. L., & Rioux, C. (2007). Near-highway pollutants in motor vehicle exhaust: a review of epidemiologic evidence of cardiac and pulmonary health risks. Environmental health, 6(1), 1-12.

Cai, J., Yu, S., Pei, Y., Peng, C., Liao, Y., Liu, N., ... & Cheng, J. (2018). Association between airborne fine particulate matter and residents’ cardiovascular diseases, ischemic heart disease and cerebral vascular disease mortality in areas with lighter air pollution in China. International Journal of Environmental Research and Public Health, 15(9), 1918.

Cameron T. A., & James, M. D. (1987) Efficient Estimation Methods for Closed-Ended Contingent Valuation Surveys. The Review of Economics and Statics, 1987, pp. 269-276.

Cardoso, D., Painho, M., & Roquette, R. (2019). A geographically weighted regression approach to investigate air pollution effect on lung cancer: A case study in Portugal. Geospatial Health, 14(1).

Chen, Q., Chen, Q., Wang, Q., Xu, R., Liu, T., Liu, Y., ... & Sun, H. (2022). Particulate matter and ozone might trigger deaths from chronic ischemic heart disease. Ecotoxicology and Environmental Safety, 242, 113931.

Cho, J.H., Cha, E.J., & Kim, Y.J. (2018) The effect on the participatory action of leisure activity participants cognition on fine dust problem. Journal of Leisure Studies 16(3):1-19. (in Korean)

Cho, Y. S. (2003) Estimating the Economic Benefits of Air Quality Improvements on Mortality. Environmental Policy. 11(1):29-53.

Chung, C.K., & Lee, D.H. (2012). Exploratory study on causality of expansion strategy into emerging market: Systems thinking approach. Korean System Dynamics Review 13(3): 67-98. (in Korean)

Ciabattini, M., Rizzello, E., Lucaroni, F., Palombi, L., & Boffetta, P. (2020). Systematic review and meta-analysis of recent high-quality studies on exposure to particulate matter and risk of lung cancer. Environmental Research, 110440.

Dasgupta S., Laplante B., Wang H., & Wheeler D. (2002). Confronting the Environmental Kuznets Curve. The Journal of Economic Perspectives, 16(1): 147~168.

Dong, K. Y. & Zeng, X. G. (2018) Public willingness to pay for urban smog mitigation and its determinants: A case study in Beijing, China. Atmospheric Environment. 173: 355-363.

Du, Y., Xu, X., Chu, M., Guo, Y., & Wang, J. (2016). Air particulate matter and cardiovascular disease: the epidemiological, biomedical and clinical evidence. Journal of thoracic disease, 8(1), E8.

Elhorst, J. P. (2014). Spatial panel data models. In Spatial econometrics (pp. 37-93). Springer, Berlin, Heidelberg.

Elhorst, J.P., Vega, S.H. (2013). On spatial econometric models, spillover effects, and W. 53rd Congress of the European Regional Science Association: "Regional Integration: Europe, the Mediterranean and the World Economy", 27-31 August

2013, Palermo, Italy. European Regional Science Association, Louvain-la-Neuve.

Environmental Valuation System (EVIS) homepage. (http://evis.kei.re.kr/)

Eom, Y. S., Kim, J. O., & Ahn, S. E. (2019). Measuring willingness to pay for PM 10 risk reductions: evidence from averting expenditures for anti-PM 10 masks and air purifiers. Environmental and resource economics review, 28(3), 355-383.

EPA Homepage (https://www.epa.gov/).

Freeman, R, Liang, W. Q., Song, R. & Timmins, C. (2019) Willingness to pay for clean air in China. Journal of Environmental Economics and Management. 94: 188-216.

Gany F, Bari S, Prasad L, Leng J, Lee T,Thurston GD, Gordon T, Acharya S, & Zelikoff JT (2017) Perception and reality of particulate matter exposure in New York City taxi drivers. J Expo Sci Environ Epidemiol 27(2): 221–226. http://doi:10.1038/jes.2016.23.

Gil, B.O., & Kim, C.N. (2010) Q methodology's theory and application: North Korean defectors' self reverential subjectivity and the direction for homogeneity's recovery between South and North. The Korea Association for Policy Analysis and Evaluation (2): 101-129. (in Korean)

Gross, A.G. (1994) The roles of rhetoric in the public understanding of science. Public understanding of science 3(1):3-23.

Gu, Yu & Jun, Myung Jin (2021). The Effects of Particulate Matter (PM) Exposure on Death from Lung Disease using Spatial Panel Data Models. Journal of the Korean Regional Dvelopment Association, 33(4), 137-153

Hahn J. S. (2020a). Plan for an Alternative to the Use of Diesel Fuel by Trucks to Reduce Pollutants in the Transportation Sector. Journal of Environmental Policy, 28(1): 101-117.

Hahn J. S. (2020b). Study of the Analysis on the Emission Factors of Diesel Trucks. Journal of Environmental Policy, 28(3): 1-18.

Hahn J. S. (2020c). Solution to Improve the Gas Tax Subsidy to Reduce Pollution from Freight Trucks. Journal of Environmental Policy, 28(6): 1-20.

Hahn J. S. (2021). A Study of the Travel Factors of Truck for the Low Emission Zone. Journal of the Korea Academia-Industrial cooperation Society, 22(6): 492-498.

Hahn J. S., Lee S. M., Jeong Y. M., Park M. C., & Kim S. H. (2019). Research on the Reduction of PM and GHG from Ground Freight Transportation. Korea Environment Institute.

Hao Y., & Liu Y. M. (2016). The influential factors of urban PM2.5 concentrations in

China: a spatial econometric analysis. Journal of Cleaner production, 112, 1443-1453.
Hosseinabad, E.R., & Moraga, R. (2017) A System Dynamics Approach in Air Pollution Mitigation of Metropolitan Areas with Sustainable Development Perspective: A Case Study of Mexico City. Journal of Applied Environmental and Biological Sciences 7(12): 164-174.
Hwang I. C. (2019). Particulate Matter Management Policy of Seoul: Achievements and Limitations. The Korea Association for Policy Studies, 2018(27), 27-60.
Hwang, I. C., & Son, W. I. (2020) Socioeconomic benefits of PM2.5 management policy in Seoul: An application of contingent valuation. JIET. 4(1):107-134.
Interagency coordination. (2017). Comprehensive Plan on Fine Dust Management. Available at: https://www.motie.go.kr.
Interagency coordination. (2019). Comprehensive Plan on Fine Dust Management. Available at: https://www.motie.go.kr.
IQAir. (2021). 2021 World Air Quality Report: Region & City PM2.5 Ranking. IQAir Press.
Jang, I. S., Ann, H. S., & Kim H. S. (2018). Technical Efficiency of Medical Resource Supply and Demand, 34(2), 3-19.
Jin J. K., & Jin J. I. (2021). A Study on the Effect of Traffic Congestion on Particulate Matter Concentration in Seoul : Big Data Approach. Journal of Korea Planning Association, 56(1), 121-136.
Jo, Y. S. (2003). Estimating the Economic Benefits of Air Quality Improvements on Mortality. Environmental policy, 11(1), 29-53.
Joo, H. S. (2018). Comprehensive plan on fine dust management.
Jung, G.H. (2000) A Q-methodological study on the types of environmental conservation discourses. Korea Environmental Policy and Administration Society 8(1): 93-111. (in Korean)
Kang K. K., & Kim J. W. (2015). Evaluation and Improvement of a Subsidy Policy on Early Scrapping of Old Diesel Vehicles. Journal of Environmental Policy, 14(2), 73-99.
Kang S. W., Lee D. H., Go G. G., Jin D. Y., Han K. J., Kang S. A., & Kim D. Y. (2019). Big Data Analysis: Application to Environmental Research and Service III. Korea Environment Institute.
Kang, H. (2019). An analysis of the causes of fine dust in Korea considering spatial correlation. Environmental and Resource Economics Review, 28(3), 327-354.
Kim H. K. (2018). Estimating Changes of Causative Factors' Influences: Focusing on

Diesel. Journal of The Korean Data Analysis Society, 20(2), 747-757.
Kim J. E., Sung H. H., Jo Y. H., Lee Y. C., Park I. K., & Woo W. H. (2018). Study on Improving the Survey Methods of Freight Transportation in Korea. Journal of Transport Research, 25(1), 41-55.
Kim J. H., & Kim M. S. (2008). Hypothesis Test of Environmental Kuznets Curve in Gyeonggi-do: Focusing on Air Pollutants. Journal of Environmental Studies, 47, 141-155.
Kim J. W., Jung, T. Y., Lee, T. D., & Lee, D. G. (2019). Analysis on Socio-cultural Aspect of Willingness to Pay for Air Quality (PM10, PM2.5) Improvement in Seoul. Environmental impact assessment. 28(2), 101-112.
Kim N. Y., Kim K. H., Shin H. C., & Sung W. (2017a). An Analysis of the Power Market Impact of Fine Dust Emission Reduction Measures in the Power Generation Sector. Korea Energy Economics Institute.
Kim S. I., & Kang B. W. (2020) Analysis of the effect of fine dust reduction policy in the power generation and transportation sector. Korea Energy Economics Institute. Research Report 20-17.
Kim Y. A., Kim S. H., & Seo G. (2020). Key Drivers of the Electric Vehicles Penetration Using Regional Panel Data. Journal of Korea Planning Association, Vol. 55(3), 69-80.
Kim Y. H., Kim E. H., Kang Y. H., You S. H. Bae M. A., Son K. W., & Kim S. T. (2021). Impact of Diesel Vehicle Emissions on PM2.5 Concentrations in Seoul Metropolitan Area during the Seasonal PM2.5 Management. Journal of Korean Society for Atmospheric Environment, 37(1), 169-190.
Kim Y. M., Moon N. K., Ha J. S., & Kim M. A. (2017b). Study on Improvement of Estimation of Emission of Air Pollutants Emitted from Vehicles in Environmental Impact Assessment. Korea Environment Institute.
Kim, D.H., Jung, C.K., Lee, J.H., Kim, K.K., JeKarl, J., & Yoo, S.H. (2018) A systems thinking approach to explore the structure of urban walking and health promotion in Seoul. Korea Journal of Health Education and Promotion. DOI : 10.14367/kjhep.2018.35.5.1. (in Korean)
Kim, D.H., Moon, T.H., Kim, D.H. (2001) System dynamics. Gyeonggido: Daeyoung Publishing. (in Korean)
Kim, E. J., Kim, J. H., Kim, H. Y., Koo, K. J., Ma, K. R., Lee, S. K. & Lim, U. (2015) The Regional and urban economics. The Regional Economics
Kim, H.K. (2008) Q methodology: philosophy of science, theory, analysis and application. Seoul: Communication Books. (in Korean)

Kim, J. H., & Kang, S. W. Analysis of Factors Influencing PM10 Pollution in Korea, 2018. Korea Environmental Economics Association, 779-791.

Kim, J.H. (2010) Prospects and limits on the grounded theory as an approach of case study in the public administration. Proceedings of the Symposium Presentation of Korean Society and Public Administration. pp. 753-765. (in Korean)

Kim, K. E., Cho, D., & Park, H. J. (2016). Air pollution and skin diseases: Adverse effects of airborne particulate matter on various skin diseases. Life sciences, 152, 126-134.

Kim, K., & Oh, H. (2011). A Study on the Treatment of Protest Zero Bids in Dichotomous Contingent Valuation Models. Seoul: Korea Development Institute.

Kim, W.C. (2016) Particulate Matter. Journal of Environmental Studies. Seoul National University Graduate School of Environmental Studies. (in Korean)

Kim, Y. S., Lee, Y. J., Park, W. S., Nam, J. M., & Kim, J. H. (2003). Estimation of Willingness to Pay for Reduction of Environmental Mortality Risk. Environmental Health and Toxicology, 18(1), 1-13.

Kim, Y.P. (2017) Research and policy directions against ambient fine particles. Journal of Korean Society for Atmospheric Environment 33(3): 191-204. https://doi.org/10.5572/KOSAE.2017.33.3.191. (in Korean)

Kim, Y.W., Lee, H.S., Jang Y.J., & Lee, H.J. (2016b) A study on differences between experts and lay people about risk perceptions toward particulate matter: a focus on the utilization of mental models. Communication Theories 12(1):53-117. (in Korean)

Kim, Y.W., Lee, H.S., Jang, Y.J., & Lee, H.J. (2016a) A cluster analysis on the risk of particulate matter: focusing on differences of risk perceptions and risk-related behaviors based on public segmentation. Journal of Public Relations 20(3):201-235. http://DOI: 10.15814/jpr.2016.20.3.201. (in Korean)

Korea Disease Control and Prevention Agency (KDCA) (2022) 1st Climate Health Impact Assessment Results Report.

Korea Transportation Safety Authority. (2018). Average Mileage of Automobile -2018 Statistics-. Korea Transportation Safety Authority Press.

Korea Transportation Safety Authority. (2019). Average Mileage of Automobile -2018 Statistics-. Korea Transportation Safety Authority Press.

Korean Society for the Scientific Study of Subjectivity (2014) Application and case of Q method. Seoul: Prunsasang. (in Korean)

Kwang, K.G. (2018) Comprehensive Measures for Fine Dust Management (2018).

Korea Environmental Institution report and presentation. (in Korean)

Kwon K. H., & Seo, I. S. (2010). Estimation of value of the atmospheric environment in Seoul using CVM. Journal of policy analysis and evaluation. 20(2), 185-208.

Lee K. J. (2018). Characteristics and Management plan for Fine Dust Emission from Small Freight Vehicles: Debate on System Improvement for Eco-friendly Conversion of Small Freight Vehicles (2018.12.19). Available at: https://www.eco.or.kr/.

Lee, D. G., Kim, Y. R., & Kim, J. H. (2017) Basic research on the impact of vehicle emissions PM2.5. Korea Institute of Public Finance.

Lee, M. K., & Yim, D. S. (2006). An Experimental Study on the Economic Valuation of Village Forest Using CVM, Collection of Korean studies, 33, 153-194.

Lee, S. H., Shin, H. S. & Kim, D. E. (2016) Economic valuation of statistical life in life loss of heat wave attributed to the climate change. The Economic & Health Policy Research.

Lee, S. W., Yoon, S. D., Park, J. Y., & Min, S. H. (2006) Application of Spatial Econometrics Model. Geunyoungsa.

Lee, Y., Yang, J., Lim, Y., & Kim, C. (2021). Economic damage cost of premature death due to fine particulate matter in Seoul, Korea. Environmental Science and Pollution Research, 28(37), 51702-51713.

LeSage, J. (2014). What regional scientists need to know about spatial econometrics. Review of Regional Studies 44 (1): 13–32.

LeSage, J., Pace, R.K. (2009). Introduction to Spatial Econometrics. Chapman and Hall/CRC

Lim, C.S. (2015) Analysis of stakeholder perspectives for biofuel policy using Q-methodology in Korea. New & Renewable Energy 11(1):36-48. https://doi.org/10.7849/ksnre.2015.03.1.036. (in Korean)

Lopez-Feldman, A., (2012) Introduction to Contingent Valuation Using Stata.

Maji, K. J., Ye, W. F., Arora, M. & Nagendra, S. M. (2018) PM2.5 related health and economic loss assessment for 338 Chinese cities. Environment International. 121: 392-403.

Mazzi, E. A., & Dowlatabadi, H. (2007). Air quality impacts of climate mitigation: UK policy and passenger vehicle choice.

Ministry of Ecology and Environment of the People's Republic of China Homepage (https://www.mee.gov.cn/).

Ministry of Environment (2015) Comprehensive Second Air Quality Improvement Plan (2016 -2025). (in Korean)

MOE. (2021). Ministry of Environment Budget and Fund Overview. Available at: https://me.go.kr/.

National Air Emission Inventory and Research Center Homepage (https://www.air.go.kr/).

Oanh, N. T. K., Thiansathit, W., Bond, T. C., Subramanian, R., Winijkul, E., & Paw-armart. I. (2010). Compositional characterization of PM2. 5 emitted from in-use diesel vehicles. Atmospheric Environment, 44(1), 15-22.

OECD. (2016). The Economic Consequences of Outdoor Air Pollution. OECD Publishing, Paris. https://doi.org/10.1787/9789264257474-en.

Oh, J.K., & Kwon, Y.H. (2016) Study of the recognition of establishing renewable energy policy using Q. Renewable energy 12(4): 30-39. (in Korean)

Park S. A., & Shin H. J. (2017). Analysis of the Factors Influencing PM2.5 in Korea: Focusing on Seasonal Factors. Journal of Environment Policy, 25(1), 227-248.

Park S. K. (2021). How much the energy source, GRDP, population change contribute to the emission of particulate matter?. Journal of Regional Studies and Development, 30, 157-188.

Park, E.S., Oh, H.J., Kim, S.H., & Min, A. (2018) The relationships between particulate matter risk perception, knowledge, and health promoting behaviors among college students. Journal of Korean Biological Nursing Science 20(1):20-29. https://doi.org/10.7586/jkbns.2018.20.1.20. (in Korean)

Park, Y. C. (2002). Valuation of non-market goods. Korean Society and Administrative Research, 13(3), 283-300.

Perez, L., Trüeb, S., Cowie, H., Keuken, M. P., Mudu, P., Ragettli, M. S., ... & Künzli, N. (2015). Transport-related measures to mitigate climate change in Basel, Switzerland: A health-effectiveness comparison study. Environment international, 85, 111-119.

Platt, S. M., El Haddad, I., Pieber, S. M., Zardini, A. A., Suarez-Bertoa, R., Clairotte, M., Daellenbach, K. R., Huang, R. J., Slowik, J. G., Hellebust, S., Temime-Roussel, B., Marchand, N., Gouw, J. D., Jimenez, J. L., Hayes, P. L., Robinson, A. L., Baltensperger, U., Astorga C., & Prévôt, A. S. H. (2017). Gasoline cars produce more carbonaceous particulate matter than modern filter-equipped diesel cars. Scientific reports, 7(1), 1-9.

Pope III, C. A., Coleman, N., Pond, Z. A., & Burnett, R. T. (2020). Fine particulate air pollution and human mortality: 25+ years of cohort studies. Environmental research, 183, 108924.

Proietti, E., Röösli, M., Frey, U., & Latzin, P. (2013). Air pollution during pregnancy and neonatal outcome: a review. Journal of aerosol medicine and pulmonary drug delivery, 26(1), 9-23.

Pu, S. S., Shao, Z. J., Yang, L., Liu, R. Y., Bi, J. & Ma, Z. W. (2019) How much will the Chinese public pay for air pollution mitigation? A nationwide empirical study based on a willingness-to-pay scenario and air purifier costs. Journal of Cleaner Production. 218: 51-60.

Ramli, N. A., Md Yusof, N. F. F., Shith, S., & Suroto, A. (2020). Chemical and biological compositions associated with ambient respirable particulate matter: a review. Water, Air, & Soil Pollution, 231(3), 1-14.

Realmeter (2016) 75% of the nation, "Unsatisfactory government measures" (Realmeter). http://www.realmeter.net/. Accessed 10 August 2018.

Reşitoğlu, İ. A., & Keskin, A. (2017). Biodiesel production from free fatty acids and the effects of its blends with alcohol–diesel on engine characteristics. Clean Technologies and Environmental Policy, 19, 925-931.

Richardson, G.P. (2012) System dynamics: Simulation for policy analysis from a feedback perspective. Qualitative Simulation Modeling and Analysis 5:144-169. doi: 10.1007/978-1-4613-9072-5_7.

Saaroni, H., Levi, E., & Ziv, B. (2018). Particulate matter in the summer season and its relation to synoptic conditions and regional climatic stress–the case of Haifa, Israel. Water, Air, & Soil Pollution, 229(10), 1-18.

Sala, R., Oltra, C., & Goncalves, L. (2015) Attitudes towards urban air pollution: a Q methodology Study. Psyecology 359-385. https://doi.org/10.1080/21711976.2015.1041293.

Seo and Lee (2019) How air pollutants influence on Environmental diseases? : Focused on Seoul Metropolitan Area. Seoul Studies, 20(3), 39-59.

Seo, I. S., Ha, M. J., & Kwon, K. H. (2010). Analysis of the effect of environmental perception-related factors on the willingness to pay for air quality improvement in Seoul: Focusing on the comparative analysis of the multiple regression(OLS) model and the Tobit model. Korea Public Administration Research, 9(4), 83-105.

Seok J. H., Kang S. M., & Yoon D. S. (2018). A study on the system improvement plan for the introduction of electric vehicles in the freight transport sector. Korea Energy Economics Institute Research Report, 1-125.

Shi, L., Zhu, Q., Wang, Y., Hao, H., Zhang, H., Schwartz, J., ... & Liu, P. (2023). Incident dementia and long-term exposure to constituents of fine particle air pollution: A national cohort study in the United States. Proceedings of the

National Academy of Sciences, 120(1), e2211282119.
Shin, Y. C. (2007) Estimating Values of Statistical Lives using Choice Experiment Method. Resource and Environmental Economic Research. 16(3): 683-701.
Song C. G., Kim D. G., Jin H. A., Seol S. H., Lee K. M., Lee H. K., & Kim B. E. (2014). PM2.5 Emission coefficient data collection: Based on air pollutant emissions in 2011. National Institute of Environmental Research.
Spruijt, P., Knol, A.B., Petersen, A.C., & Lebret, E. (2016) Differences in views of experts about their role in particulate matter policy advice: Empirical evidence from an international expert consultation. Environmental Science and Policy 59: 44-52. https://doi.org/10.1016/j.envsci.2016.02.003.
Sterman, J.D. (1989) Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. Management Science 35(3): 321-339. doi: 10.1287/mnsc.35.3.321.
Suleiman A., Tight M. R., & Quinn A. D. (2019). Applying machine learning methods in managing urban concentrations of traffic-related particulate matter (PM10 and PM2. 5). Atmospheric Pollution Research, 10(1), 134-144.
Sung, S. Y., Yoon E. J., Park J. S., & Hong J. W. (2020). A Study on Classification of National Territory for Space Specific Particulate Matters Concentration Mitigation Policy. KRIHS Report 20-38.
Tan, J. & Zhao, J. (2014) The value of clean air in China: evidence from Beijing and Shanghai. Frontier of Economics in China 9(1): 109-137.
The Korea Times (2019) South Korea, China seek to joint fine dust warning system.
The Office for Government Policy Coordination Prime Minister's Secretariat (2020). 'Fine dust seasonal management scheme' has been executed over one month December last year. Retrieved July 26, 2021, from https://www.mafra.go.kr/.
United States Environmental Protection Agency (USEPA). (2021). Health and Environmental Effects of Particulate Matter (PM). Retrieved September 15, 2021, form https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM
United States Environmental Protection Agency (USEPA). (2022). Health and Environmental Effects of Particulate Matter (PM). Retrieved January 21, 2022, form https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm
Varnavas, S. P. (2020). The Role of Meteorological Factors in the Air Particulate Matter of the Patras Port Atmosphere, Greece. Water, Air, & Soil Pollution, 231(9), 1-14.
Wang Q., Kwan M. P., Zhou K., Fan, J., Wang Y., & Zhan, D. (2019). The impacts of

urbanization on fine particulate matter (PM2. 5) concentrations: Empirical evidence from 135 countries worldwide. Environmental pollution, 247, 989-998.

Wang, J., Xie, X., & Fang, C. (2019). Temporal and spatial distribution characteristics of atmospheric particulate matter (PM10 and PM2. 5) in changchun and analysis of its influencing factors. Atmosphere, 10(11), 651.

Watts, S., & Stenner, P. (2012) Doing Q methodological research: theory, method & interpretation. SAGE Publications Ltd.

WHO (2016) Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease. WHO Press, Geneva.

Wihersaari H., Pirjola, L., Karjalainen, P., Saukko, E., Kuuluvainen, H., Kulmala, K., & Rönkkö, T. (2020). Particulate emissions of a modern diesel passenger car under laboratory and real-world transient driving conditions. Environmental Pollution, 265, 114948.

Xu, Z., & Shan, J. (2018). The effect of risk perception on willingness to pay for reductions in the health risks posed by particulate matter 2.5: A case study of Beijing, China. Energy & Environment, 29(8), 1319-1337.

Yang, Y., Luo, L., Song, C., Yin, H. & Yang, J. T. (2018) Spatiotemporal Assessment of PM2.5 related economic losses from health impacts during 2014-2016 in China. Int. J. Environmental Research and Public Health. 15(6): 1278.

Yim, H. S., Cho, S. H., & Seo, B. (2021). Impacts of Ambient Air Pollution on Health Risk in Korea: A Spatial Panel Model Assessment. Journal of Economic Theory and Econometrics, 32(1), 1-24.

Yin, H., Pizzol, M., Jacobsen, J. B., & Xu, L. (2018). Contingent valuation of health and mood impacts of PM2. 5 in Beijing, China. Science of the Total Environment, 630, 1269-1282.

Yoo, S. H., Kwak, S. J., & Lee, J. S. (2003). Measuring the Environmental Costs of Air Pollution Impacts in Seoul: A Conjoint Analysis. Journal of the Korean Regional Science Association, 19(3), 1-17.

Yoon E. J. (2020a). Application of Environmental Planning Considering the Trend of PM10 in Ambient Air. Journal of Environmental Impact Assess, 29(3), 210-218.

Yoon E. J. (2020b). Regional Types Considering Changes in Fine Dust Concentration. Korea Research Institute for Human Settlements. WP 20-02.

Yoon E. J., Park J. S., Sung S. Y., & Hong J. W. (2022). Regional Strategy for Fine Dust by Land Use Classification. KRIHS Policy Brief. No. 860.

Yorifuji, T., & Kashima, S. (2016). Fine-particulate air pollution from diesel emission control and mortality rates in Tokyo. Epidemiology, 27(6), 769-778.

Zhang, M., Song, Y., Cai, X., & Zhou, J. (2008). Economic assessment of the health effects related to particulate matter pollution in 111 Chinese cities by using economic burden of disease analysis. Journal of environmental management, 88(4), 947-954.

Zhao, D., & Kang, S. M. (2017). PM2.5 Management in Suburbs of China: Focusing on The Capital of Beijing. Korean Society for Environmental Policy. Conference Academic Paper, 77-78.

Zhao, R., Gu, X., Xue, B., Zhang, J., & Ren, W. (2018). Short period PM2. 5 prediction based on multivariate linear regression model. PloS one, 13(7), e0201011.

국문초록

미세먼지로 인한 건강영향 및 정책개선의 사회적 후생효과 분석

이 현 지

농경제사회학부 지역정보학전공

서울대학교 대학원

PM2.5의 발생요인 중 수송부문의 도로에서 발생하는 PM2.5는 시민들이 쉽게 노출되어 건강 위해성을 미칠 수 있는 오염물질로 호흡을 통해 폐로 유입되고 인간의 질병 및 사망에 부정적인 영향을 미친다. 수송부문 미세먼지와 관련한 실증분석 연구는 미세먼지 정책 대안에 대한 타당성 및 근거를 마련하는 데 매우 중요하다. 본 연구의 목적은 수송부문의 경유차 미세먼지 발생이 질병으로 인한 사망률에 영향을 미치는 지 확인하고, PM2.5 저감을 위한 정책이행 방향을 검토하여 PM 정책 개선에 따른 사회적 후생 효과를 파악하는 데 있다.

첫 번째 연구는 경유차의 PM2.5 배출량이 호흡기질환 및 허혈성 심장질환으로 인한 사망률에 미치는 영향을 분석하고, 이에 영향을 미치는 요인들을 파악하는 것을 목적으로 한다. 연구 수행을 위해 2015년부터 2019년까지 수도권 지역의 자치구 및 시·군 데이터를 활용하여 지역 간 공간 인접성을 고려한 공간 패널 모델을 적용하였으며, 연구의 주요 결과는 다음과 같다. 첫째, 경유차의 PM2.5 배출량이 높을수록 호흡기계 질환으로 인한 사망률이 높아지는 것을 확인하였다. 경유차의 PM2.5 배출량은 PM2.5 배출의 원인 중 하나이므로 PM2.5 배출이나 PM2.5 농도에 비하여 호흡기계 질환으로 인한 사망률에

미치는 영향을 적게 줄 수 있는데, 그럼에도 불구하고 호흡기로 인한 사망률에 유의한 결과가 도출된 점은 긴요한 발견이라고 할 수 있다. 둘째, PM2.5의 2차 생성물인 SO2는 허혈성 심장질환으로 인한 사망률에 양(+)의 영향을 미치는 것으로 나타났다. 또한 공간더빈모형 분석을 통해 해당 지역에서 발생하는 SO2가 인근 지역의 허혈성 심장질환 사망률에 영향을 미치고, 인근 지역의 SO2는 해당 지역의 종속변수에도 양(+)의 영향을 미침을 밝혔다. 셋째, 수도권과 중소도시의 더미변수를 생성한 후 경유차의 미세먼지 배출량과의 상호작용 항을 이용하여 비수도권과 수도권의 차이를 살펴본 결과, 경유차의 PM2.5 배출량이 증가할 때 비수도권이 수도권보다 호흡기 사망률의 영향을 상대적으로 더 많이 받는 것으로 나타났다. 이러한 결과는 비수도권과 수도권의 인프라 차이가 작용한 것으로 판단되며, 호흡기 질환으로 인한 사망률에 다양한 요인이 영향을 미칠 수 있으므로 향후 의료 및 환경 인프라를 고려하여 지역별 차이를 심층적으로 살펴볼 필요가 있다.

본 연구는 경유차의 PM2.5 배출량이 호흡기와 심혈관계로 인한 사망률이 미치는 영향을 공간상관성을 고려하여 분석할 경우 기존 논문과 어떤 차이가 있는지를 검토하였으며, 연구의 의의 및 차별성은 아래와 같다. 첫째, 분석모형에서 공간자기상관성을 고려하여 추정치가 과소 또는 과대 추정될 가능성을 방지하였다. 공간자기상관성을 확인하기 위해 연속 데이터에 적합하고, 지역간 거리가 가까울수록 서로 상호작용하거나 영향을 미칠 가능성이 높을 때 적용할 수 있는 역거리 가중치(IDW) 방식을 선택하다. 둘째, 본 연구는 국가대기정책 지원시스템(CAPSS)의 도로 이동오염원의 대기오염물질 배출량 산정방법을 활용하여 경유차의 PM2.5 발생량을 산출하여 모형의 주요 변수로 활용하였다. 연구 결과에서 경유차의 PM2.5 배출량의 변수가 호흡기로 인한 사망률에 유의한 영향관계를 미치고 있음을 밝혔다. 셋째, 온도와 습도가 높을수록 호흡기와 심혈관계로 인한 사망률에 영향을 주는 것으로 나타났으며, SO2의 경우 심혈관계로 인한 사망률에만 유의하게 양의 영향을 미치는 것으로 나타났다. 공간더빈모형 분석

결과에서 해당 지역에서 발생하는 SO2는 인근 지역의 허혈성 심장질환 사망률에 영향을 미치고, 인근 지역의 SO2는 해당 지역의 종속변수에도 영향을 미치는 것으로 나타났다. 이는 공간상관성을 고려하지 않은 일반 계량모형에서는 밝혀내지 못했던 것으로, 특히 IDW 방식을 통한 공간가중치 행렬을 구성할 때 그 특징이 명확해짐을 확인하였다. 넷째, 중국의 기상요인을 고려하기 위해 중국의 산둥성(Shandong Provinces), 허베이성(Hebei Provinces), 장수성(Jiangsu Provinces)의 기온, 상대적 흡도 및 강수량의 월별 평균 자료를 고려하였다. 국외 변수에 대한 고려는 미세먼지 관련 연구에서 중요하며, 향후 인접 국가 간 연구도 향후 수행될 필요가 있다. 다섯째, 비수도권의 호흡기에 의한 사망률은 수도권보다 경유차의 PM2.5 배출량으로부터의 영향을 상대적으로 더 많이 받는 것으로 나타났다. 이러한 차이는 비수도권과 수도권의 의료·환경 인프라 때문으로인 것으로 판단되며, 지역별 차이가 나타나는 이유에 대한 추가적인 연구의 필요성을 제기하였다. 추가 연구를 통해 비수도권이 경유차의 PM2.5 배출량으로부터의 영향을 상대적으로 더 많이 받는 것이 확인된다면 PM2.5로부터 시민들의 건강을 보호하기 위해 비수도권에 PM2.5 대피소를 설치하는 단기적인 대책 마련이 필요할 것으로 보인다.

두 번째 연구는 차종별(승용, 승합, 화물), 규모별(소형, 중형, 대형) 경유자동차의 PM2.5 발생량이 한국의 미세먼지 농도에 미치는 영향을 분석하였으며, 대도시와 중소도시에 따라 결과에 차이가 있는지 파악하였다. 분석결과는 다음과 같다. 첫째, 경유 승용, 승합 및 화물차의 PM2.5 발생량은 모두 한국의 미세먼지 농도에 유의한 영향을 미치며, 이 중 화물차가 가장 큰 영향을 미치는 것으로 나타났다. 둘째, 화물차 중 소형 화물차의 PM2.5 발생량이 종속변수에 가장 큰 영향을 주는 것으로 나타났다. 이러한 결과는 소형 화물차가 중대형 화물차에 비해 10년 이상 노후된 차량이 가장 많고, 특히 영업용 소형 화물차는 주로 택배나 배달 차량이 많아 승용차 대비 주행거리가 높아 나타난 결과로 판단된다(이규진, 2018). 셋째, 대도시에서 대형 승용차, 소형 승합차,

중형 화물차의 PM2.5 발생량은 중소도시보다 한국의 미세먼지 농도에 미치는 영향이 큰 것으로 나타났다. 이는 수도권을 포함한 대도시는 인구가 밀집되어 교통체증이 발생하는 경우가 많아 나타난 결과로 보여지며, 수도권을 중심으로 고농도 미세먼지가 발생한다는 현실을 반영한다. 연구 결과에 따른 시사점은 아래와 같다. 첫째, 경유차종 중 화물차의 PM2.5 발생량이 한국의 미세먼지 농도에 더 큰 영향을 미치고 있으므로 조기폐차 및 저공해차 운행 등의 경유차 대책에서 화물차를 중심으로 제도 개선과 이행이 필요할 것으로 사료된다. 특히 화물차 시장에서 단기적으로는 경유차 대체가 가능한 연료 차량의 보급을 확대해야 하고, 중장기적으로는 미세먼지 무배출 화물차를 보급하는 전략을 병행해야 할 필요가 있다(한진석, 2020). 둘째, 차종별 규모를 고려할 때, 소형 화물차의 PM2.5 발생량이 한국의 미세먼지 농도에 더 큰 영향을 주고 있기 때문에 미세먼지 대책에서 차종 및 규모에 따라 세부 대책을 마련해야 하며, 특히 노후된 차량이 많은 소형 화물차를 중심으로 미세먼지 저감 대책을 개선해야 한다. 셋째, 대형 승용차, 소형 승합차 및 소형 화물차의 PM2.5 발생량이 대도시에서 한국의 PM2.5에 더 큰 영향을 미치는 결과는 지역별 맞춤형 미세먼지 저감 대책의 중요성을 증명하고 있으며, 정부가 지자체별로 미세먼지 관리 수립 대책을 마련하고 평가하는 체계를 마련하는 것이 시급하다. 연구는 기존 선행연구들을 통해 부문별로 대표변수를 도출하여 분석하고 한국의 정책방향을 점검했다는 점에서 의의를 가지며, 특히 차종별(승용, 승합, 화물), 규모별(소형, 중형, 대형)로 세분화하여 경유차의 PM2.5 발생량이 한국에 미세먼지에 주는 영향을 분석한 점은 연구의 차별성으로 강조될 수 있다.

세 번째 연구는 본 연구의 목적은 현재 우리나라의 PM 문제를 해결하고 디젤연료 및 차량에 대한 PM 정책 관련 정책 및 관리방향에 대한 전문가(정부 공무원 및 연구원)의 의견을 분류하는 것이다. 연구결과 경유정책에 대한 전문가들의 인식은 경유규제 옹호형, 경유규제 소극형, 정부예산지원형, 여론 민감대응형으로 구분된다. Q-

방법론과 시스템 사고분석 결과를 토대로 보면, 비효율적인 경유정책의 주요 원인은 부처의 역할 부재, 이해관계자에게 정보 전달 부족, 시민참여 불확실성 등이다. 전문가들은 정책에 대한 국민들의 반발에 대해 우려하며, 이로 인해 정책 시행이 지연되고 있다. 따라서 다음과 같은 시사점을 검토할 필요가 있다. 첫째, 4개 유형 중 매개적 역할을 할 수 있는 집단을 찾아야 한다. 4개 유형 중 정부예산지원형은 정책의 장단점을 강조하고 개선의 필요성을 대부분 수용할 뿐만 아니라 정책효과를 긍정적으로 평가하기 때문에 중재자 역할을 하기에 최적의 그룹이다. 중재자 역할을 할 수 있는 단체를 선택한 뒤 시민권 참여를 원하는지, 어떤 형태의 자금을 지원할지 피드백을 받을 필요가 있다. 둘째, 부처 간 이해와 정리를 높이기 위해 부처의 기능과 역할을 재고해야 한다. 또한 이해관계자들 간의 보다 건전하고 지속적인 협력을 위해 부처 간 역할과 기능에 대한 더 나은 이해가 고려되고 재정의될 필요가 있다.

네 번째 연구에서는 조건부 평가방법을 이용하여 정책 개선을 통해 대기오염으로 인한 사망 가능성을 0.0001 감소시키는 시나리오에 대한 응답자의 지불의사금액(WTP)를 도출하였다. 통제변수를 포함하여 이중경계 양분선택형(DBDC) 분석 결과에 따르면 평균 지불의사금액은 연간 41,643원(월 평균 3,470원)이며, 납부거부 응답자를 포함할 경우 평균 지불의사금액은 연간 22,397원(월 평균 1,866원)이다. PM2.5로 인한 사망률을 1만분의 1 수준으로 감소시키기 위한 경제적 가치는 연간 약 8,940억원(8940만90만7100원)에 달한다. 통계적 생명가치의 가치는 0.4164억원이며, 10년 지급기간을 적용하여 도출된 통계적 생명가치는 약 41억 643만원으로 추정되었다. 지역 별로 미세먼지 정책 개선을 통해 사망 가능성을 0.0001 감소시키는 시나리오에 대한 지불의사금액에 차이가 존재할 수 있으므로, 향후 연구를 통해 차이가 발생하는 원인에 대해 규명해야 할 필요가 있다. 또한 국내외 연구 비교연구를 통해 미세먼지로 인한 조기사망률 감소에 대한 효용 수준 및 위치를 파악함으로써 국내 미세먼지 저감 대책 및 시민 건강보호를 위한 예산

계획 시 참고 자료로 활용될 수 있다.

본 논문은 미세먼지 분석 연구에 대한 일반 시민들의 공감과 이해를 증대시키기 위해 미세먼지 수송부문의 현황 및 건강 영향에 대한 이해, 미세먼지 저감을 위한 수송부문 정책 이행 방향 제시, 정책 개선에 따른 사회적 후생효과 분석의 논리적 흐름으로 구성하였으며, 향후 수송부문 미세먼지 정책 개선 및 사회정책적 이슈 대응을 위해 방향성을 타진할 수 있는 기초 자료로 활용되기를 기대한다.

Keyword: 초미세먼지(PM2.5), 공간계량모형, 조건부가치측정법, 지불의사금액 (WTP), 통계적 생명가치 (VSL), 사회적 후생효과, 고정/랜덤 효과모형, 환경정책 인식, Q-방법론

Student Number: 2018-33158