Master Thesis in Engineering

Air Pollutant Emissions Effects of Electric Vehicle Diffusion

: Computable General Equilibrium Model Approach

전기차 확산에 따른 대기오염물질 배출량 증감 효과 분석
: 연산가능 일반균형모형 접근을 통하여

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Graduate School of Seoul National University

Technology Management, Economics, and Policy Program

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Abstract

Air Pollutant Emissions Effects of Electric Vehicle Diffusion

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South Korea's electric vehicle market, whose growth has been accelerating since 2015, is not only driving changes in the sales of electric vehicles, but also in the electric power market.

This study focuses on the air pollutant emissions caused by this diffusion of electric vehicles, based on the share of such vehicles in the passenger car market.

It uses a computable general equilibrium (CGE) model. In addition, based on the Bank of Korea's input-output statement, this study aimed to reflect the effects on the market

share of electric vehicles. This research will allow us to quantitatively observe changes in the air pollutant emissions of electric vehicles as the market grows rapidly.

Based on the CGE model, we analyzed policy scenarios in line with South Korea's roadmap for encouraging the adoption of electric vehicles. In addition, scenarios were analyzed considering different fuels to identify the ones that represent the most efficient reduction in emissions when replacing electric vehicles. Scenario results revealed that air pollution emissions from the transportation sector will decrease due to the spread of electric vehicles, but the primary metal industry associated with the battery industry will undergo expansion as the industry grows rapidly due to the production of electric vehicles. Accordingly, the four air pollutants, SOx, TSP, PM10, and PM2.5 were derived from the increase in air pollutants caused by the spread of electric vehicles, and the NOx and NH3 sectors also showed that much of the reduction effect expected by the transportation sector was offset by the emissions of other industries.

This research reveals that only the transportation sector lacks quantitative changes to observe changes in the emission levels of air pollutants caused by the spread of electric vehicles, and that the calculation of emission levels should also consider the linkages among various industries. If the current industrial structure continues, the transportation sector’s policies to reduce emissions will instead increase the overall amount of air pollutants.

This study suggests that direct and indirect effects of the industry as a whole should be considered to reduce emissions of air pollutants.

Keywords: Computable General Equilibrium, Distributional Effects, Transport, Electric Vehicle

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Chapter 1. Introduction

1.1 Research Background

The implementation of the so-called "green automobile policy" that minimizes emissions of road transport air pollutants is also having a big impact on the vehicle industry market. The trend of air pollutants emitted from the road transport sector in Korea is the same as Figure 1.

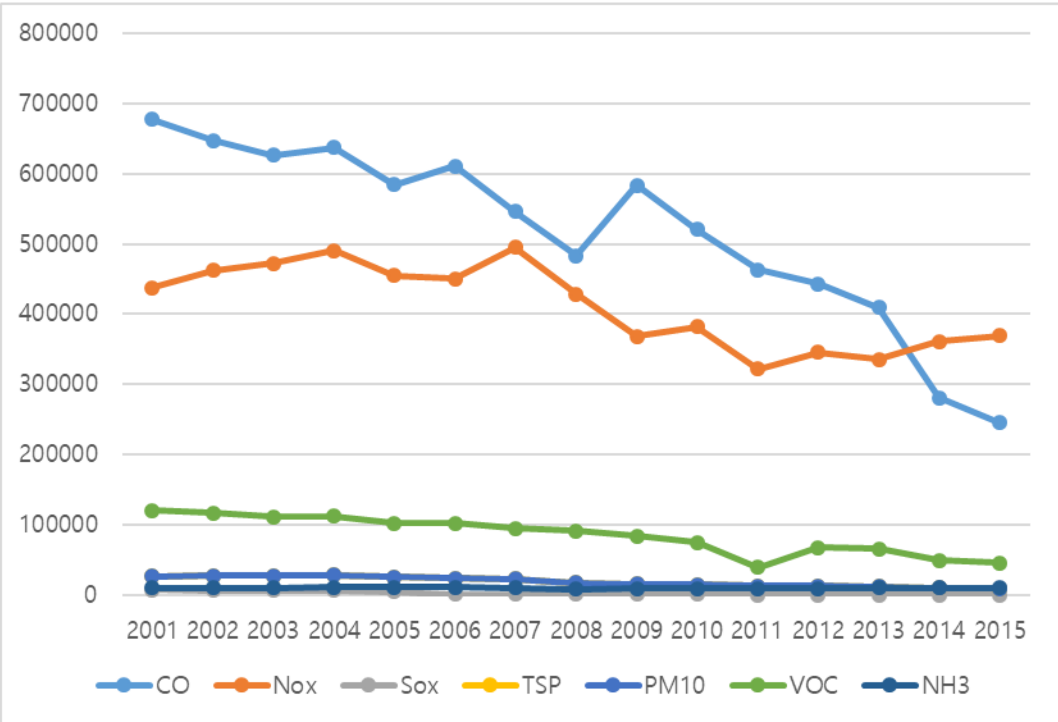


Figure 1. Trends of Air pollutants in Road-Transportation Sector

Note: 1) y-axis unit : ton, 2) x-axis unit : year

Source : National Institute of Environmental Research's National Air Pollution Discharge Service[1]

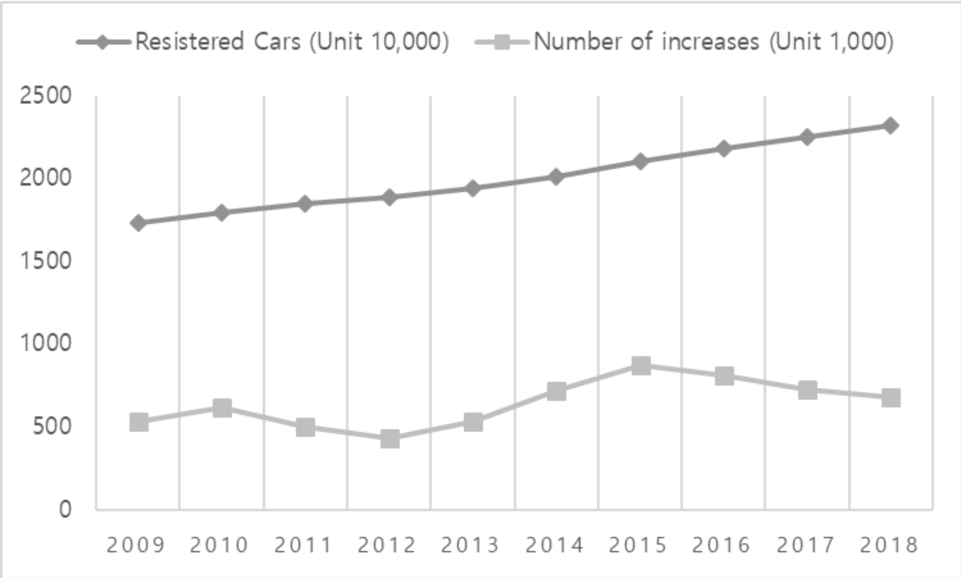


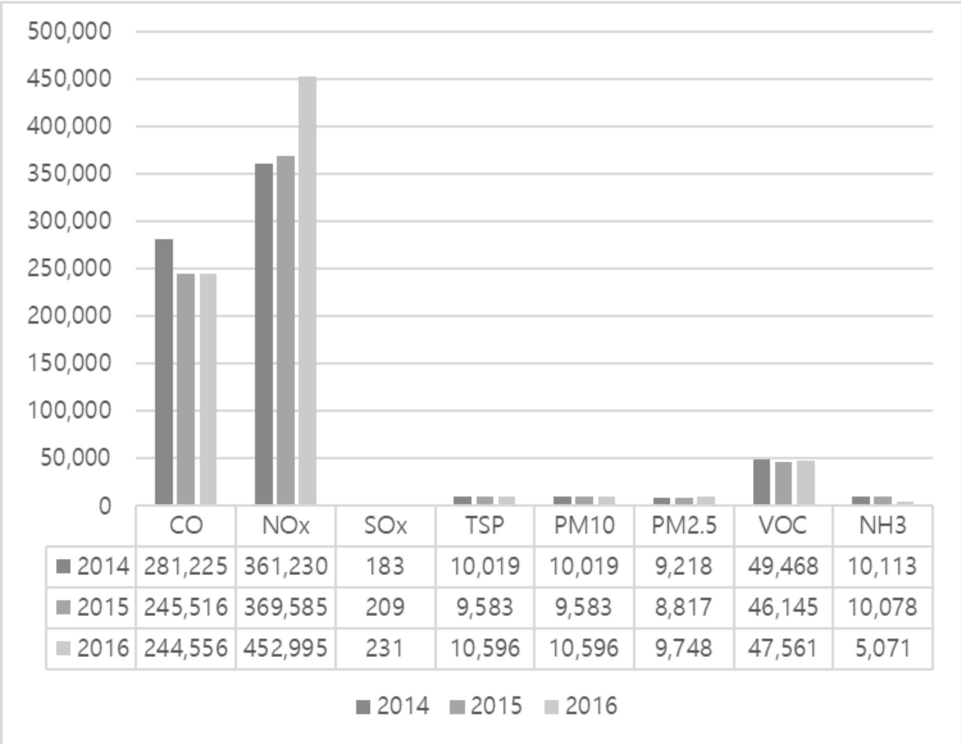
Figure 2. Changes in Registered Cars in Korea

Source: Statistics Korea, Ministry of Land Infrastructure and Transport

In Figure 2, the number of cars registered increased by about 21 percent from about 17.33 million in 2009 to 20.99 million in 2015, but the trend shows that pollutants such as carbon monoxide (CO) and sulfur oxides (SOx) are decreasing. However, Nitrogen Oxide (NOx) is showing signs of rising again recently. In Figure 3, this is a figure of the air pollutants emitted from road transportation sources. Data for 2014, 2015 and 2016 were collected and compiled from the Korea National Air Pollutants Emissions Service. As the

[1] Korea Transport Institute, 2015 National Traffic Statistics Commentary, 2016.

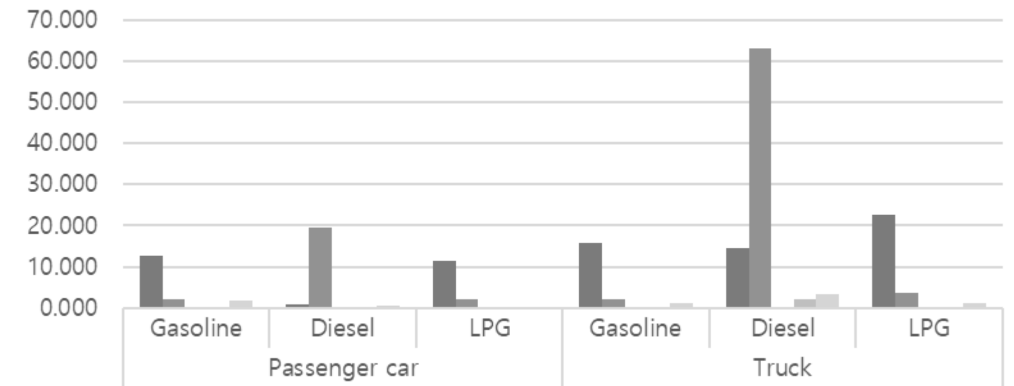
graph shows, NOx has steadily increased over the past three years, with TSPs, PM10, and PM2.5. It’s likely to decrease in 2015, but rather higher emissions in 2016 than in 2014.



	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
2014	281,225	361,230	183	10,019	10,019	9,218	49,468	10,113
2015	245,516	369,585	209	9,583	9,583	8,817	46,145	10,078
2016	244,556	452,995	231	10,596	10,596	9,748	47,561	5,071

Figure 3. Emissions by Sector

Source: Korea National Air Pollutants Emission Service



	Passenger car			Truck		
	Gasoline	Diesel	LPG	Gasoline	Diesel	LPG
CO	12.623	0.774	11.317	15.861	14.396	22.711
NOx	2.062	19.677	2.218	2.205	63.251	3.707
SOx	0.005	0.005	0.006	0.003	0.021	0.006
PM2.5	0.003	0.084	0.000	0.000	1.957	0.000
VOC	1.799	0.401	0.360	1.048	3.456	1.014

Figure 4. Air pollutant emissions by vehicle type (2014)

Note: Unit : kg/vehicle

Source: Korea National Institute of Environmental Research

According to Korea National Institute of Environmental Research(Figure 4), We can distribute the emissions of car by fuel type. As this figure shows, in almost every field, Truck has emitted more air pollutants than Passenger car. In particular, for diesel vehicles, Truck emissions were nearly three times greater.

In order to establish a sustainable transportation system around the world, all over the world needs to make efforts to supply electric vehicles (green cars).

Around 3.1 million electric cars were sold worldwide as of 2017. This represents a 56 percent increase from 2016. The number of electric vehicles in the country, which stood at 1.24 million units in 2015, is rapidly increasing to 1.98 million units in 2016 and 3.1

million units in 2017. Of them, China accounts for about 1.23 million units, or 40 percent of the world's electric cars. The U.S. ranks second with about 760,000 units. Starting with 338 units in 2011, Korea's electric vehicles have doubled on average annually, with 57,000 units in operation as of the end of 2018. As of 2018, it has supplied 32,000 units, 1.2 times more than its performance in the past seven years (2011-2017). In response, the government is presenting various roadmaps related to electric vehicles, presenting a vision to lead the Republic of Korea as a leading eco-friendly car, and announcing its key strategy for promoting the vehicle.

1.2 Research Purpose and Methodology

Because the distribution of electric vehicles contributes greatly to the energy saving of transport sectors, the diversification of energy sources and the improvement of the air environment, most countries that distribute electric cars are promoted under the government's policy. Electric cars are emerging as a potential alternative to energy conservation and greenhouse gas reduction, but research on their effects is insufficient in Korea. The South Korean government has selected electric cars as a powerful means to achieve green growth, and is making efforts to develop technologies and create markets. However, it is true that technical and policy assessments of the practical energy saving and greenhouse gas reduction effects of electric vehicles are insufficient. In response to changes in international energy and environmental issues, it is necessary to analyze the domestic energy and atmosphere and discuss the expected effects of the introduction of electric vehicles and the issues that need to be addressed for their dissemination.

This study adopted the Computable General Equilibrium (CGE) as a methodology. The previous industry-related analysis model used in the analysis of specific industries had advantages in estimating the economic ripple effects of the spread of electric vehicles, the automobile industry with large front and rear effects. However, there are disadvantages of not being able to identify the price changes and the consequent effects of changes in technology and the final demand. On the other hand, the Partial Equilibrium Model lacks consideration for the full-back associative effects. The CGE approach has the advantage of addressing many of these shortcomings. This study used CGE to analyze and evaluate the impact of electric vehicle introduction on the price of air pollutants and major products (Han, Lim, and Kim, 2018).

1.3 Outline of the Study

This study is described in the following sequence. Chapter 2 explains the theoretical background of this study. This chapter summarizes various literature on the social effects associated with the electric vehicle market and the literature using CGE models in the transportation sector. The third chapter details the methodology used in this study. In this chapter, we start with the basic concepts of models and detail the models used in this study. Chapter 4 analyzes and describes the results of Scenario assuming when various policies are applied. Finally, Chapter 5 concludes the study, summarizes the results briefly and proposes implications and future research.

Chapter 2. Theoretical Background

2.1 Effect of Electric Vehicle on the Environment

Weis et al. (2016) analyzed the environmental impact of PEV expansion by reflecting 2010 data in the largest power market in the United States and hypothetical scenarios in which power configuration plans and wind power will be expanded by 2018. The study analyzed that PEVs were more environmentally damaging than HEVs, as the proportion of coal power generation in the plan for power generation increased. However, Weis et al. (2016) noted that power generation of cars can be changed and from a long-term perspective, compared with alternatives such as biofuels and natural gas, is a means to reduce air pollution in the transportation sector.

Tessum et al. (2014), estimated the health effects of air pollution and air pollution caused by replacing 10% of the expected vehicle mileage with electric vehicles in 2020. From the production of electric vehicles, the scenario of not polluting the environment was constructed, and the electricity of charging electric cars was also composed of eco-friendly energy. In these two scenarios, environmental benefits were estimated to arise in the climate change sector. The study found that while replacing conventional cars with less pollution-free cars to improve the environment, electric cars were not the only means to do so.

Hawkins et al.(2013) and PE International (2013) confirmed that electric vehicles have a greenhouse gas reduction effect over internal combustion engine vehicles unless the vehicle production process is taken into account, but said that the greenhouse gas reduction effect is uncertain if the vehicle's production process is taken into account. Hawkins et al. (2013) estimated a 10 to 24% reduction in greenhouse gas emissions when replacing equivalent internal combustion engine cars with electric vehicles, assuming an average vehicle life of 150,000 km under the assumption of a European energy combination. PE International(2013) also estimated that from 2020 to 2030, the life cycle analysis of electric vehicles and internal combustion engine cars showed a 7 to 70 percent reduction in emissions of internal combustion engine cars compared to 2012, while the reduction in emissions of electric vehicles amounted to 12 to 55 percent.

Table 1. PE International (2013) Report Key Prerequisites

	Electricity mix	**Weight (kg)**	**Vehicle life (km)**	**Battery life (km)**	**Electricity(Fuel) Consumption**	**Emissions (tCO2eq)**
EV	EU (ethanol 10% mixture)	1,530	150,000	160,000	14(kWh/100km)	24.5
CV	EU (ethanol 10% mixture)	1,240	150,000	N/A	5.83(1/100km)	30.7

Ma et al. (2012), Messagie et al. (2010) argue that there is a greenhouse gas reduction effect for electric vehicles even when all life cycles are considered. Ma et al. (2012) argued that electric vehicles have better greenhouse gas intensity than internal combustion engine cars based on the analysis of actual operation conditions in the U.K.

and California and their share of additional power in the use of electric vehicles. Messagie et al. (2010) found that from the analysis of the life cycle maintained and assumed by Belgium's energy union (46% nuclear power, 21% natural gas, 9% coal), electric vehicles predominate over internal combustion locomotives in four areas: greenhouse gas emissions, air acidification, health and eutrophication.

2.2 General Equilibrium Analysis of Electric Vehicle Market

Osawa and Nakano (2015) used Japan's Inter-industry Relationship Table to calculate the economic effects of the spread of HEVs, PHEVs and hydrogen fuel cell vehicles, including electric vehicles. This will result in a 1.5 trillion(JPY) drop in production in Japan's economy in 2030, 1.4 trillion(JPY) of which will be reduced in passenger car manufacturing. This was due to reduced production of engine manufacturing, oil refining and others that had been used in conventional internal combustion vehicles.

Choi et al. (2012) analyzed the effect of the distribution of electric vehicles on domestic energy supply and greenhouse gas emissions. The stability of the power supply was assessed and future supply and demand was calculated through this way. Choi et al. (2012) used KEEI-EGMS and this method calculated the amount of supply and energy demand per vehicle. The results showed that despite the spread of electric cars in 2035, demand for electricity rose 1.5 percent. However, it was predicted that the peak load increase in the supply and demand of electricity will increase relatively.

Leurent and Winsdich (2015) conducted an analysis based on the cost structure of internal combustion engine cars and electric vehicles to calculate the economic and social effects of the spread of electric vehicles. Leurent and Winsdich (2015) concluded that an increase in the electric vehicle industry in a hypothetical scenario would reduce the injection of internal combustion-related parts and significantly increase the input of electrical and electronic equipment parts. It also said the spread of electric cars would have a significant economic impact on the country's production-export processes. On the other hand, it analyzed that internal combustion engines that go through the production-export process of their own country are replaced by electric cars that go through the foreign production-import process, which has an economic negative impact.

Miyata et al. (2014) analyzed the impact of the introduction of electric vehicles into the economy of a Japanese city where Toyota Motor Corp. is located through a computable general equilibrium model. In the study, the industry consists of 38 sectors, including general car manufacturing, electric car manufacturing, general car transportation services and electric car transportation services. Shock was given by giving subsidies of 5 to 25 percent to five sectors to the manufacturing of electric vehicles, the transportation service of electric cars, solar power, cogeneration and other transport businesses. The result shows that while gross domestic product rises in detail, carbon dioxide emissions decrease.

Han et al. (2019) analyzed and evaluated the impact of introducing electric and hydrogen vehicles on gross domestic product and carbon dioxide emissions using the

Computable General Equilibrium Model. The study approached electric and hydrogen cars by incorporating shock into CGE the results of the Bass model for diffusion within the automotive industry. Economic and environmental impacts were estimated through CGE analysis that shocked the inputs of the automobile industry and the industries using the automobile and the final energy demand. The results showed that electric cars have a negative effect in terms of carbon dioxide emissions, while hydrogen cars reduce carbon dioxide emissions, and both electric and hydrogen cars have a positive effect in terms of GDP. In terms of carbon dioxide emissions in the industrial sector using cars, electric vehicles saw a slight increase in emissions and hydrogen cars saw a slight decrease.

2.3 Overview of the Electric Vehicle Industry

The paradigm of the global auto market is shifting from internal combustion engine cars to electric vehicles. Strengthening international environmental regulations on automobile emissions, increasing the possibility of depletion of oil resources and continuing high oil prices are the main reasons. In particular, consumers increase their preference for high-efficiency cars as a burden on rising oil prices. Among other things, sales of fuel-efficient light cars, hybrid electric vehicles (HEVs) and imported diesel cars have been rising significantly in Korea recently. Not only in Korea but also around the world, the hybrid passenger car market shows a rapid growth. Developed countries are strongly pushing for policies to distribute pure electric vehicles (EVs) and plug-in hybrid electric vehicles

(PHEVs). So much so, electric cars are emerging as an effective global greenhouse gas reduction tool and an essential alternative for a sustainable environment. Electric cars are commonly referred to as cars powered by electric batteries and electric motors, and are included in the government-set "green cars." In accordance with the role of the battery and motor or electric drive system using electric cars now divided into four types as shown below.

Table 2. Classification of electric cars

Classification of electric cars
1. Electric Vehicle: EV
2. Plug-in Hybrid Electric Vehicle: PHEV
3. Hybrid Electric Vehicle: HEV
4. Fuel Cell Electric Vehicle: FCEV

In this study, 'electric vehicles' are used as a generic term for EVs, which are pure electric vehicles that do not use fossil fuels.

2.3.1 Policy background

According to the survey, the Ministry of Land, Infrastructure and Transport, 2016, 84.3

percent of the vehicle is almost a majority by car. The following Table 3 shows that the market share of the city's electric passenger cars is lower than 0.1 percent, followed by gasoline (61.3 percent), diesel (26.8 percent), LPG (10.0 percent), and hybrid (1.7 percent).

Table 3. Registration status of Seoul’s passenger cars by fuel: 2016

Sortation	Gasoline	Diesel	LPG	Elec
Registered cars	1,593,968	697,496	259,417	1,484
Sortation	CNG	Hybird	Other	Total
Registered cars	678	44,823	478	2,598,344

The transportation sector accounts for more than 30 percent of the city's total energy consumption, with passenger cars accounting for a significant 56 percent of the total. Fifty-seven percent of Seoul City's air pollution takes place on roads, with various policies being pursued to reduce car emissions that pose serious harm to the air environment.

In major plans and systems related to the road transport sector of the Seoul Metropolitan Government by year, they include "Basic Plan for Sustainable Transportation Logistics Development" in 2011, "Comprehensive Plan to Reduce One Nuclear Power Plant" in 2012 and "Basic Plan for Atmospheric Environmental Management in the Capital Region" in 2013. In this study, the Seoul Metropolitan Government will refer to the

"Seoul-type 2030 Smart Eco-friendly Transport Master Plan" (Seoul Institute, 2014) which was announced by the Seoul Metropolitan Government in 2014 to review the current status of the city's road transportation sector and mid- and long-term policy goals.

Chapter 3. Methodology

3.1 Construction of Social Accounting Matrix

The basic data in the CGE model is built into a social accounting matrix (SAM) that describes the transaction flow between economic players in a country. To build a CGE model, it is essential to create a social accounting matrix using data from that year. This study developed SAM with the input-output data from the Bank of Korea in the year of 2015. SAM requires data such as household or government savings and relocation expenditures that are not presented in the Industrial Relations Statement. Additional input data were prepared using the National Account Data of the Bank of Korea.

3.1.1 Overview of SAM

A social accounting matrix depicts the macroeconomic snapshot of the comprehensive economic system considering the interaction between the economic agents (Pyatt and Round, 1985). Table 4 shows the basic structure of social accounting matrix. The social accounting matrix is established using the industrial association table and national account data. The social accounting matrix construction work consists of reducing the level of the industry association table and rearranging the reduced level of industry association table and national account data to suit the social accounting matrix.

The social accounting matrix is a matrix of income and expenditure of the economic entities that make up the top-down module, which is classified and recorded in the row according to the economic players whose expenditures are subject to payment. And in the column, the income of each economic entity is classified and recorded according to the economic entity that paid the income. The income and expenditure of all economic players are consistent. The economic entities that make up the social accounting sequence established in this study consist of industries, goods, production factors, residues, taxes, households, governments, savings-investment, and overseas sectors. Table 4 represents the relationship between the 49 industries that make up the top-down modules in this study.

3.1.2 Construction of SAM

In order to construct a social accounting matrix using the data in the Industrial Relationship Table, the basic 381 units of the Industrial Relationship Table must first be reorganized to match the industrial classifications of this study. In this phase, the industrial association table comprising 47 industries is prepared by taking the sum of the values of the industry association table as follows:

Table 4. Industrial classification adjustment

A (381 x 381)	D (381 x d)	→	A (47 x 47)	D (47 x d)

V (v x 381)	(blank)		V (v x 47)	(blank)

The figure on the left of Table 4 represents the usual basic sector industry association table. Item A represents transactions between goods, item V represents the value added from each production of the goods and item D represents the final demand. The figure on the right shows an industry association table adjusted for the industry classifications of this study. The process of adjusting an industrial association table from the basic sector industry association table to the industry classifications of this study goes through the following Eq.(1) ~ Eq.(3).

$$A : \overline{a_{I,J}} = \sum_{i \in S_I}, \sum_{j \in S_J} a_{i,j} \quad \cdots\cdots \text{Eq. (1)}$$

$$V : \overline{a_{I,J}} = \sum_{i \in S_I}, \sum_{j \in S_J} a_{i,j} \quad \cdots\cdots \text{Eq. (2)}$$

$$D : \overline{D_{I,d}} = \sum_{i \in S_I} D_{i,d} \quad \cdots\cdots \text{Eq. (3)}$$

$(i, j = 1, \cdots, 381 \; basic \; sector)$

$(I, J = 1, \cdots, 47 \; Industrial \; classfication \; of \; this \; study)$

$(The \; set \; of \; i(j) \; constituting \; S_P S_J = I(j))$

The relationship between the basic segments of the Industrial Relationship Table and the industry segment of this study is as follows in Table 5.

Table 5. Redistribution of the basic section of the Industrial Relationship Table

This Study	Basic Sector of Industrial Relationship Table
Agri	0111, 0112, 0113, 0114, 0121, 0122, 0191, 0192, 0193, 0194, 0195, 0196, 0199, 0211, 0212, 0291, 0292, 0299, 0301, 0302, 0303, 0309, 0401, 0402, 0500
Coal	0611, 0612
Oil	0621
NaturalGas	0622
Mining	0711, 0719, 0721, 0722, 0729
Food	0811, 0812, 0813, 0814, 0821, 0822, 0831, 0832, 0841, 0842, 0843, 0851, 0852, 0861, 0862, 0871, 0872, 0873, 0879, 0880, 0911, 0912, 0913, 0919, 0920, 1000
FiberLeather	1111, 1119, 1121, 1122, 1123, 1130, 1141, 1142, 1149, 1151, 1152, 1153, 1154, 1155, 1201, 1202, 1203, 1204, 1209
WoodPaper	1311, 1312, 1313, 1321, 1322, 1329, 1410, 1421, 1429, 1431, 1432, 1433, 1434, 1439, 1500
CoalPro	1611, 1612
OilPro	1621, 1628, 1631, 1639
Gasoline	1622
JetOil	1623
Kerosene	1624
Diesel	1625
HeavyOil	1626
LPG	1627
Chemical	1711, 1712, 1713, 1719, 1721, 1722, 1723, 1801, 1802, 1900, 2000, 2101, 2102, 2211, 2212, 2221, 2222, 2291, 2292, 2299, 2310, 2391, 2392, 2393, 2399, 2410, 2491, 2499

NonMetal	2501, 2505, 2503, 2509, 2611, 2612, 2613, 2614, 2620, 2631, 2362, 2691, 2692, 2693, 2694, 2699
PriMetal	2711, 2712, 2713, 2721, 2722, 2723, 2724, 2725, 2726, 2727, 2730, 2791, 2799, 2811, 2812, 2813, 2814, 2819, 2821, 2822, 2829, 2900
Metal	3011, 3012, 3013, 3014, 3021, 3022, 3031, 3032, 3091, 3092, 3093, 3094, 3095, 3099
Computer	3101, 3102, 3201, 3209, 3310, 3391, 3399, 3401, 3402, 3409, 3511, 3512, 3519, 3521, 3522, 3523, 3611, 3612, 3613, 3691, 3692, 3693
ElecEquip	3713, 3721, 3722, 3723, 3724, 3740, 3751, 3752, 3759, 3791, 3792, 3799
Elec_Batt	3731
Machine	3810, 3820, 3831, 3832, 3840, 3851, 3852, 3891, 3899, 3911, 3912, 3920, 3930, 3941, 3942, 3991, 3992, 3993, 3994, 3995, 3999
TransEquip	4012, 4013, 4021, 4022, 4031, 4101, 4102, 4103, 4210, 4220, 4291, 4299
TransEquipCV	4011_1
TransEquipEV	4011_2
TransEquipEG	4032
MissManu	4311, 4312, 4319, 4391, 4392, 4393, 4394, 4395, 4396, 4399
IndEquip	4401, 4402
Elec	4501, 4502, 4503, 4504, 4505
Gas	4610
Steam	4620
WaterWaste	4700, 4801, 4802, 4911, 4912, 4920
Const	5010, 5020, 5030, 5111, 5112, 5113, 5121, 5122, 5123, 5124, 5131, 5132, 5133, 5134, 5190
WholeServ	5200
TransServOthers	5310, 5322, 5401, 5402, 5500, 5611, 5612, 5613, 5620, 5630, 5690, 5710, 5720
TransServ_Gas	5321_1
TransServ_Diesel	5321_2
TransServ_LPG	5321_3
TransServ_EV	5321_4

AccomServ	5811, 5812, 5813, 5814, 5820
ITServ	5911, 5912, 5991, 5999, 6001, 6002, 6100, 6211, 6212, 6290, 6300, 6401, 6402
FinServ	6510, 6591, 6599, 6601, 6602, 6603, 6700
EstateServ	6800, 6911, 6912, 6920
ScienceServ	7001, 7002, 7003, 7004, 7111, 7112, 7120, 7210, 7291, 7292, 7299
BusiServ	7300, 7410, 7420, 7490
Administration	7511, 7512, 7520
EduServ	7601, 7602, 7603
SocialServ	7701, 7702, 7703, 7801, 7802
CultureServ	7901, 7902, 7903, 7904, 8001, 8002
MissServ	8101, 8109, 8211, 8212, 8221, 8222, 8223, 8229
Miss	8300

Based on the data in the Inter-industry Relations table, the following social accounting matrix is prepared: The way in which the social accounting matrix is written varies among researchers, and it is difficult to say that a particular method is superior.

3.1.3 Separation of Electric Vehicle (EV) sector

A typical general balance analysis can be analyzed only by establishing a social accounting matrix. However, this research focuses on research related to diffusion of electric vehicles. Research on diffusion of electric vehicles needs to be able to analyze changes in industrial structure due to demands for electric vehicles and changes in composition of energy input. To this end, it is necessary to separate electric vehicle items from transportation services and passenger car items. The I-O table established in this study is the result of the redistribution of transport segment SAM based on the basic segment industry association table, which is the most detailed description of the input and consumption structure.

The study separated the basic segment, 'passenger cars,' from TransEquip, which includes the 'passenger cars' segment among 49 industries previously classified. This was classified as TransEquipCV, among which an additional electric vehicle was separated to form the 'TransEquipCV'. It also separated the engine sector, one of the TransEquip items, and moved all of the engine segments to TransEquipCV so that the demand for TransEquipEVs could be zero. For similar reasons, the 'Elec_Batt' segment was formed by separating the battery segment from the 'ElecEquip'.

According to South Korea's Ministry of Land, Infrastructure and Transport, an additional 871,000 cars were registered as of 2015 compared to the previous year. Also, the number of electric vehicles in the country was 2,907 as of 2015, according to the

Korean Environment Ministry of Environment. Thus, the 2015 CV was calculated from 871,000 units to 868,093 units, minus 2,907. This is based on the 2015 I-O table and is based on the 2015 data. The study also included price indices for passenger cars. The price of electric vehicles was 41.5 million won(KRW), the average price of the Hyundai Ionic EV, in 2016, and the price of CVs was 29.1 million won(KRW) based on data from automotive research firm Consumer-Insight.

Based on such data, the ratio of electric vehicles in Korea, which takes into account the price index by multiplying the number of vehicles and the price of vehicles, was 0.48 percent. In this study, 0.48% of the I-O table's TransEquipCV segment was divided into TransEquipEV segments. Transfer 0.48% to TransEquipEV in all production parts, but different ratios for batteries and engines. For engines, the cost of EVs was zero, so the engine items entered into the EV were treated as zero. Table 6 shows the separation of the TransEquipEG sector.

Table 6. Classification of Engine goods

	TransEquipCV	TransEquipEV
Intermediate Input	$X_{CV} - (X_{CV} * 0.48\%)$	$X_{CV} * 0.48\%$
TransEquipEG	8,462,984	0

($X_{CV} =$ amount of Intermediate Input to TransEquipCV sector)

In this study, the Elec_Batt section was further separated from the I-O table in 2015 by reference to data that 43.7% of the price that constitutes an electric vehicle corresponds to the price of the battery (Fabien and Elisabeth, 2015). The Elec_Batt input into the TransEquipCV before disconnecting the EV corresponds to 331,749(million won). In addition, the total price of a TransEquipEV separated using a ratio of 0.48% corresponds to 415,884(million won). Because 415,884 (million won) and 43.7% of the Elec_Batt input to be added is the Elec_Batt input, the corresponding cost of 181,739 (million won) is transferred from the Elec_Batt part of the TransEquipCV. These classifications of Elec_Batt are shown in Table 7. :

Table 7. Classification of Battery goods

	TransEquipCV	TransEquipEV
Elec_Batt	150,010	181,739
Total	87,083,309	415,881

As shown above, further classification of TransEquipEG (engine) and Elec_Batt (battery) extends the SAM from the existing 47 to 49X49 Matrix, as follow Table 8.

Table 8. 49X49 SAM Configuration

A (47 x 47)	D (47 x d)
V (v x 47)	(blank)

A (49 x 49)	D (49 x d)
V (v x 49)	(blank)

3.1.4 Transportation Segment Top-down Module

To analyze CV and EV industries consumed by Household into CGE models, top-down models were refined to enable linkage of transport sectors. In order to separate the energy demand in the transport sector, the demand for energy divided into transport demand in the industrial sector and the demand for gasoline, diesel and LPG in the household were all transferred to the road passenger service. This implies that the majority of transport energy demand within the household and industry sectors replaces passenger services (even when large transport vehicles such as buses are used), and that it is common for freight services in each industry to employ external services rather than internal supply. In this study, the term was newly coined, as shown in the following table, when reorganizing the industry association tables. The following are the English form that can be used directly in the operation and the matching on the industry association Table 9.

Table 9. Matching table between Industrial relationship table and this research

Number	Name on Industrial relationship table	Name on this Research
1	Agricultural and fisheries products	Agri
2	Coal	Coal
3	Crude oil	Oil
4	Natural Gas	NaturalGas

5	Mining (excluding 2,3,4)	Mining
6	Groceries	Food
7	Textile and leather goods	FiberLeather
8	Wood and paper, printing	WoodPaper
9	Coal products	CoalPro
10	Other Petroleum products	OilPro
11	Gasoline	Gasoline
12	Jet Oil	JetOil
13	Kerosene	Kerosene
14	Diesel	Diesel
15	Heavy Oil	HeavyOil
16	LPG	LPG
17	Chemical products	Chemical
18	Nonmetallic mineral products	NonMetal
19	Primary metal products	PriMetal
20	Secondary metal products	Metal
21	Computer, Electronics and Optical Devices	Computer
22	Electrical Equipment	ElecEquip
23	Battery	Elec_Batt
24	Machinery and Equipment	Machine
25	Transportation Equipment	**TransEquip**

26	Car (CV)	**TransEquipCV**
27	Electric vehicle (EV)	**TransEquipEV**
28/	Engine	**TransEquipEG**
29	Other Manufactured products	MissManu
30	Repair manufacturing and industrial equipment	IndiEquip
31	Electricity and renewable energy	Elec
32	LPG	Gas
33	Steam and hot water	Steam
34	Wastewater, Waste Disposal	WaterWaste
35	Construction	Const
36	Wholesale and retail goods brokerage service	WholeServ
37	Transport Service	**TransServOthers**
38	Road Passenger Transport Service (CV) (Bus, Taxi, and Vehicle which are not included Gasoline/Diesel/LPG)	**BusTaxi**
39	Road Passenger Transport Service (CV_Gasoline)	**TransServ_Gasoline**
40	Road Passenger Transport Service (CV_Diesel)	**TransServ_Diesel**
41	Road Passenger Transport Service (CV_LPG)	**TransServ_LPG**
42	Road Passenger Transport Service (EV)	**TransServ_EV**
43	Restaurants and Accommodation Services	AccomServ

44	Information and Communication Service	ITServ
45	Financial and Insurance Services	FinServ
46	Real estate service	EstateServ
47	Professional, scientific and technical services	ScienceServ
48	Business support service	BusiServ
49	Public administration, national defense and social security	Administration
50	Educational service	EduServ
51	Social welfare service	SocialServ
52	Arts, sports and leisure-related services	CultureServ
53	Other services	MissServ
54	etc	Miss

The SAM was reconstructed by classifying 'Road Passenger Transport Service' (I-O Table Basic Sections 5321), which included passenger cars, in a matrix that was divided into existing transport services(TransServOthers) according to 4^{th} report of 'Development of Integrated Reducing System for Greenhouse Gases in Korea'. Road passenger transport services include passenger cars and public transportation. In other words, in the SAM used in this study, Household changed its use of passenger cars to those used by the transportation service industry, not directly by passenger cars. In other words, Household is a form of transportation service industry. And transport service industry buys passenger cars that were classified as TransEquipCV and TransEquipEV. It is assumed that the 'road passenger transport service' divided into Bus and Taxi(BusTaxi), and Vehicles with three fuel types configurations again, and that all road passenger transport services used by other industrial groups are CVs. More specifically, passenger cars were divided into three groups according to fuel. Each passenger car was divided into gasoline, diesel and LPG vehicles, and all other fuel-use vehicles were included in the BusTaxi group. This granular SAM configuration can be found in the following Table 10 and Table 11:

Table 10. Original Household consume structure

	BusTaxi	Household
TransEquipCV	A	B
BusTaxi	C	D

Table 11. Household consume structure for this study

	BusTaxi	Household
TransEquipCV	A+B	0
BusTaxi	C	D+B

In this study, 54X54 consists of the following Table 11 items, including the additional categories of three fuel types of vehicles in the consumption.

Table 12. 54X54 SAM Configuration

A (49 x 49)	D (49 x d)
V (v x 49)	(blank)

A (54 x 54)	D (54 x d)
V (v x 51)	(blank)

3.1.5 RAS

The 54X54 SAM often contain cells with negative values. This is the negative value that arises from the act of reselling used goods, etc., and we have to treat it arbitrarily as '0' for the analysis of the computable general equilibrium model. In addition, households' income should be arbitrarily changed to '0' if negative values exist. If we change the data of cells with random negative values, the column sum and row sum of 54X54 SAM will not match. In this study, the balance of SAM is finally adjusted using the RAS method to balance the matrices (Veronique Robichaud, 2010). RAS is a methodology widely used to balance or update the matrix. This technique starts with an initial shared matrix where the final matrix must be derived, such as the sum of rows and columns given is respected.

3.2 Construction of Computable General Equilibrium Model

A structure-based system is required throughout the national economy to systematically understand the overall flow of complex national economies and to understand the effects of various types of economic policies or changes in economic systems on economic variables. This type of structural equation is called General Equilibrium Mode: GE Model. The general equilibrium model seeks the solution of the coalition formula system, which gives us information on what situation the national economy is in under certain assumptions. What is more important in a realistic sense, however, is the applicability of the general equilibrium theory mentioned above to the real problem. CGE (computable general equilibrium) model the abstract general equilibrium model specific concerning the production technology, government relations, the government's economic policy by introducing a family of the economy. Expressed in an equation that describes the general equilibrium framework. Therefore, CGE Model can be regarded as a feasible form of a general equilibrium theory, or general equilibrium model (Choi, 2002).

3.2.1 Structure of CGE

Factors that change due to increased demand for electric vehicles include input prices, consumption of goods, and investment and savings. To see the changes in these various factors, this study developed the CGE model according to the static standard CGE model (Hosoe et al., 2010). In this model, the nested Armington structure (Armington, 1969) was used by default. For more detailed analysis, we divided the various energy sources (oil, gas and electricity) in detail.

3.2.2 Equation of CGE model

3.2.2.1 Variable description

In the CGE model, there are various variables and various quotations. Variables and quotations are important measures of economic activity. The table below shows the parameters and quotations used in this study.

Table 13. Variables description

Parameters	Definition
α_i	Share parameter in utility function
β_j^h	Share parameter in production function
b_j	Scale parameter in production function
$ax(i, j)$	Intermediate input requirement coefficient
$ay(j)$	Composite factor input requirement coefficient
μ_i	Government consumption share
λ_i	Investment demand share
δ_i^m	Share parameter in Armington's function
δ_i^d	Share parameter in Armington's function
γ_i	Scale parameter in Armington's function
$X_i^d(i)$	Share parameter in transformation function

$X_i^e(i)$	Share parameter in transformation function
$theta(i)$	Scale parameter in transformation function
ssp	Average propensity for private saving
ssg	Average propensity for government saving
$taud$	Direct tax rate
$Taue(en)$	Carbon tax rate (applied for energy sector only)
$gammay(j)$	Scale parameter in CES function (Y)
$deltaHKTE(j)$	Share parameter in CES function (HKTE)
$ae(i,j)$	Energy input requirement coefficient
$ak(j)$	Capital requirement coefficient

Table 14. Variables description

Variables	**Definition**
$Y(j)$	Composite factor
$F(h,j)$	The h^{th} factor input by the j^{th} firm
$X(i,j)$	Intermediate input
$Z(j)$	Output of the j^{th} good
$X^p(i)$	Household consumption of the i^{th} good
$X^g(i)$	Government Consumption

$X^v(i)$	Investment demand
$E(i)$	Exports
$M(i)$	Imports
$Q(i)$	Armington's composite good
$D(i)$	Domestic good
$p^f(h)$	The h^{th} factor price
$p^y(j)$	Composite factor price
$p^z(j)$	Supply price of the i^{th} good
$p^q(i)$	Armington's composite good price
$p^e(i)$	Export price in local currency
$p^m(i)$	Import price in local currency
$p^d(i)$	The i^{th} domestic good price
epsilon	Exchange rate
S^p	Private saving
S^g	Government saving
T^d	Direct tax
$T^z(j)$	Production tax

$T^{m}(i)$	Import tariff
$T^{e}(j)$	Carbon tax
UU	Utility [fictitious]
$T_{i}^{h}(i,uh)$	Indirect tax-household
$T_{i}^{i}(i,ui)$	Indirect tax-investment
$T_{i}^{e}(i,ue)$	Indirect tax-export

3.2.2.2 Domestic production

Firms shall be intermediate inputs and production factors values, and examples of production factors are capital and labor. Capital and labor are used in the production of composite factor or value added.

The production process of composite components can be seen as a virtual factory's behavior of maximizing profits by selecting the production level and input usage according to the relative price to which the technology is targeted. The composite factor is then combined with intermediate inputs to create a cross dynamic output. We call this the gross dynamic output function.

3.2.2.3 Government behavior

The CGE model is also used in policy analysis. The most important consideration is 'can we respond to the continuing changes in government policy?' Moreover, the actual CGE model must include government factors, where governments pay taxes and consume goods. Of course, the government's activities cannot be completely modelled from a microeconomic point of view, but they are modelling government activities as perfectly as possible in line with the analysis purpose and data of this study. In other words, government income comes from taxes in this model are direct tax, direct tax, import and export target. In this study, it is assumed that the government uses τ^d as the direct tax rate of household company and τ_j^Z as the direct tax rate of the gross dynamic output. Also τ_i^m for an ad valorem import tariff on imports. In this study, it assumes that the government spends all tax revenues on their consumption and consume goods in fixed rates of total expenditure. These assumptions are as follows Eq.(4) ~ Eq.(9) :

$$T^d = \tau^d \sum_h p_h^f FF_h \quad \cdots\cdots \text{Eq. (4)}$$

$$T_j^Z = \tau_j^Z p_j^Z Z_j \quad \forall j \quad \cdots\cdots \text{Eq. (5)}$$

$$T_i^m = \tau_i^m p_i^m M_i \quad \forall i \quad \cdots\cdots$$

$$X_i^g = \frac{\mu_i}{p_i^q}\left(T^d + \sum_j T_j^Z + \sum_j T_j^m + \sum_j T_{j,HOH}^{ih} + \sum_j T_{j,INV}^{ii} + \sum_j T_{j,EXT}^{ie} - S^g \right) \quad \forall i \quad \cdots \text{Eq. (6)}$$

$$T_{i,uh}^{ih} = \tau_{i,uh}^{ih} p_i^q X_i^p \quad \cdots\cdots \text{Eq. (7)}$$

$$T_{i,ui}^{ii} = \tau_{i,ui}^{ii} p_i^q X_i^v \quad \cdots\cdots \text{Eq. (8)}$$

$$T_{i,ue}^{ie} = \tau_{i,ue}^{ie} \varepsilon p_i^{We} E_i \quad \cdots\cdots \text{Eq. (9)}$$

When the government sells assets, such sales appear to be negative in the IO table. The application of proportionate government expenditure activities described above may not be appropriate for such negative consumption cases. We can instead develop models that allow negative value to some government consumption.

3.2.2.4 Investment and savings behavior

In the CGE model used in the study, investments and savings are also reflected in the model. Investments and savings cannot be easily reflected in a basic static model, but CGE models reflect them in consideration of the large impact on end demand.

Investment agent receives funds from household, government and external sensors invest in buying investment products. Although Household and the government can determine their respective investments and savings, the model used in this study assumes that the virtual agent absorbs all savings and uses a certain percentage for buying goods. The constant share at this time is λ_i. This investment-related demand function Eq.(10) is as follows. This formula is similar to the government's demand function for goods.

$$X_i^v = \frac{\lambda_i}{(1+\tau_{i,INV}^{ii} p_i^q)} \left(S^p + S^q + \varepsilon S^f \right) \quad \forall i \quad \cdots\cdots \text{Eq. (10)}$$

The variables in the right parentheses depend on household saving and administration and external sector saving. The important thing is that share parameters are like unity and the total savings in the economy from above are always equal to total investment. Assume that savings in household and governments' savings are determined by a constant average tendency for savings. By this assumption, we can get the following equations from Eq.(11) to Eq.(12) about savings.

$$S^p = ss^p \sum_h p_h^f FF_h \quad \cdots\cdots \text{Eq. (11)}$$

$$S^g = ss^g \left(T^d + \sum_j T_j^Z + \sum_j T_j^m + \sum_j T_j^e + \sum_j T_{j,HOH}^{ih} + \sum_j T_{j,INV}^{ii} + \sum_j T_{j,EXT}^{ie} \right) \quad \cdots\cdots \text{Eq. (12)}$$

It is important that investments determined by the investment equation mean giving up products that do not contribute to household utility or solid production. Utility function is not dependent on investment X_i^v.

3.2.2.5 Household consumption behavior

To maintain the utility function, the budget constraint of the household must be defined as follows. In this study, the consumption equation of household is as follows because the funds that household can consume goods were reduced by savings of household and direct tax payment. Households have a Cobb-Douglas utility function consisting of household savings and 'Armington's commodity consumption' and choose the biggest utility. Eq(13). Explains household demand function for i-th good.

$$X_i^p = \frac{\partial_i}{((1+\tau_{i,HOH}^{ih})p_i^q}\left(\sum_h p_h^f FF_h - S^p - T^d\right) \quad \forall i \quad \cdots\cdots\cdots\cdots\cdots\cdots \text{Eq. (13)}$$

3.2.2.6 International trade

Since the country buys the goods from the other countries and sells the products to other countries, CGE model should concern about the export and import too. Here, the price based on the local exchange rate can be expressed in an quotations related to p_i^e , p_i^m and the prices related to foreign exchange rates can be expressed in p_i^{We}, p_i^{Wm} , respectively. In addition, in a Standard CGE Model, contract prices and import prices based on foreign exchange rates can be represented as in Eq.(14) ~ Eq.(16).

$$p_i^e = (1-\tau_{i,EXT}^{ie})\varepsilon p_i^{We} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{Eq. (14)}$$

$$p_i^m = \varepsilon p_i^{Wm} \quad \cdots\cdots \text{Eq. (15)}$$

$$\sum_i (1+\tau_{i,EXT}^{ie}) p_i^{We} E_i + S^f = \sum_i (p_i^{Wm} M_i) \quad \cdots\cdots \text{Eq. (16)}$$

3.2.2.7 Armington's function

The CGE model assumes an incomplete alternative relationship in consumption between goods imported and domestic production goods, which is called the Armington's assumption. Therefore, Armington goods are supplied by CES technology as an input element for imported and domestic goods. Businesses demand Armington goods as interim goods and households and governments as final consumer goods (Kim and Park, 2012). The producing equation for i-th Armington composite good is written as Eq.(17).

$$Q_i = \gamma_i (\delta m_i M_i^{\eta_i} + \delta d_i D_i^{\eta_i})^{\frac{1}{\eta_i}} \quad \cdots\cdots \text{Eq. (17)}$$

Additionally, the demand functions for imports and the domestic good on the first order conditions are written as Eq.(18) and Eq.(19).

$$M_i = \left[\frac{\gamma_i^{\eta_i} \delta m_i p_i^q}{(1+\tau_i^m) p_i^m} \right]^{\frac{1}{1-\eta_i}} Q_i \quad \forall i \quad \cdots\cdots \text{Eq. (18)}$$

$$D_i = \left[\frac{\gamma_i^{\eta_i} \delta d_i p_i^q}{p_i^d} \right]^{\frac{1}{1-\eta_i}} Q_i \quad \forall i \quad \cdots\cdots \text{Eq. (19)}$$

3.2.2.8 Transformation function

In terms of supply, there are exports and domestic goods. We assume the companies turn domestic gross production into goods sold in the international and domestic markets. In this transition, we also assume an incomplete replacement between exports and the supply of domestic goods.

The problem of maximizing profits for the i-th company, which turns gross domestic product into exports and domestic products, can be expressed as follows like Eq.(20).

$$Z_i = \theta_i (\xi e_i E_i^{\phi_i} + \xi d_i D_i^{\phi_i})^{\frac{1}{\phi_i}} \quad \cdots\cdots \text{Eq. (20)}$$

By solving these maximization problems, we get the following supply functions for exports and domestic goods as Eq.(21) and Eq.(22).

$$E_i = \left[\frac{\theta_i^{\phi_i} \xi e_i (1+\tau_i^Z) p_i^Z}{p_i^e} \right]^{\frac{1}{1-\phi_i}} Z_i \quad \cdots\cdots \text{Eq. (21)}$$

$$D_i = \left[\frac{\theta_i^{\phi_i} \xi d_i (1+\tau_i^Z) p_i^Z}{p_i^d} \right]^{\frac{1}{1-\phi_i}} Z_i \quad \cdots\cdots \text{Eq. (22)}$$

3.2.2.9 Market-clearing conditions

The previous quotations described all the economic conditions. Now, in the last step, set the following equation so that the demand and supply match in all the markets. Equation 23 described the market-clearing condition for the Armington composite goods. The Q_i, composite good is used by household, the government and the investment agent for intermediate input. We put the equal price as p_i^q for all of them. Equation 24 is the factor market clearing condition. In this model, the price p_i^q (the price that the household faces) isn't directly linked to the price p_i^z (firm faces). The substitution between imports goods and domestic goods represented by CES and CET, face the equality between the demand and supply of goods by the agents.

Eq.(23) and Eq.(24) are the final stage of this modelling process, which can meets supply and demand in the markets.

$$Q_i = X_i^p + X_i^g + X_i^V + \sum_j X_{i,j} \quad \forall i \quad \cdots\cdots \text{Eq. (23)}$$

$$\sum_j F_{CAP,j} = FF_{CAP} \quad \cdots\cdots \text{Eq. (24)}$$

3.3 Configure Scenarios that reflect policies

In this study, it will form a scenario that reflects policies regarding electric vehicles in South Korea. Korea's ‘2030 Greenhouse Gas Reduction Roadmap’ is the first. The roadmap's transportation section describes the expansion and distribution of electric cars to reduce greenhouse gas emissions. The plan is to supply 3 million electric cars by 2030. To that end, the government said it will gradually expand development of electric vehicle technologies and subsidies. The second is based on the ‘Korea Energy Vision 2040 Third Basic Plan for Sustainable Prosperity’. The Energy Basic Plan is the top-level statutory plan for the energy sector, which is set up every five years, and is a comprehensive plan that presents the vision, goals and implementation strategies of mid- and long-term energy policies for the next 20 years. The third basic energy plan noted that the transportation sector plans to distribute 8.3 million electric vehicles by 2040.

The number of cars registered, including electric vehicles, also follows the outlook of the Ministry of Land, Infrastructure and Transport. According to the Ministry of Land, Infrastructure and Transport's Vehicle Management Information System (VMIS), the overall increase in the number of cars registered is slowing down, but the annual growth rate of 3 percent is expected to be maintained. Based on data from the Ministry of Land, Infrastructure and Transport that 23.2 million cars were registered as of 2018, this study predicts the total number of cars registered in Korea, as shown in Table 15.

Table 15. Estimate the number of cars registered

	2018	2030	2040
Number of cars (million)	23.2	33.08	44.45

In other words, suppose 3 million out of the total 33.08 million vehicles were electric vehicles as of 2030, according to the government's scenario. Then, as of 2030, the percentage of electric cars is about 9.07 percent. Similarly, if 8.3 million out of 44.45 million vehicles were electric vehicles as of 2040, the ratio would be about 18.7 percent.

The study organized a scenario based on the above policies to spread electric vehicles, which would further raise the nation's electric vehicle registration rate. Based on the table above, it was assumed that 30 percent of the nation's automobile registration rate corresponds to electric vehicles. In addition, the ratio of gasoline, diesel and LPG vehicles to electric vehicles was different, so the reduction in which vehicles (i.e., which fuel vehicles are replaced) could have a significant impact on air pollutant emissions.

Table 16. Scenarios in this research

Scenario	Gasoline	Diesel	LPG	EV
Scenario A		Consistent with current		30%
Scenario B	Replace 30%	No Change	No Change	30%

	increase in EV			
Scenario C	No Change	Replace 30% increase in EV	No Change	30%
Scenario D	No Change	No Change	Replace 30% increase in EV	30%

3.3.1 Comparison of emissions of air pollutants

In this study, policy scenarios are analyzed based on emissions of air pollutants per unit price. To calculate emissions based on policies to be reflected in the scenario, the concept of 'emission per unit price' is used. The dictionary definition of emission per unit price refers to the amount of raw materials, power, and labor required to make a single product. Therefore, the unit discharge amount of unit price can be defined as the amount of contaminants emitted when producing a single product. The emission per unit price standards help determine product superiority in environmental aspects because they allow direct comparisons between production.

In this way, once the emission per unit price in 2015 are calculated based on the 2015 Industrial Relations table and 2015 Air Pollutant emissions, this coefficient allows us to calculate future emissions. Multiply the industry year 2015's emission per unit price in an industry association table that will be changed by the electric vehicle policy roadmap, so that air pollutants emissions can be calculated in the year in which the policy will be implemented.

The air pollution data is taken from the Clean Air Policy Support System (CAPSS). CAPSS is a comprehensive air quality management system based on the Air Pollutants Emissions Inventory, which provides information service to the public that is required to carry out policies such as measures to improve the air environment in the Seoul metropolitan area, the air pollution control system, and the efficiency assessment of local governments' air exhibition policies through systematic data collection and management. The CAPSS emission classification system and calculation method are based on the European CORINAIR emission source classification system (SNAP 97), and since 2007, the emission source classification system has been changed to suit the domestic reality, and the existing 11 sections have been changed to 13 sections. In addition, in 2011, biological combustion was added to 13 sections from the previous 12 sections. The emission coefficients for determining emissions are calculated by developing and applying emission coefficients that reflect domestic conditions based on the European CORINAIR and U.S. EPA emission coefficients.

In this study, the emission sources provided by CAPSS are newly classified according to the industry association table. Although the SAM used in this study consisted of 51 rows and columns, the classification of the CAPSS emission sources was different from that of SAM's industrial association table, so 21 industries were divided to convert the emission of air pollutants.

Chapter 4. Simulations and Results

In Scenario A, B, C, and D, it is assumed that South Korea's electric vehicle market share has become 30%. Scenario A assumes that the proportion of electric vehicles in Korea is 30% and that the proportion has been reduced to the same rate as the current one. Scenario B assumes that the electric vehicle ratio is the same as 30%, but that ratio has been replaced by a gasoline vehicle. In Scenario C, it is assumed that electric vehicles have replaced diesel cars, and in Scenario D, LPG vehicles have replaced diesel cars.

Prior to each scenario, the 2015 statistics on air pollutant emissions provided by CAPSS are presented as shown in the following Table 17. In particular, it can be seen that the oil refining industry, nonmetals, primary metals, and transport industries emit high amounts of air pollutants. As the figures below show, transportation of freight, railways, and aviation were the overall amount of air pollutants emitted by transport services

Table 17. Amount of air pollutants emitted by industry

	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3	Total
Agri	1.9%	2.0%	0.4%	1.0%	1.6%	2.2%	0.6%	0.5%	1.5%
Mining	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Food	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	18.8%	0.0%	2.6%

FiberLeather	0.1%	0.3%	0.8%	0.9%	0.8%	0.4%	0.0%	0.0%	0.3%
WoodPaper	0.6%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Oil Refining	3.4%	1.3%	21.2%	0.4%	0.2%	0.1%	17.1%	62.6%	7.3%
Chemical	1.8%	1.2%	0.9%	1.6%	1.3%	1.7%	13.7%	0.2%	3.0%
Nonmetal	0.6%	9.1%	9.4%	7.7%	6.9%	5.6%	0.3%	0.2%	6.0%
PriMetal	2.1%	8.0%	25.2%	68.7%	61.5%	52.7%	6.2%	4.8%	16.4%
Metal	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%
Machine	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
Computer	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
ElecEquip	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
MissManu	0.2%	0.6%	1.9%	3.2%	2.8%	1.9%	0.0%	0.1%	0.9%
Elec, Wastewater	11.8%	14.3%	23.7%	2.8%	4.1%	5.4%	2.0%	2.9%	11.9%
Const	12.4%	11.2%	0.0%	3.7%	5.7%	8.3%	4.2%	0.1%	8.0%
Service	4.6%	4.8%	4.3%	0.4%	0.5%	0.6%	17.6%	1.6%	5.8%
TransportEquip	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
TransEquipCV	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
TransServOthers	28.9%	39.1%	11.9%	9.2%	14.1%	20.6%	10.6%	0.3%	25.7%
BusTaxi	1.9%	3.5%	0.0%	0.1%	0.2%	0.3%	3.8%	0.0%	2.3%
TransServGasoline	26.0%	1.8%	0.0%	0.0%	0.0%	0.0%	4.7%	26.2%	6.3%
TransServDiesel	0.1%	1.6%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.7%
TransServLPG	2.9%	0.3%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.6%

Total_TransServ	59.9%	46.3%	11.9%	9.4%	14.4%	21.0%	19.2%	26.5%	35.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

The following table shows the 'emission per unit price' calculated using Table 19. It is a table to find out which industries emit more air pollution at the same price unit by industry. It found that the emission of SOx, TSP, PM10 and PM2.5 are high in nonmetallic and primary metal industries. In addition, emissions of SOx, TSP, PM10, and PM2.5 were high in general transport, not passenger cars. On the other hand, in the passenger car transport sector, it was derived that the remaining air pollutant emissions, excluding CO, are not significantly higher than those of other industries.

Table 18. Emission per unit price by industry

	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3	Total
Agri	0.29	0.72	0.05	0.06	0.06	0.05	0.07	0.01	1.31
Mining	0.03	0.11	0.12	0.00	0.00	0.00	0.00	0.00	0.26
Food	0.00	0.01	0.00	0.00	0.00	0.00	0.69	0.00	0.71
FiberLeather	0.01	0.04	0.04	0.02	0.01	0.00	0.00	0.00	0.13
WoodPaper	0.09	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.12
Oil Refining	0.19	0.17	0.93	0.01	0.00	0.00	0.75	0.31	2.36
Chemical	0.04	0.07	0.02	0.01	0.01	0.01	0.26	0.00	0.42
Nonmetal	0.09	3.31	1.14	0.45	0.27	0.14	0.03	0.00	5.43
PriMetal	0.09	0.79	0.84	1.10	0.64	0.35	0.20	0.02	4.02
Metal	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Machine	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Computer	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01

ElecEquip	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
MissManu	0.02	0.13	0.14	0.11	0.06	0.03	0.00	0.00	0.48
Elec, Wastewater	1.61	4.53	2.53	0.14	0.14	0.11	0.22	0.03	9.31
Const	0.42	0.87	0.00	0.05	0.05	0.04	0.11	0.00	1.54
Service	0.03	0.08	0.02	0.00	0.00	0.00	0.09	0.00	0.22
TransportEquip	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
TransEquipCV	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.03
TransServOthers	1.66	5.23	0.53	0.20	0.20	0.18	0.47	0.00	8.48
BusTaxi	1.06	4.59	0.00	0.03	0.03	0.03	1.66	0.00	7.41
TransServGasoline	6.62	1.07	0.00	0.00	0.00	0.00	0.92	0.59	9.20
TransServDiesel	0.06	1.59	0.00	0.01	0.01	0.01	0.03	0.00	1.71
TransServLPG	3.70	0.77	0.00	-	-	-	0.11	-	4.58
Total	0.20	0.46	0.15	0.07	0.05	0.03	0.15	0.02	1.14

* Unit : (kg/millionKRW)

4.1 Scenario A

The first scenario reflects the 2040 Government Roadmap referred to in Chapter 3. According to the South Korean government's plan, the country plans to gradually increase its market share of electric cars. Scenario A assumes that electric vehicles have a market share of 30 percent, and that the proportion of the type of internal combustion vehicles that are decreasing is consistent with the present.

Table 19. Ratio of Scenario A

	Gasoline	Diesel	LPG	EV
Ratio in 2015	55.5%	33%	11%	0.38%
Ratio of	45.6%	23%	1%	30%

Based on the scenario, the proportion of electric vehicles will became 30%. The amount of air pollutants emitted by this scenario is as shown in Table 22. According to Table 22, air pollutants emitted from the passenger car transport sector will be reduced by about 46,747 tons. More specifically, CO was significantly reduced by a 31,327 ton decrease, but did not show a significant decrease in the SOx and TSPs, PM10, and PM2.5. Rather, air pollutants increased greatly in the changes of the PriMetal and Nonmetal industries.

In addition, the production volume of the ElecEquip industry, which includes the battery industry, a major component of electric vehicle volume, increased the emission of air pollutants in the ElecEquip industry.

Even more dramatic was the PriMetal industry, which showed a particularly large increase in NOx, SOx, TSP, PM10, and PM2.5.

The transport sector's policies have led to a reduction in all parts of the air pollution emissions of the transport sector, but the increase in the electric vehicle production market has resulted in an increase in the number of primary metals, engine and other related industries, thereby offsetting the overall amount of air pollution emissions.

According to the results of Scenario A, if 30% of market share of electric vehicles are satisfied in future, there will be a decrease in overall air pollutant emissions as the manufacturing market for electric vehicles will be activated. Although reductions in internal combustion engine vehicles could have led to reductions in CO and NOx, the categories SOx and TSP, PM10, and PM2.5 show higher emissions than those caused by electric vehicles in other industries.

Table 21 shows the rate of increase and decrease in air pollutant emissions for all industrial groups, including transport and transport. The increase in electric vehicles also reduced all air pollutants in the transportation sector. However, the decrease rate of TSP, PM10, and PM2.5, which is equivalent to dust, was not significant, and SOx, which is a precursor to fine dust, also showed a smaller decrease rate. For this reason, the process to produce electric vehicles in other industrial groups is in operation, indicating a positive increase in SOx, TSP and PM10.

The following Table 20 shows the increase and decrease of air pollutant emissions from gasoline, diesel and LPG vehicles in Scenario A. In Scenario A, the rate of decreasing vehicle type is consistent with the previous one, and the following emissions increases and decreases are as follows:

Table 20. Increase and decrease of air pollutants by fuel type (Scenario A)

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
CV(Gasoline)	-20,040.4	-3,225.9	-9.4	-3.7	-3.7	-3.4	-2,785.6	-1,785
CV(Diesel)	-192.1	-4,796.2	-1.5	-20.3	-20.3	-18.7	-100.5	-3.4
CV(LPG)	-11,094.5	-2,303.9	-9.5	0.0	0.0	0.0	-329.8	0.0
Total	-31,539.4	-7,113.9	426	3,063.2	1,786.6	948.7	-4,896.1	-2,537

Table 21. Rate of increase and decrease (Scenario A)

%	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
Transportation	-12.38	-2.35	-0.16	-0.26	-0.26	-0.26	-5.15	-17.89
Total	-7.43	-0.72	0.13	1.93	1.72	1.45	-1.49	-6.74

Contrary to the expectation that all air pollutants will be reduced due to the change in the transportation market, the linkage structure of the entire Korean industrial structure shows that direct emission of fine dust has increased. In addition, emissions that can be a precursor to fine dust have also been largely offset by other industrial groups.

Table 22. Amount of air pollutants emitted by industry

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3	Total
Agri	-13.8	-34.3	-2.2	-2.9	-2.8	-2.4	-3.4	-0.3	-62.1
Mining	0.9	3.9	4.4	0.0	0.0	0.0	0.1	0.1	9.6
Food	-0.6	-1.7	-0.1	-0.0	-0.0	-0.0	-98.3	-0.0	-100.8
FiberLeather	-3.4	-24.1	-25.4	-13.4	-7.8	-2.7	-0.5	-0.1	-77.4
WoodPaper	6.7	1.6	0.4	0.12	0.1	0.1	0.1	0.0	9.0
Oil Refining*	-484.2	-436.8	-2,383.9	-21.8	-6.5	-1.8	-1,912.6	-800.5	-6,048.0
Chemical	-27.1	-42.1	-11.3	-9.5	-5.0	-4.0	-164.8	-0.3	-264.2
Nonmetal	46.7	1,658.3	573.9	225.7	133	67.7	16.8	1.4	2,723.6
PriMetal	239.4	2,103.6	2,229	2,913.9	1705.0	919.8	544.3	47.9	10,702.8
Metal	-7.6	-22.1	-2.1	-2.0	-1.2	-0.6	-1.0	-0.3	-37
Machine	-5.7	-16.3	-0.5	-0.0	-0.0	-0.0	-0.8	-0.2	-23.6
Computer	-17.2	-47.3	-0.1	-0.0	-0.0	-0.0	-2.3	-0.7	-67.7
ElecEquip	70.8	199.5	5.5	0.3	0.2	0.2	9.5	2.8	288.8

MissManu	0.4	3.1	3.3	2.6	1.5	0.7	0.1	0.0	11.7
Electricity**	81.4	228.9	128.0	7.2	6.9	5.7	11.0	1.8	470.9
Const	29.2	61.1	0.0	3.3	3.3	3.0	7.7	0.0	107.6
Service	-14.9	-36.2	-10.9	-0.5	-0.4	-0.3	-44.7	-0.5	-108.2
TransEquip	-9.8	-45.1	-21.1	-0.4	-0.3	-0.2	-1.3	-0.9	-79.0
TransEquipCV	30.7	86.8	1.0	0.1	0.1	0.1	4.0	1.3	124.2
TransServOthers	-129.5	-408.0	-41.7	-15.5	-15.5	-14.2	-36.7	-0.1	-661.1
CV (etc.)	-4.8	-20.6	0.0	-0.1	-0.1	-0.1	-7.4	0.0	-33.2
CV (Gasoline)	-20,040.4	-3,225.9	-9.4	-3.7	-3.7	-3.4	-2,785.6	-1,785.0	-27,857.1
CV (Diesel)	-192.1	-4,796.2	-1.5	-20.3	-20.3	-18.7	-100.5	-3.4	-5,153.1
CV (LPG)	-11,094.5	-2,303.9	-9.5	0.0	0.0	0.0	-329.8	0.0	-13,737.6
Total	-31,539.4	-7,113.9	426.0	3,063.2	1,786.6	948.7	-4,896.1	-2,537.0	-39,862.0

Note: 1) Oil Refining* contains CoalPro, OilPro, Gasoline, JetOil, Kerosene, Diesel, HeavyOil, LPG

2) Electricity** contains Elec, Gas, Steam, WasteWater

4.2 Scenario B

In Scenario B, the reduction rate was different for each fuel, unlike Scenario A. For Scenario B, it was assumed that when electric vehicles occupied 30% of the total market, all of those increases would be converted from gasoline vehicles. The changes are showed in Table 23.

Table 23. Changes in Scenario B

	Gasoline	Diesel	LPG	EV
Ratio in 2015	55.5%	33%	11%	0.38%
Changes in Scenario B	25.9%	33.1%	11.1%	30%

Changes in air pollutant emissions due to these assumptions are shown in Table 24. Since the number of diesel and LPG vehicles was maintained, the reduction in air pollutant emissions was very small. However, with 30 percent of the passenger car market being replaced by electric vehicles from gasoline vehicles, the amount of increase and decrease in air pollutant emissions from gasoline vehicles has greatly increased.

Table 24. Increase and decrease of air pollutants by fuel type (Scenario B)

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
CV(Gasoline)	-59,182.15	-9,526.48	-27.76	-10.95	-10.95	-10.07	-8,226.12	-5,271.31

CV(Diesel)	-1.58	-39.47	-0.01	-0.17	-0.17	-0.15	-0.83	-0.03
CV(LPG)	-27.00	-5.61	-0.02	0.00	0.00	0.00	-0.80	0.00
Total	-59,692.55	-6,567.71	-883.35	3,121.33	1,829.33	977.68	-10,984	-6,467.39

As shown in the table above, the reduction of air pollutants in diesel and LPG vehicles is very small. However, there has been a significant drop in CO, NOx, VOC and NH3. What is different from Scenario A is that the air pollutants in the SOx have decreased. This may be because gasoline is the type of fuel that had high levels of price unit of SOx emissions as of 2015. Due to the explosive reduction of gasoline, the amount of SOx emissions was also reduced, which soon led to an overall reduction in the amount of SOx emissions. Table 25 and Table 26 shows the rate of increase and decrease in Scenario B and Amount of air pollutants emitted by industry in Scenario B.

Table 25. Rate of increase and decrease (Scenario A-b)

%	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
Transportation	-23.35	-2.19	-0.18	-0.18	-0.18	-0.18	-13.06	-52.73
Total	-14.06	-0.67	-0.27	1.96	1.76	1.49	-3.33	-17.17

Table 26. Amount of air pollutants emitted by industry (Scenario B)

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3	Total
Agri	-14.3	-35.6	-2.2	-3.0	-2.9	-2.5	-3.6	-0.4	-64.4
Mining	1.0	3.9	4.5	0.1	0.0	0.0	0.1	0.1	9.7
Food	-0.6	-1.8	-0.1	0.0	0.0	0.0	-102.1	0.0	-104.6
FiberLeather	-3.5	-25.0	-26.4	-13.9	-8.1	-2.8	-0.5	-0.1	-80.4
WoodPaper	6.4	1.5	0.4	0.1	0.1	0.1	0.1	0.0	8.5
Oil Refining*	-755.6	-681.5	-3,719.6	-34.1	-10.1	-2.8	-2,984.3	-1,249.0	-9,437.0
Chemical	-29.2	-45.3	-12.2	-10.2	-5.4	-4.3	-177.2	-0.3	-284.0
Nonmetal	46.6	1,655.1	572.8	225.3	132.7	67.6	16.8	1.4	2,718.4
PriMetal	244.6	2,148.9	2,276.8	2,976.5	1,741.7	939.6	556.0	48.9	10,933.0
Metal	-7.0	-20.5	-1.9	-1.9	-1.1	-0.6	-0.9	-0.3	-34.2
Machine	-5.7	-16.1	-0.5	0.0	0.0	0.0	-0.8	-0.2	-23.3
Computer	-17.7	-48.6	-0.1	0.0	0.0	0.0	-2.4	-0.7	-69.6
ElecEquip	70.3	198.3	5.5	0.2	0.2	0.2	9.5	2.8	287.0

MissManu	-0.1	-0.7	-0.7	-0.6	-0.3	-0.2	0.0	0.0	-2.6
Electricity**	75.7	212.9	119.1	6.7	6.5	5.3	10.2	1.6	438.0
Const	29.6	61.9	0.0	3.3	3.3	3.1	7.8	0.0	109.0
Service	-15.2	-37.0	-11.1	-0.5	-0.4	-0.3	-45.6	-0.5	-110.5
TransEquip	-9.0	-41.2	-19.3	-0.3	-0.3	-0.2	-1.2	-0.8	-72.3
TransEquipCV	34.9	98.9	1.2	0.2	0.1	0.1	4.6	1.5	141.5
TransServOthers	-129.3	-407.4	-41.6	-15.4	-15.4	-14.2	-36.7	-0.1	-660.1
CV (etc.)	-3.9	-16.8	0.0	-0.1	-0.1	-0.1	-6.1	0.0	-27.1
CV (Gasoline)	-59,182.2	-9,526.5	-27.8	-11.0	-11.0	-10.1	-8,226.1	-5,271.3	-82,265.8
CV (Diesel)	-1.6	-39.5	0.0	-0.2	-0.2	-0.2	-0.8	0.0	-42.4
CV (LPG)	-27.0	-5.6	0.0	0.0	0.0	0.0	-0.8	0.0	-33.4
Total	-59,692.6	-6,567.7	-883.4	3,121.3	1,829.3	977.7	-10,984.0	-6,467.4	-78,666.6

Note: 1) Oil Refining* contains CoalPro, OilPro, Gasoline, JetOil, Kerosene, Diesel, HeavyOil, LPG

2) Electricity** contains Elec, Gas, Steam, WasteWater

4.3 Scenario C

ScenarioC assumes a scenario in which a diesel vehicle is replaced by an electric vehicle, unlike Scenario B. As South Korea is establishing a road map to abolish old diesel cars, the analysis of increased and reduced emissions of air pollutants will be meaningful as a result of the scenario C.

Table 27. Changes in Scenario C

	Gasoline	Diesel	LPG	EV
Ratio in 2015	55.5%	33%	11%	0.38%
Changes in Scenario C	55.5%	3.4%	11%	30%

Based on these assumptions, the analysis of the increase and decrease of the emission of air pollutants has been performed again, and the results are shown in the following table. As can be seen in Table 28 gasoline and LPG vehicles have maintained a proportion, but diesel vehicles have replaced 30 percent of the total passenger car market with electric vehicles. As a result, TSP, PM10, and PM2.5, which had high emissions of existing price units, have significantly decreased. On the other hand, in CO, SOx, VOC and NH3, where emissions in price units were lower than other fuels, the change in air pollutant emissions was minimal, despite a 30 percent change in the overall market.

Table 28. Increase and decrease of air pollutants by fuel type (Scenario C)

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
CV(Gasoline)	-201	-32	-0	-0	-0	-0	-28	-18
CV(Diesel)	-569	-14,194	-4	-60	-60	-55	-297	-10
CV(LPG)	-23	-5	-0	0	0	0	-1	0
Total	-969	-10,947	449	2,984	1,726	904	-1,948	-768

However, it did not have a significant impact on the overall increase or decrease in air pollutant emissions. The amount of SOx, TSP, PM10 and PM2.5 increased rather, similar to that of Scenario A Compared with Scenario B, the rate of reduction of NOx and CO was shown to increase rather than increase.

Table 29. Rate of increase and decrease (Scenario C)

%	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
Transportation	-0.35	-3.18	-0.09	-0.48	-0.48	-0.48	-0.57	-0.28
Total	-0.23	-1.11	0.14	1.88	1.66	1.38	-0.59	-2.04

The table above shows the rate of increase and decrease of air pollutants in scenario C. The reduction rate of dust-related air pollutants, which had high emissions in price units, has increased, but this has also been offset by the explosive increase in the battery industry. Overall, it is analyzed that changes in the transport sector have less effect on the increase and decrease of air pollutant emissions in CO, VOC and NH_3 compared to scenario B.

Table 30. Amount of air pollutants emitted by industry (Scenario C)

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3	Total
Agri	-12.6	-31.4	-2.0	-2.6	-2.6	-2.2	-3.1	-0.3	-56.8
Mining	0.9	3.9	4.5	0.0	0.0	0.0	0.1	0.1	9.6
Food	-0.6	-1.6	-0.1	0.0	0.0	0.0	-90.5	0.0	-92.7
FiberLeather	-3.1	-22.0	-23.1	-12.2	-7.1	-2.5	-0.4	-0.1	-70.5
WoodPaper	7.2	1.7	0.4	0.1	0.1	0.1	0.1	0.0	9.7
Oil Refining*	-478.3	-431.4	-2,354.6	-21.6	-6.4	-1.8	-1,889.2	-790.6	-5,973.9
Chemical	-22.7	-35.3	-9.5	-7.9	-4.2	-3.3	-137.9	-0.3	-221.1
Nonmetal	46.7	1,659.3	574.3	225.9	133.1	67.8	16.8	1.4	2,725.3
PriMetal	235.2	2,066.2	2,189.3	2,862.1	1,674.7	903.5	534.6	47.0	10,512.6
Metal	-7.9	-23.0	-2.2	-2.1	-1.2	-0.7	-1.1	-0.3	-38.5
Machine	-5.6	-15.9	-0.5	0.0	0.0	0.0	-0.8	-0.2	-23.0
Computer	-15.8	-43.6	-0.1	0.0	0.0	0.0	-2.1	-0.6	-62.3
ElecEquip	70.2	198.1	5.5	0.2	0.2	0.2	9.5	2.8	286.6

MissManu	0.6	4.6	5.0	3.9	2.3	1.0	0.1	0.0	17.4
Electricity**	82.3	231.4	129.4	7.3	7.0	5.8	11.1	1.8	476.1
Const	26.4	55.3	0.0	3.0	3.0	2.7	7.0	0.0	97.5
Service	-14.6	-35.5	-10.6	-0.4	-0.4	-0.3	-43.8	-0.4	-105.9
TransEquip	-10.3	-47.6	-22.3	-0.4	-0.4	-0.2	-1.4	-0.9	-83.4
TransEquipCV	26.3	74.5	0.9	0.1	0.1	0.1	3.5	1.1	106.6
TransServOthers	-96.0	-302.6	-30.9	-11.5	-11.5	-10.6	-27.3	-0.1	-490.4
CV (etc.)	-4.9	-21.4	0.0	-0.1	-0.1	-0.1	-7.7	0.0	-34.4
CV (Gasoline)	-201.1	-32.4	-0.1	0.0	0.0	0.0	-28.0	-17.9	-279.5
CV (Diesel)	-568.6	-14,194.3	-4.4	-60.2	-60.2	-55.3	-297.4	-10.1	-15,250.4
CV (LPG)	-22.9	-4.8	0.0	0.0	0.0	0.0	-0.7	0.0	-28.4
Total	-969.1	-10,947.5	448.8	2,983.5	1,726.4	904.0	-1,948.4	-767.7	-8,569.9

Note: 1) Oil Refining* contains CoalPro, OilPro, Gasoline, JetOil, Kerosene, Diesel, HeavyOil, LPG

2) Electricity** contains Elec, Gas, Steam, WasteWater

4.4 Scenario D

Scenario D assumes that the LPG vehicle has been replaced by an electric vehicle following scenarios B and C. Importantly, LPG vehicles do not emit TSPs, PM2.5, PM10 and NH3 according to CAPSS data. The following table shows the changes in Scenario B.

Table 31. Changes in Scenario D

	Gasoline	Diesel	LPG	EV
Ratio in 2015	55.5%	33%	11%	0.38%
Changes in Scenario C	46.8%	28%	0%	25.2%

According to Table 31, changes in air pollutant emissions are calculated. Since the LPG vehicles do not emit much air pollutant, emissions reductions were the lowest compared with other scenarios. Table 32 shows the increase and decrease of air pollutants by substitution between LPG vehicles and EV.

Table 32. Increase and decrease of air pollutants by fuel type (Scenario D)

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
CV(Gasoline)	-372.55	-59.97	-0.17	-0.07	-0.07	-0.06	-51.78	-33.18
CV(Diesel)	-2.47	-61.62	-0.02	-0.26	-0.26	-0.24	-1.29	-0.04
CV(LPG)	-12,297	-2,554	-10.54	0.00	0.00	0.00	-365.51	0.00

Total	-11,871	3,601.69	3,572.90	4,550.73	2,680.62	1,456.04	-10.15	-152.39

The analysis results show an increasing pattern in Scenario D, compared with the results of a decrease in NOx on a whole industry basis in Scenario A, B and C.

Table 33. Amount of air pollutants emitted by industry (Scenario D)

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3	Total
Agri	-17.2	-42.9	-2.7	-3.6	-3.5	-3.0	-4.3	-0.4	-77.6
Mining	1.3	5.3	6.1	0.1	0.1	0.0	0.1	0.2	13.2
Food	-0.6	-1.7	-0.1	0.0	0.0	0.0	-97.9	0.0	-100.3
FiberLeather	-4.0	-28.4	-29.9	-15.8	-9.2	-3.2	-0.6	-0.2	-91.0
WoodPaper	11.4	2.7	0.6	0.2	0.1	0.1	0.1	0.0	15.3
Oil Refining*	-120.7	-108.9	-594.4	-5.4	-1.6	-0.5	-476.9	-199.6	-1,508.1
Chemical	-3.0	-4.7	-1.3	-1.1	-0.6	-0.4	-18.3	0.0	-29.4
Nonmetal	52.9	1,879.4	650.4	255.8	150.7	76.8	19.0	1.6	3,086.7
PriMetal	350.7	3,081.6	3,265.1	4,268.5	2,497.7	1,347.4	797.3	70.1	15,678.6
Metal	0.6	1.7	0.2	0.2	0.1	0.1	0.1	0.0	2.8
Machine	-3.3	-9.4	-0.3	0.0	0.0	0.0	-0.4	-0.1	-13.6
Computer	-26.1	-71.9	-0.2	-0.1	-0.1	-0.1	-3.5	-1.0	-102.9
ElecEquip	73.4	207.0	5.7	0.3	0.3	0.2	9.9	2.9	299.6

MissManu	1.6	12.5	13.5	10.6	6.2	2.6	0.3	0.1	47.3
Electricity**	123.3	346.6	193.8	10.9	10.5	8.7	16.6	2.7	713.0
Const	79.2	165.8	0.1	8.9	8.9	8.2	21.0	0.1	292.0
Service	28.2	68.7	20.6	0.9	0.7	0.5	84.8	0.9	205.3
TransEquip	-0.6	-2.6	-1.2	0.0	0.0	0.0	-0.1	-0.1	-4.6
TransEquipCV	82.7	234.1	2.7	0.4	0.3	0.3	10.9	3.6	334.9
TransServOthers	170.2	536.3	54.7	20.3	20.3	18.7	48.3	0.2	869.0
CV (etc.)	1.3	5.7	0.0	0.0	0.0	0.0	2.1	0.0	9.2
CV (Gasoline)	-372.6	-60.0	-0.2	-0.1	-0.1	-0.1	-51.8	-33.2	-517.9
CV (Diesel)	-2.5	-61.6	0.0	-0.3	-0.3	-0.2	-1.3	0.0	-66.2
CV (LPG)	-12,297.2	-2,553.6	-10.5	0.0	0.0	0.0	-365.5	0.0	-15,226.8
Total	-11,871.0	3,601.7	3,572.9	4,550.7	2,680.6	1,456.0	-10.2	-152.4	3,828.4

Note: 1) Oil Refining* contains CoalPro, OilPro, Gasoline, JetOil, Kerosene, Diesel, HeavyOil, LPG

2) Electricity** contains Elec, Gas, Steam, WasteWater

Chapter 5. Conclusions

Through the Scenario A,B,C and D, air pollution emissions from the transportation sector will decrease due to the spread of electric vehicles, but the primary metal industry accompanying the battery industry will also surge as the battery industry grows rapidly due to the production of electric vehicles.

According to Scenario A, the four air pollutants, SOx, TSP, PM10, and PM2.5, were derived from the increase of air pollutants caused by the spread of electric vehicles, and the NOx and NH3 sectors also showed that much of the reduction effect expected by the transportation sector was offset by the emission of other industries.

Scenario B, C and D show slightly different aspects. In Scenario B, where gasoline cars are assumed to replace electric cars, it was not much different from Scenario A in parts TSP, PM10, and PM2.5. However, in the SOx segment, the overall reduction in air pollutant emissions increased by one item, changing from positive to negative. In particular, in CO, VOC and NH3, the amount nearly doubled compared to Scenario A. This shows that if gasoline cars are replaced by electric cars, positive effects can be expected from the SOx segment.

Scenario C assumed that electric cars replaced diesel cars. Because diesel was the fuel with the highest price unit emissions in TSP, PM10, and PM2.5 categories, it was expected that there will be a lot of reduction. However, it did not translate into negative values in the overall industrial structure. On the contrary, CO has significantly decreased the rate of emission reduction due to the small amount of CO emissions per unit of diesel vehicles. However, it was not much different from Scenario A in the TSP, PM10, and PM2.5, including SOx, and it was the best of all scenarios in NOx.

Scenario D assumed a scenario in which LPG vehicles were replaced by electric vehicles. LPG vehicles showed the worst effects of the scenario, as there was no emission of TSP, PM10, and PM2.5, regardless of after replacement. Pollution levels increased in five categories, and only in three categories decreased by a small amount.

The following table shows how air pollutants have changed in the entire industrial group by scenario. Although scenario B showed the best effect in terms of contaminants, the degree of increase and decrease in each pollutant varies slightly, so the advantages and disadvantages of each scenario should be identified.

Table 34. Increase and decrease of air pollutants by Scenarios

(unit : ton)	CO	NOx	SOx	TSP	PM10	PM2.5	VOC	NH3
Scenario A	-31,539	-7,114	426	3,063	1,787	949	-4,896	-2,537
Scenario B	-59,693	-6,568	-883	3,121	1,829	978	-10,984	-6,467
Scenario C	-969	-10,947	449	2,984	1,726	904	-1,948	-768
Scenario D	-11,871	3,602	3,573	4,551	2,681	1,456	-10	-152

The study shows that the spread of electric cars can cause an increase in air pollutants. In other words, looking only at the transport market to see changes in air pollutants suggests that it is a rather biased trend. In order to examine the increase and decrease of air pollutants in the entire nation, we need to figure out the link structure of the entire nation's industrial structure.

South Korea is using various policies to reduce emissions of air pollutants. In January 2018, the Ministry of Environment implemented ‘Total allowable emissions in market place’ in Seoul, Incheon and Gyeonggi Province. However, most businesses, such as the primary metal industry with high levels of air pollutant emissions, are located far from Seoul, which is not subject to the restrictions. In other words, when the Korean government establishes an "atmospheric pollutant reduction policy," an accurate definition of the industries that generate a lot of air pollutants will be needed and the location of the businesses should be fully considered.

It should also be noted that the government's policy to distribute electric and hydrogen cars. South Korea supplied 5.7 million electric vehicles and 889 hydrogen vehicles in 2017 and 2018. The government also decided to expand the ratio of green cars owned by public organizations in Seoul and other metropolitan areas and the ratio of mandatory purchases. The mandatory purchase ratio will be expanded gradually to 70 percent from 2019 and 80 percent from 2021. However, as the study shows, the increase in electric vehicles does not cause an unconditional decrease in air pollutants, so this policy should also take into account various industrial groups.

The transportation sector's policies were also strengthened. The Environment Ministry's policy is that old diesel cars should be scrapped early and replaced with eco-friendly ones. In other words, since diesel cars emit a lot of air pollutants, the government should instead spread eco-friendly vehicles. In particular, the automobile manufacturing industry was required to sell pro-environment to realize the popularization of eco-friendly cars. Again, the policy will have to be reorganized in the same sense. According to the scenario implemented in this study, even if diesel vehicles were abolished and replaced by electric vehicles, air pollution emissions did not have a positive effect for the entire industrial group.

The types of pollutants emitted by gasoline, diesel and LPG vehicles are different, and the amount of pollutants emitted is different. However, it would not be good to unconditionally replace ‘emissions-heavy vehicle’ with eco-friendly vehicles. Rather than focusing on 'primary pollutant emissions' alone, policies that comprehensively consider the air pollutants emitted from the manufacture of vehicles will have to be implemented throughout the country.

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Abstract (Korean)

2015년 이후 가속화된 국내 전기차 시장은 전기차의 판매뿐 아니라 전기차에 수반되는 다양한 산업에도 변화를 주고 있다. 본 연구는 다양한 요인 중 승용차 시장에서 전기 차량의 비율에 따른 대기오염물질 배출 효과에 초점을 맞추고 있다.

이번 연구에서는 연산가능일반균형모델을 이용하여 전기차의 보급에 따른 대기오염물질 배출량을 분석한다. 또한 한국은행이 제공하는 산업연관표를 바탕으로 전기차의 시장점유율에 따른 산업별 영향을 반영하고자 하였다.

이 모형을 기반으로 우리나라 전기차 확산 로드맵에 따른 정책 시나리오를 분석하였다. 시나리오 결과는 전기차 확산으로 인해 수송부문의 대기오염배출량은 줄어들지만, 전기차 생산으로 인해 전지산업이 급성장함에 따라 전지산업에 수반되는 1차금속산업 역시 급등하는 것으로 나타났다. 이에 따라 SOx, TSP, PM10, PM2.5 네 가지 대기오염 물질에서는 전기차 확산으로 인한 대기오염물질이 오히려 증가하는 것으로 도출되었으며 NOx와 NH3 부문 역시 수송부문에서 기대했던 감축효과보다 많은 부분이 타 산업의 배출로 인해 상쇄되는 결과를 보였다.

이번 연구를 통해 전기차 확산으로 인한 대기오염물질 변화를 보기 위해 수송시장부문만의 정량적 변화 관측은 부족하며 전체 우리나라 산업 구조의 연관성을 파악해서 대기오염물질 배출량을 산정해야함을 알 수 있다. 지금과

같은 산업구조가 지속된다면 대기오염물질 배출 저감을 위한 수송부문의 정책만으로는 대기오염물질을 오히려 증가시킬 것이다.

이처럼 본 연구는 대기오염물질 배출 저감을 위해 산업 전체의 직, 간접적 효과를 종합적으로 고려해야함을 시사하고 있다.

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