INTEGRATED ENVIRONMENTAL STRATEGIES (IES)
PHASE II PART II

Cost-Benefit Analysis of Integrated Environmental Strategies for Air Quality Improvement and Greenhouse Gas Emission Reductions

Final Report

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Cost-Benefit Analysis of Integrated Environmental Strategies for Air Quality Improvement and Greenhouse Gas Emission Reductions

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Cost-Benefit Analysis of Integrated Environmental Strategies for Air Quality Improvement and Greenhouse Gas Emission

EXECUTIVE SUMMARY

Korea, like many countries, is trying to balance environmental and public health concerns against economic growth. Previous government policies to improve air quality in the Seoul metropolitan area have achieved remarkable outcomes; however, many measures have reached their limits of effectiveness due to the soaring number of vehicles and other pollution sources in the region. Recognition of these serious challenges led to the legislation of the Special Act on Seoul Metropolitan Air Quality Improvement Plan and the implementation of the Basic Plan for Seoul Metropolitan Area Air Quality Management (SAQMP) in December 2004.

In addition to aggressively pursuing improved air quality, Korea joined the international efforts to reduce greenhouse gases (GHGs) by signing the United Nations Framework Convention on Climate Change (UNFCCC) in Rio, Brazil, in 1993. Although Korea is not a member of the Annex I group under the Kyoto protocol (1997), Korean ministries put together action plans to meet the Kyoto Protocol's goals.

For a county with limited economic resources and severe air pollution problems like Korea, implementing integrated measures, which address both local air pollution and GHG emissions, is essential to achieving necessary air pollution reductions and preparing for future agreements on climate change. Integrated strategies have been implemented worldwide as cost-effective mechanisms to reduce air pollutant impacts on ecosystems and human health and risks associated with climate change, especially when GHGs and local air pollutants are co-generated by fossil fuels combustion.

To assess the potential for integrated measures to help Korea achieve its environmental goals, the Integrated Environmental Strategies (IES)-South Korea program was initiated in February 1999. This program is a collaboration between the U.S. Environmental Protection Agency (EPA), the Republic of Korea's Ministry of Environment, the Korean Environment Institute (KEI), and the National Renewable Energy Lab (NREL). Its objective is to assess and quantify the environmental and public health benefits resulting from integrated measures to reduce GHGs and local air pollution.

This study report completes Phase II of IES-South Korea, which assesses the co-benefit potential of measures from the SAQMP aimed specifically at improving air quality and selected measures targeting GHG emissions. This co-benefit analysis includes an estimation of health benefits and associated economic valuation, yielding a cost-effectiveness value for each measure. Based on cost effectiveness optimization, the study develops an alternative scenario of emission reduction measures to achieve Korea's goals for both air quality improvement and GHG reduction.

Specific outcomes of this study include the following.

- o Identification of cost-effective integrated strategies to improve air quality and reduce GHG emissions
- o Estimation of co-benefit potential of the air quality improvement plan and GHG mitigation measures
- o Cost-benefit assessment for each measure that encompasses implementation and operating costs, GHG reduction effects, and public health benefits

The major research activities undertaken to achieve these objectives are shown in Table ES-1.

Table ES-1. Major Research Activities

Area	Research Activities
Current and projected air pollutant and GHG emissions from fuel use in Seoul metropolitan area	o Conduct GHG emission analysis and projection based on fuel use in Seoul metropolitan area o Conduct air pollutant emission analysis and projection based on fuel use in Seoul metropolitan area
Cost benefit analysis for metropolitan air quality improvement plan	o Quantify air pollutant emission reductions for each measure o Quantify GHG emission reductions for each measure o Quantify cost for each measure
Cost benefit analysis for GHG mitigation plan	o Quantify air pollutant emission reductions for each measure o Quantify GHG emission reductions for each measure o Quantify cost for each measure
Development of IES scenario	o Conduct cost benefit analysis for each measure - Recommend measures based on the best benefit-cost ratio o Identify the most cost effective IES scenarios
Air quality modeling	o Run model to project emissions for the target year with each scenario o Convert air quality modeling outcome to BenMAP-ready format
Valuation of health benefits with BenMAP model	o Perform estimation of health benefits with BenMAP for each scenario o Conduct valuation of health benefits from air quality improvement
Cost-benefit analysis	o Conduct cost benefit analysis for integrated valuation of health and GHG mitigation benefits
International workshops	o Korea-US Environmental Protection Agency (EPA) joint workshops o Workshops on international case studies for experts, policy makers, NGOs and press o Korea Environment Institute (KEI) coordinates workshops and participants in consultation with Korean Ministry of Environment (MOE) and EPA

The geographic scope of this study was the Seoul Metropolitan area including Seoul, Incheon and Kyonggi. Power plants in the Chuchung area were included in the air quality modeling due to their impact on the air quality in the Seoul metropolitan area. The base year of the study was 2003, and 2014 was the year used for analyzing impacts of emission reduction scenarios compared to business as usual (BAU). The pollutants included in the analysis were sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter with aerodynamic diameter less than 10 microns (PM_{10}), carbon dioxide (CO_2), and methane (CH_4).

Measures examined in this study were selected from the SAQMP and additional GHG mitigation measures associated with fuel consumption. The sources impacted by these measures included industrial energy combustion, non-industrial combustion, manufacturing industry combustion, and mobile sources. Emission changes resulting from each measure were estimated from published studies on emission factor changes. Air quality impacts of these emission reductions were estimated using EPA's Models-3/Community Multiscale Air Quality (CMAQ) modeling system, and the impact of changes in air quality on human health were estimated using EPA's Environmental Benefits Mapping and Analysis Program (BenMAP).

The estimated costs of implementing a measure included the capital and operating costs, which were summed and converted into an Equivalent Annual Value (EAV) for each measure. The economic values associated with reduced morbidity and mortality were estimated using the value of a statistical life (VSL) suggested by EPA and adjusted for Korea using purchasing power parity (PPP) for a value of approximately 2.5 billion won. The economic value associated with GHG reductions was determined using the marginal damage cost of 12 USD per ton of CO_2 suggested by the Intergovernmental Panel on Climate Change (IPCC) 4th Report.

Table ES-2 shows the most effective measures from the SAQMP and GHG scenarios for reducing emissions of individual pollutants and pairs of pollutants. Conversion of busses to compressed natural gas (CNG) and installation of diesel particulate filters (DPF) were the most effective measures for reducing NOx and PM_{10}. Measures with the greatest potential to reduce CO_2 were fuel switching from coal to liquefied natural gas (LNG), use of solar energy systems, and advanced passenger vehicle technologies. When looking at NOx and PM_{10} in combination with CO2 reductions, the same four measures showed the greatest combined potential, including two categories of accelerated vehicle retirement.

Table ES-2. Rank of Measures by Pollutant Emission Reductions

	NO_X	PM_{10}	CO_2	NO_X–CO_2	CO_2– PM_{10}	NO_X–PM_{10}
1	Promotion of CNG Intra-city Buses	Promotion of CNG Intra-city Buses	Fuel Control (Anthracite for Residential Use→LNG)	Accel. Veh. Retirement – Large Trucks	Accel. Veh. Retirement – Large Trucks	Accel. Veh. Retirement – Large Trucks
2	DPF Install. – Intra-city Buses	DPF Install. – Intra-city Buses	Solar Energy Systems	Promotion of Low-NO_X Boilers	Promotion of Low-NO_X Boilers	Promotion of CNG Intra-city Buses
3	DPF Install. – Chartered Buses	DPF Install. – Chartered Buses	Promotion of Electric Vehicles	CNG Intra-city Buses	CNG Intra-city Buses	DPF Install. – Large Trucks
4	DPF Install. – Large Trucks	DPF Install. – Large Trucks	Promotion of Hybrid Vehicles	Accel. Veh. Retirement – Large Pass. Vans	Accel. Veh. Retirement – Large Pass. Vans	DPF Install. – Midsize Pass. Vans

Analysis of the cost-effectiveness of measures for reducing each pollutant of interest revealed that the most cost effective measures were often those associated with fuel switching and restrictions on idling.

The cost and emission reduction potential for each measure were used as inputs to an optimization model. The output of the model was a list of cost-optimized measures that would meet GHG and air pollutant reduction goals. These measures were used to form the IES Scenario, which is shown in Table ES-3.

Table ES-3. Emission Reductions and Costs for IES2014 Scenario

Measure	CO_2 Emission Reduction (kg)	NO_X Emission Reduction (kg)	PM10 Emission Reduction (kg)	Cost (won)
Landfill Gas for Energy	1,559,675,000	0	0	-17,345,358,519
Low-NO_X Boilers	5,738,577,000	74,666	725	-1,417,760,012,487
CNG Intra-city Buses	856,893,612	6,955,892	375,447	-131,551,371,941
District Heating & Cooling	108,204,000	13,200,888	1,262,380	-4,802,420,836,720
Fuel Switching in Industry	2,042,097,140	11,440,665	1,082,558	-32,794,111,782
Idling Regulation (Gasoline)	19,134,615	62,439	0	-11,398,216,416
Idling Regulation (Diesel)	15,027,336	123,558	9,740	-6,323,684,047
LGP Conversion (Midsize trucks)	36,485,400	14,534,184	1,152,039	45,318,513,695
Accelerated Vehicle Retirement program (Midsize trucks)	152,189,100	55,477,800	3,998,400	368,250,191,064
Accelerated Vehicle Retirement program (Large trucks)	114,901,304	27,790,924	1,265,964	163,286,279,348
Total Allowable Emissions System NO_X BACT	0	42,930,000	0	588,484,440,000
Total Allowable Emissions System SO_X BACT	0	0	0	361,490,210,000
Total Allowable Emissions System PM10 BACT	0	0	1,245,000	9,034,965,000
Total	10,643,184,507	172,591,016	10,392,25	-4,883,728,992,805

Note: Values are rounded off to the nearest integers, and the total values may not be the sum of each value.

Emission reductions estimated for the IES scenario in 2014 are compared with the BAU, SAQMP, and GHG scenarios in Table ES-4.

Table ES-4. Emissions in 2014 and Cost by Scenario

	NO_X (kg)	SO_X (kg)	PM10 (kg)	CO_2 (kg)	Cost (won)
BAU 2014	353,943,649	91,114,932	17,384,277	103,084,826,000	0
SAQMP 2014	181,949,649	25,213,534	7,791,651	95,758,809,994	295,610,922,711
GHG 2014	322,085,542	77,597,622	14,653,428	92,745,217,297	-6,419,593,591,912
IES 2014	181,352,634	49,507,622	6,992,025	92,441,641,493	-4,883,728,992,805

CMAQ modeled concentration outputs were used as inputs to BenMAP, where changes in morbidity and mortality and the associated economic values were estimated to obtain a net benefit associated with reductions in air pollutant emissions. The value of 12 USD per ton CO_2 was used to estimate economic benefits from GHG reductions.

Figure ES-1 shows the costs, individual benefits (air quality and CO_2), and net benefits of each scenario. The GHG scenario costs the least to implement with a net savings of 6 trillion won before the value of benefits is added. When net benefits are examined, however, the benefits associated with the IES scenario exceed those of the SAQMP or GHG scenarios. Although the IES scenario realizes slightly less savings from project implementation and operation compared to the GHG scenario, the air quality and GHG savings exceed those in either scenario for the greatest net economic benefit. This result was expected, given that measures in the IES scenario were selected using a cost-effectiveness optimization model.

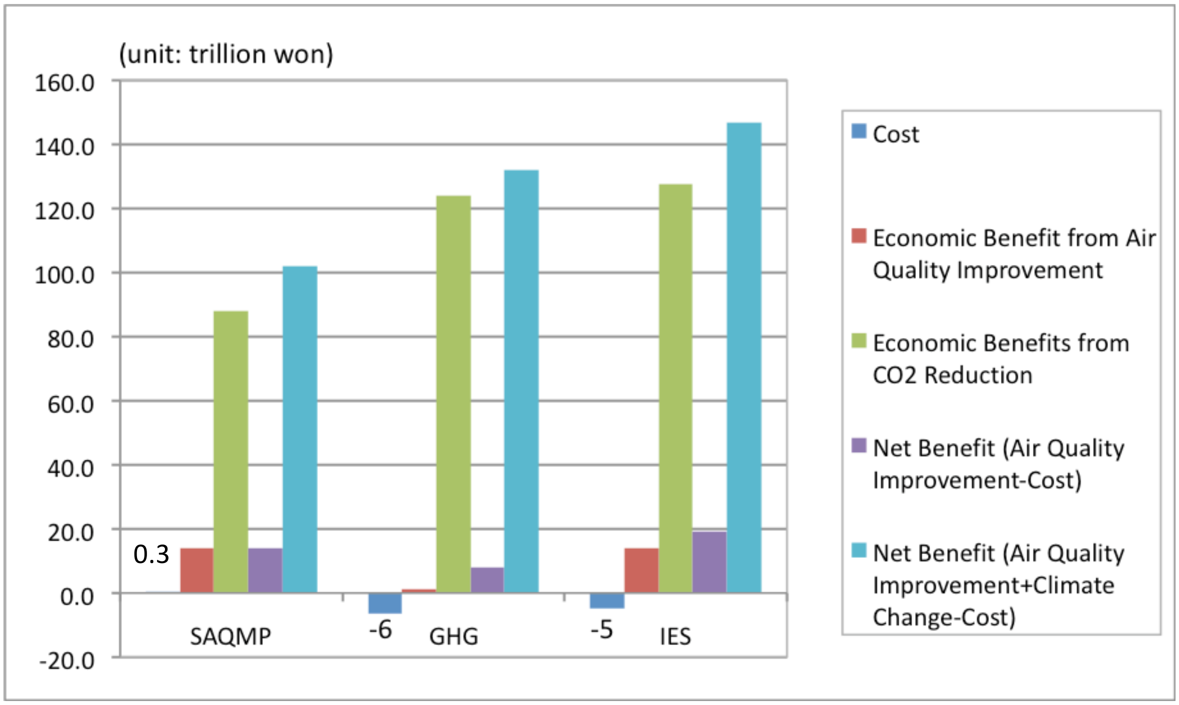

Figure ES-1. Cost and Benefit from Air Quality Improvement and GHG Reduction by Scenario

The results of this study have several implications. First, GHG reductions are possible without any additional costs due to the close linkage with fuel use and the potential for net cost savings associated with fuel savings. Second, air quality improvement is closely related to GHG emission reductions, as was shown by the estimated 7,320,000 tons CO_2 reduction expected through SAQMP and the reductions of 30,000 tons NO_X and 2,700 tons PM_{10} expected from the GHG measures. Third, integrated strategies satisfy both air pollutant and GHG reduction targets and generate economic benefits from fuel cost savings well above initial installation costs.

This study demonstrates that connecting GHG mitigation with air quality management measures is effective. For example, current air quality management measures such as mandatory use of clean fuel and bans on solid fuel use are effective in significantly reducing GHGs. Promoting CNG use in intra-city buses was also shown to be effective in air quality improvement and GHG reduction. The approximately 7,320,000 tons of CO_2 reductions expected from SAQMP is equivalent to about 8% of the total GHG emissions in the Seoul metropolitan area in 2003. Beyond SAQMP, the IES scenario showed the potential to both achieve greater GHG reductions (approximately 10,339,608 tons CO_2) and exceed air quality improvements and do so at a lower cost.

Figure ES-2 shows the percent reductions by pollutant for the three control scenarios (SAQMP, GHG, and IES) compared to BAU and the sectors where the emission reductions are occurring. This shows the importance of mobile sources in achieving reductions of both air pollutant and GHG emissions under the IES scenario.

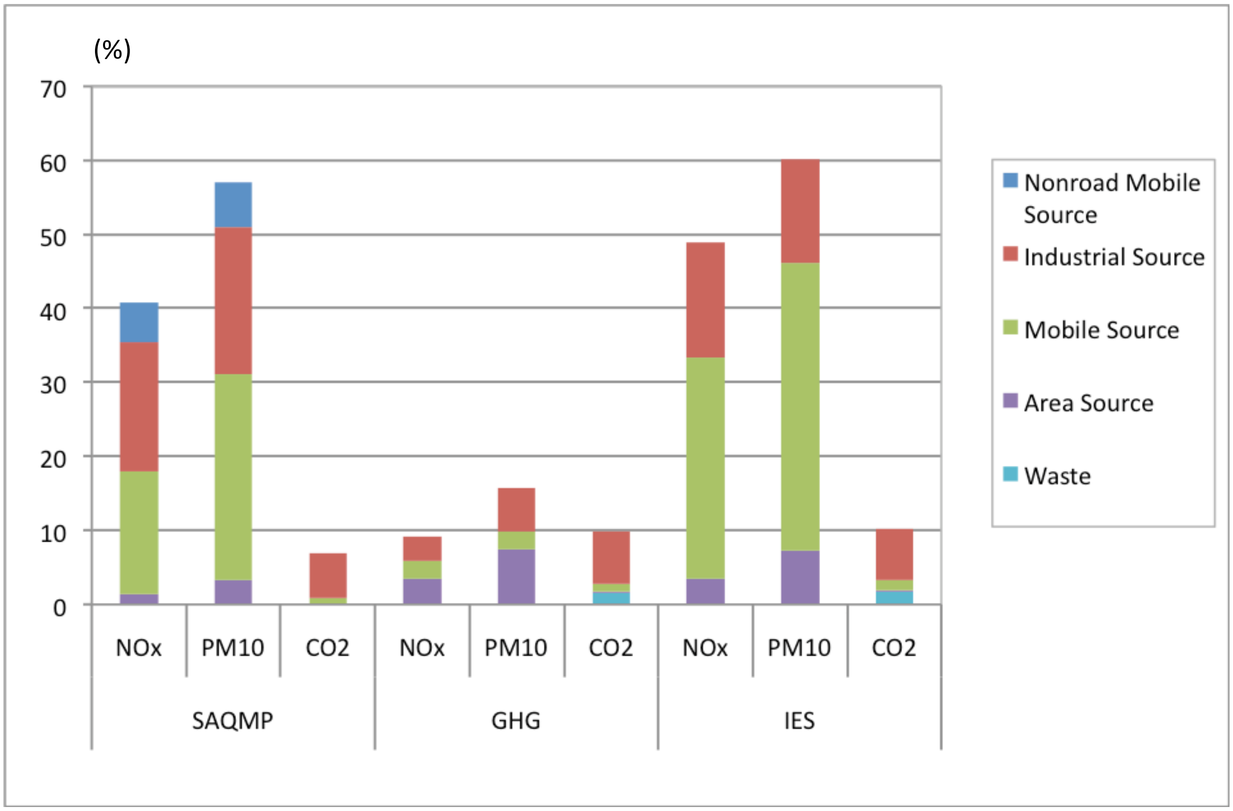

Figure ES-2. Reduction of Emissions by Scenario Compared to Emissions under BAU 2014 Scenario

Other measures not included in this study for analysis, such as improvement of fuel efficiency, connecting air pollutant and GHG emission trading, and voluntary agreements on emission reductions, also have great potential as integrated strategies. Additional studies are needed to clarify their effects on emissions and cost effectiveness.

Several areas require further investigation to improve understanding of Korea's potential for GHG and air pollutant reductions. Better definition of the maximum level of penetration for each measure would assist in more concretely defining emission reduction potential; to do this would require thorough consideration of the social, economic and political aspects of each measure. Unified standards for cost assessments could improve comparability of benefits between measures. Additional health benefits may be realized through reductions in air pollutant concentrations beyond PM10, which were not explored in this study. Further, GHGs other than carbon dioxide, such as nitrous oxide and methane, have a high global warming potential and should be analyzed for completeness. Studies of the effects of integrated strategies for Korean regions beyond the Seoul metropolitan area could reveal additional low- to no-cost opportunities for integrated planning.

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND AND PURPOSE

Fossil fuels have provided convenience and mobility but have also caused serious environmental problems through emissions of air pollutants and greenhouse gases during production and consumption processes. Climate change and air pollution from fossil fuel consumption have great adverse effects on ecosystems, the ambient environment and public health. Many countries are trying to balance environmental and public health concerns against economic growth. Integrated strategies are the most cost-effective in reducing air pollution and its downstream impacts on ecosystems and human health in the short-term as well as reducing increased risks due to climate change in the long-term. Worldwide, integrated measures have been implemented to reduce local air pollution and GHG emissions simultaneously where they are generated together by fossil fuel combustion.

Integrated strategies refer to actions to reduce both local air pollution and GHG emissions at the same time. Among the measures to improve air quality, retrofit technologies such as catalytic converter and desulfurization reduce only local air pollutants; integrated measures such as promotion of compressed natural gas (CNG) buses and district heat and cooling systems reduce both local air pollutants and associated global GHGs by switching fuel type and increasing fuel efficiency. The objectives of this study are to identify cost-effective integrated strategies to address both local air quality issues and GHG mitigation concerns and to conduct economic valuation and analysis of integrated planning compared with current air quality improvement plans and GHG mitigation approaches.

A combination of high population density and an economic structure with high energy demand very likely leads to serious air pollution problems in Korea. Especially in Seoul metropolitan area, air quality improvement is critical due to high population density and a heavy volume of traffic. Air quality management measures such as fuel control and stringent emission standards led to significant decreases in the concentrations of some air pollutants common in developing countries (e.g. SO_X and CO). In Seoul, SO_X concentration was reduced from 0.094ppm in 1980 to 0.005ppm in 2001, and CO concentration from 3.2ppm in 1989 to 0.9ppm in 2001.

However, the concentrations of other air pollutants common in developed countries (e.g. NO_2, PM10 and O_3) either stay the same or tend to increase. NO_2 and O_3 concentrations increase mainly due to increase of vehicle exhaust emissions. PM10 concentration decreased till 1998 because of economic slowdown, but it has been on the rise since then. For the last decade, Seoul metropolitan area Gross Regional Domestic Product (GRDP) increased by more than 6% every year. The fact that PM10 and NO_2 concentrations continued to rise for the last 3 years indicates current air pollution control approaches are insufficient.

Various government policies to improve air quality in the Seoul metropolitan area have achieved remarkable outcomes. However, current air quality improvement measures reached to the limits due to soaring number of vehicles and various sources. Thus, the efforts to cope with these serious challenges led to the legislation of the Special Act on Seoul Metropolitan Air Quality

Improvement Plan and implementation of Basic plan for Seoul Metropolitan Area Air Quality Management to execute it (December, 2004). Municipal governments will conduct local level implementation of air quality improvement measures.

As environmental problems become global issues, international treaties on climate change increase. Korea joined the international efforts to reduce GHGs by signing the United Nations Framework Convention on Climate Change (UNFCCC) in Rio, Brazil in 1993. Although Korea is not a member of Annex I group of Kyoto protocol (1997), Korean ministries put together action plans to meet the Kyoto Protocol's goals.

For a county with limited economic resources and severe air pollution problems, implementing integrated measures is essential to achieve co-benefits (air pollution and GHG reduction) and to prepare for future agreement on climate change.

Specific objectives of this study are to

- Identify cost-effective integrated strategies to improve air quality and to reduce GHG emissions
- Conduct co-benefit analysis of air quality improvement plan and GHG mitigation measures
- Conduct cost-benefit analysis considering costs of IES programs, GHG reduction effects and public health benefits in connection with previous Phase I, II and III IES studies

1.2 RESEARCH ACTIVITIES AND SCOPE OF STUDY

1.2.1 Research Activities

The major research activities and framework of this study are illustrated in Figure 1.1.

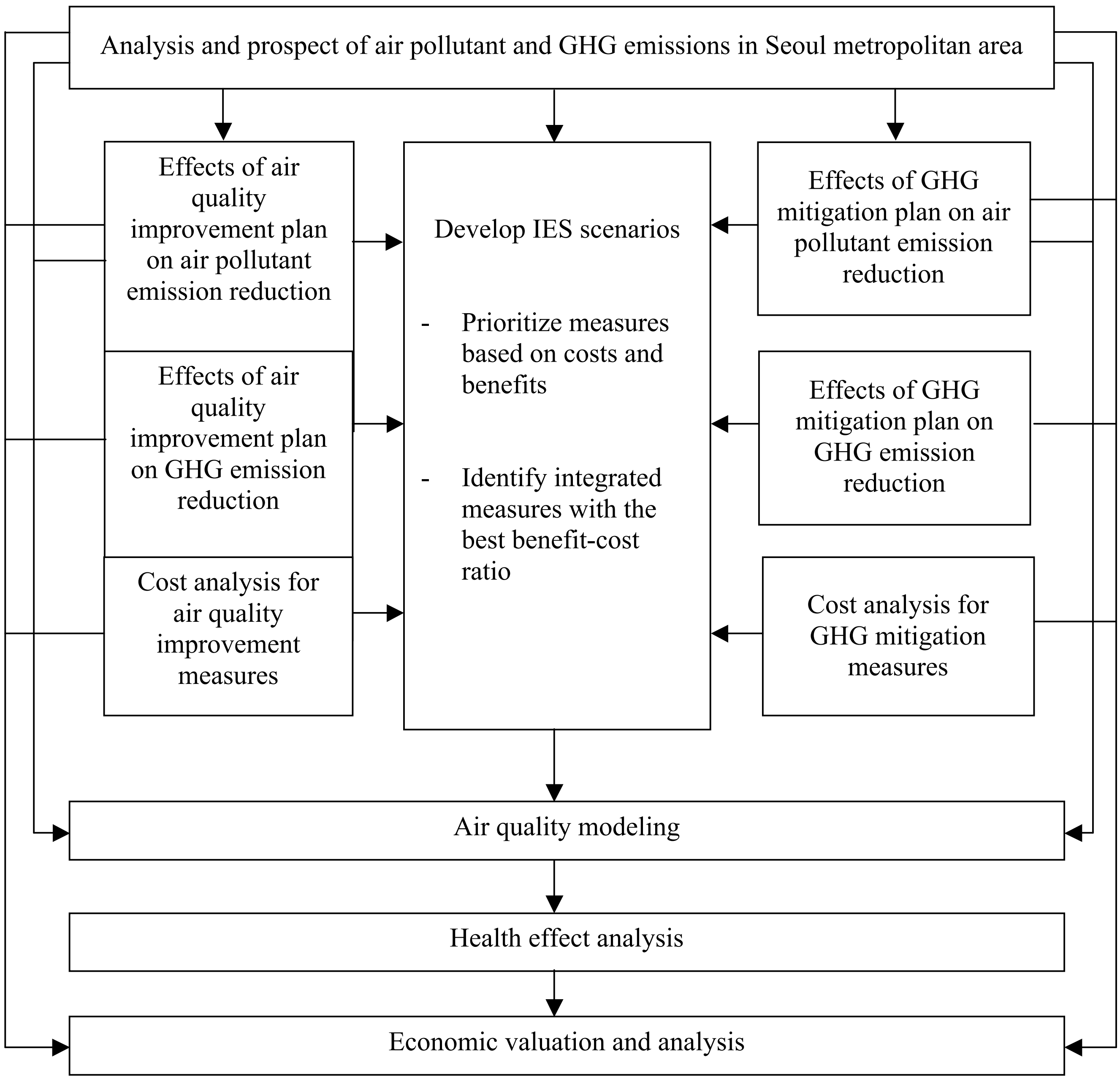

Figure 1.1 Framework of the Study

Table 1-1. Major Research Activities

Area	Research Activities
Current and projected air pollutant and GHG emissions from fuel use in Seoul metropolitan area	o Conduct GHG emission analysis and project from fuel use in Seoul metropolitan area o Conduct air pollutant emission analysis and project from fuel use in Seoul metropolitan area
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Cost benefit analysis for GHG mitigation plan	o Quantify air pollutant emission reduction for each measure o Quantify GHG emission reduction for each measure o Quantify cost for each measure
Development of IES scenarios	o Conduct cost benefit analysis for each measure - Recommend measures based on the best benefit-cost ratio o Identify the most cost effective IES scenarios
Air quality modeling	o Run model to project emissions for the target year with each scenario o Convert air quality modeling outcome to BenMAP-ready format
Valuation of health benefits with BenMAP model	o Perform valuation of health benefits with BenMAP for each scenario o Conduct valuation of health benefits from air quality improvement
Cost-benefit analysis	o Conduct cost benefit analysis for integrated valuation of health and GHG mitigation benefits
International workshops	o Korea-US Environmental Protection Agency (EPA) joint workshops o Workshops on international case studies for experts, policy makers, NGO and press o Korea Environment Institute (KEI) coordinates workshops and participants in consultation with Korean Ministry of Environment (MOE) and EPA

1.2.2 Scope of Study

Geographical scope

- The geographical scope of this study is limited to Seoul metropolitan area including Seoul, Incheon and Kyonggi
- For the air quality modeling analysis, power plants in Chuchung area are included due to their impacts on the air quality of Seoul metropolitan area

Time period

- Year 2003 plays the role of base year and 2014 was selected for projection
- Year 2003 is selected as the base year due to the availability of reliable data for other years
- Only if necessary and available, more recent data than those in 2003 are used

Pollutants of concern

- Air pollutants: SO_X, NO_X, PM10
- GHGs: CO_2, CH_4

Policies

- Air pollutant reduction plan: Seoul metropolitan air quality improvement plan
- GHG reduction plan: GHG mitigation measures associated with environmental fuel consumption

Sources

- In this study, sources for analysis are limited to those from fuel combustion (Table 1-2).

Table 1-2. Sources for Analysis

Emission source	Samples of source
Energy industry combustion	Public power plants
	District heating facilities
	Oil refineries
Non-industrial combustion	Commercial and public buildings
	Residential buildings
Manufacturing industry combustion	Combustion facilities
	Furnaces
Road mobile source	Cars
	Taxies
	Passenger vans
	Buses
	Trucks
	Special vehicles
	Two-wheeled vehicles

Analysis Model

- Quantitative models are adopted to model air quality and health effects.
- Air quality model: EPA-MODELS3/CMAQ
- Health effect model: BenMAP

1.3 SPECIAL ACT ON SEOUL METROPOLITAN AIR QUALITY IMPROVEMENT AND GHG REDUCTION MEASURES

1.3.1 Special Act on Seoul Metropolitan Air Quality Improvement

The emission reduction policy to improve air quality can be classified as regulations for industrial site management (total allowable emissions system, emission trading, etc), area source control (including VOC control), on-road mobile source control and non-road mobile source control. Components of each category are described below.

- Industrial source control: total allowable emissions system and emission trading system play the key role. For other facilities not under total allowable emissions system, fuel control, more stringent emission standards, voluntary air quality management and support and guidance from government organization will be promoted. Small-sized incinerating facilities should be closed down and products banned from incineration should be expanded.
- Area source control: fuel control, expansion of district air conditioning and heating systems, spread of low NO_X boilers, distribution of new recycling energy, and energy demand control
- VOC control: mandatory stage II controls for gasoline service stations, regulations on arsenic emission in production process, stringent standards of organic solvent content in consumer products, low arsenic emission standards for industrial surface coating and cleaning operations and limitation of cutback asphalt usage
- Vehicle source control: low emission standards for new vehicles, supply of low emission vehicles, distribution of emission control technologies like Diesel Particulate Filter (DPF), Diesel Oxidation Catalyst (DOC), support for conversion to gas vehicles, support for accelerated vehicle retirement program, on-road motor vehicle emission and fuel standards, more stringent emission test procedures, clean fuels programs, enhancement of regulation on idling, designation of green (clean air) area as a policy for demand control, improvement of public transportation infrastructure, parking demand control, industrial traffic demand control
- Non-road mobile source control: stringent emission standards for construction machinery, marine vessels and farm equipments, retrofit technologies like Selective Catalytic Reduction (SCR) and DPF, limits on sulfur content in fuel

The measures to reduce air pollutants and CO_2 and their effects are presented in Table 1-3. Those for which CO_2 reductions can be quantified are highlighted.

Table 1-3. Effects of Seoul Metropolitan Area Air Quality Management Plan on Air Pollutants and GHG Reduction

Source	Measure	Description/Example	Air Pollutant Reduction	GHG Reduction
Industrial Sources	Total allowable emissions systems	Total allowable emissions system and emission trading	SO_X, NO_X, PM_{10}	CO_2
	Fuel control	Expand the regions for low-sulfur fuel usage	SO_X, PM_{10}	
	Stringent emission standards	Stringent emission standards and penalty on emission of nitrous oxide	NO_X, PM_{10}	
	Solid waste combustion facility management	Stringent emission standards	SO_X, NO_X, PM_{10}, VOC	
		Closedown of small-size solid waste incinerators		
		Expansion of products prohibited for incineration (incineration volume)		
	Voluntary environment management	More environmentally friendly companies	SO_X, NO_X, PM_{10}	CO_2
		Agreement on voluntary environment management		
	Support/ Education	Distribution of manual for emission facility management and guidance	SO_X, NO_X, PM_{10}	CO_2
		Diagnosis of air quality control, consulting and financial aid for environmental investment for small- and medium-sized businesses		
		Emission reduction partnership between large enterprises and their collaborate firms		
		Support for investment on infrastructure		
Area Sources	Fuel control	Switch from residential smokeless coal to city gas	SO_X, NO_X, PM_{10}, VOC	CO_2
		Expansion of region to use low-sulfur gasoline and clean fuels	SO_X, NO_X, PM_{10}, VOC	

Area Sources continued...	District air conditioning and heating	Expansion of district air conditioning and heating system	SO_X, NO_X, PM_{10}	CO_2
		Revitalization of small-size community energy system (CES)		
	NO_X regulation	Supply low-NO_X boilers	SO_X, NO_X, PM_{10}, VOC	
		Better management of LNG facilities		
	Demand control	Distribution of alternative energy: solar energy	SO_X, NO_X, PM_{10}, VOC	CO_2
		Regulation on indoor air-conditioning and heating	SO_X, NO_X, PM_{10}, VOC	
		Environment friendly (energy saving) building standards and certification programs		
On-Road Mobile Sources	Regulations on manufacturer	Stringent emission standards for new vehicles	NO_X, PM_{10}, VOC	
		Distribution of low emission vehicles	NO_X, PM_{10}, VOC	CO_2
	On-road vehicle regulations	Emission reduction plan for specified-diesel-vehicles [a]: SCR/DPF installation	NO_X, PM_{10}, VOC	
		Emission reduction plan for specified-diesel-vehicles: DOC installation	PM_{10}, VOC	
		Emission reduction plan for specified-diesel-vehicles: LPG conversion	NO_X, PM_{10}, VOC	CO_2
		Emission reduction plan for specified-diesel-vehicles: Support for accelerated vehicle retirement program	NO_X, PM_{10}, VOC	CO_2
		Improvement of on-road vehicle emission management: inspection program for on-road vehicles, introduction of remote sensing devices (RSD), occasional emission inspection program for on-road vehicles, defect inspection program, introduction of on-board diagnostics (OBD), etc	PM_{10}, VOC	

On-Road Mobile Sources continued…	Two-wheeled vehicle regulations	Stringent emission standards	VOC, NO_X	
		Higher quality standards for engine oil		
		Mandatory regular inspection program		
	Fuel Control	Higher quality standards for gasoline fuels	SO_X	
	Traffic demand control	Designation of green (clean air) district	SO_X, NO_X, PM_{10}	CO_2
		Taxation on causing heavy traffic		
		Improvement of public transportation infrastructure		
		Industrial traffic demand control		
		Parking demand control		
		Encouragement of bicycle ride		

[a] specified-diesel-vehicle: vehicle that passed the guaranteed period for specified emission rate among the diesel vehicles registered in Seoul metropolitan area

1.3.2 GHG Mitigation Measures

- GHG emissions are closely associated with fuel consumption, so the GHG mitigation plan mainly focuses on reduction of fuel consumption by improving fuel efficiency and developing alternative energy sources.
- In this study, GHG reduction measures associated with fuel consumption are analyzed.
- Effects of the GHG reduction measures on the reduction of air pollutants and GHGs are presented in Table 1-4. The measures associated with fuel consumption are highlighted.

Table 1-4. Effects of GHG Reduction Measures on Air Pollutants and GHG Emission Reduction

Area	Measure	Air Pollutant Reduction	GHG Reduction
Building energy management	Environmentally-friendly building certification program	SO_X, NO_X, PM10	CO_2
Transportation energy management	Stringent regulation on vehicle idling	SO_X, NO_X, PM10	CO_2
	Distribution of low emission vehicles like hybrid cars	SO_X, NO_X, PM10	CO_2
Waste management	Expansion of waste water treatment facilities	Odor	CH_4
	Expansion of livestock waste matter treatment facilities	Odor	CH_4
	Expansion of sewage disposal plants	Odor	CO_2, CH_4
	Energy industrialization of landfills	SO_X, NO_X, PM10, Odor	CO_2, CH_4
	Building facilities for energy industrialization of food wastes and management	Odor	CO_2, CH_4
	Distribution of green fuel such as biodiesel	SO_X, NO_X, PM10	CO_2

CHAPTER 2
ANALYSIS AND PROJECTION OF GHG AND AIR POLLUTANT EMISSIONS FROM FUEL USE IN SEOUL METROPOLITAN AREA

2.1 METHODOLOGY FOR EMISSION ESTIMATION

2.1.1 Estimating Air Pollutant Emissions

Data from Clean Air Policy Support System (CAPSS, 2005) by Korean Ministry of Environment (MOE) was utilized in order to characterize the emissions of air pollutants. Emissions of air pollutants from various source categories were estimated using methodologies that were consistent with the method presented in CAPSS[1].

A. Methodology for Estimating Air Pollutant Emissions from Stationary Combustion

Major sources contributing to air pollutant emissions from fossil fuel combustion are fossil fuel combustion for energy use (CAPSS category 01), non-industrial combustion (CAPSS category 02) and industrial combustion (CAPSS category 03). The equation to calculate emissions from fossil fuel combustion is presented below.

$$E_{ijk} = EF_{ij} \times Fuel_j \times (1 - R_{ijk})$$

- E_{ijk}: emission from air pollutant i, fuel j and facility k
- EF_{ij}: emission factor for air pollutant i and fuel j
- $Fuel_j$: fuel j consumption rate
- R_{ijk}: efficiency of installed pollution control measures for air pollutant i, fuel j and facility k

Emission factors presented in the report titled The Amount of Air Pollutant Emissions in 1999 by Korea Environment Institute (KEI, 2000) were revised using emission factors for electricity generation to obtain emission factors by sectors and fuel types in CAPSS. PM10 emission factors were estimated from Total Suspend Particulates (TSP) emission factors by sources and classification of PM10 emissions (US EPA, Speciator 1.5).

[1] Clean Air Policy Support System (Phase III) Final Report (2005)

Air pollutant emission factors by fuel type and source are presented in Table 2-1.

Table 2-1. Air Pollutant Emission Factors

Fuel type	Unit	Source	NO_X	SO_X	PM10
Anthracite Coal	kg/ton	Public electricity generation	2.4	19.5S	134
		District heating/oil refineries/solid fuels	2.4	19.5S	134
		Nonindustrial combustion point sources	2.4	19.5S	134
		Nonindustrial combustion area sources	1.3	103	0.402
		Industrial combustion point sources	2.4	19.5S	134
		Industrial combustion area sources	2.4	19.5S	134
Bituminous Coal	kg/ton	Public electricity generation	2.89	19S	33.5
		District heating/oil refineries/solid fuels	7.5	19S	33.5
		Nonindustrial combustion point sources	7.5	19S	33.5
		Nonindustrial combustion area sources	–	–	–
		Industrial combustion point sources	7.5	19S	33.5
		Industrial combustion area sources	7.5	19S	33.5
B-A Oil	kg/kL	Public electricity generation	3.84	18S	0.596
		District heating/oil refineries/solid fuels	4.81	18S	0.521
		Nonindustrial combustion point sources	4.81	18S	0.521
		Nonindustrial combustion area sources	2.4	18S	0.521
		Industrial combustion point sources	4.81	18S	0.521
		Industrial combustion area sources	4.81	18S	0.521
B-B Oil	kg/kL	Public electricity generation	3.84	18.84S	0.852
		District heating/oil refineries/solid fuels	4.81	18.84S	0.744
		Nonindustrial combustion point sources	4.81	18.84S	0.744

B-B Oil	kg/kL	Nonindustrial combustion area sources	2.4	18.84S	0.744
		Industrial combustion point sources	4.81	18.84S	0.744
		Industrial combustion area sources	4.81	18.84S	0.744
B-C Oil	kg/kL	Public electricity generation	5.87	18.84S	0.718S+0.277
		District heating/oil refineries/solid fuels	6.64	18.84S	0.682S+0.242
		Nonindustrial combustion point sources	6.64	18.84S	0.682S+0.242
		Nonindustrial combustion area sources	6.63	18.84S	0.682S+0.242
		Industrial combustion point sources	6.64	18.84S	0.682S+0.242
		Industrial combustion area sources	6.64	18.84S	0.682S+0.242
LSWR	kg/kL	Public electricity generation	5.87	18.84S	0.718S+0.277
		District heating/oil refineries/solid fuels	6.64	18.84S	0.682S+0.242
		Nonindustrial combustion point sources	6.64	18.84S	0.682S+0.242
		Nonindustrial combustion area sources	–	–	–
		Industrial combustion point sources	6.64	18.84S	0.682S+0.242
		Industrial combustion area sources	6.64	18.84S	0.682S+0.242
Diesel	kg/kL	Public electricity generation	2.4	17S	0.17
		District heating/oil refineries/solid fuels	2.4	17S	0.149
		Nonindustrial combustion point sources	2.4	17S	0.149
		Nonindustrial combustion area sources	2.4	17S	0.105
		Industrial combustion point sources	2.4	17S	0.149
		Industrial combustion area sources	2.4	17S	0.149
Kerosene	kg/kL	Public electricity generation	2.4	17S	0.17
		District heating/oil refineries/solid fuels	2.4	17S	0.149
		Nonindustrial combustion point sources	2.4	17S	0.149

Kerosene	kg/kL	Nonindustrial combustion area sources	5.46	17S	0.105
		Industrial combustion point sources	2.4	17S	0.149
		Industrial combustion area sources	2.4	17S	0.149
LPG/ Propane/ Butane	kg/kL	Public electricity generation	2.28	0.001	0.069
		District heating/oil refineries/solid fuels	2.28	0.001	0.069
		Nonindustrial combustion point sources	2.28	0.001	0.069
		Nonindustrial combustion area sources	2.18	0.001	0.035
		Industrial combustion point sources	2.28	0.001	0.069
		Industrial combustion area sources	2.28	0.001	0.069
LNG	kg /1000m^3	Public electricity generation	1.43	0.001	0.029
		District heating/oil refineries/solid fuels	2	0.001	0.029
		Nonindustrial combustion point sources	2	0.001	0.029
		Nonindustrial combustion area sources	2.62	0.001	0.029
		Industrial combustion point sources	2	0.001	0.029
		Industrial combustion area sources	2	0.001	0.029

B. Methodology for Estimating Air Pollutant Emissions from Mobile Sources

o Estimating Hot-Start emissions

- The method to estimate emissions from road mobile sources is presented below.

Emission (vehicle type, road type) = Emission Factor(vehicle type, road type) *× Vehicle Kilometer Traveled (vehicle type, road type)*

- Not all the traffic volume could be measured. Thus, total vehicle kilometer traveled (Total VKT) was determined with number of registered vehicles and average vehicle kilometer traveled. The difference between total VKT and VKT with monitored data becomes VKT without monitored data.

□ Total VKT
Total VKT (vehicle type) = Average daily VKT (vehicle type)
× Number of Registered Vehicles (vehicle type) × 365

□ VKT by Road Type
VKT by road type (vehicle type) = Traffic Volume by Road Type (vehicle type)
× Road Section

□ VKT without Monitored Data (vehicle type)
= Total VKT (vehicle type) – VKT by Road Type (vehicle type)

Allocating VKT without monitored data
= Based on the length of lanes for the section without any monitored data on traffic volume

- Estimates for emissions from mobile sources were calculated from VKT and emission factors. Emission factors were dependent on vehicle speeds and vehicle speeds on road types.
- Emissions of air pollutants were calculated from emission factors by model year presented by Automobile Pollution Research Center (APRC, Emission factors of on-road vehicles by model year, 2002.5).

Table 2-2. Emission Factors for Road Mobile Sources (g/km)

Vehicle type		Fuel	CO_2	CO	VOC	CH_4	NO_X	N_2O	PM
Passenger Cars	Extra-Small	Gasoline	137.8	0.656	0.069	0.03	0.19	0.03	-
	Small	Gasoline	180.9	0.821	0.042	0.02	0.132	0.05	-
	Midsize	Gasoline	212.9	0.962	0.037	0.02	0.131	0.06	
	Large	Gasoline	235.7	0.994	0.031	0.02	0.135	0.04	-
Taxies		LPG	231.0	2.31	0.126	0.042	0.586	0.038	-
Passenger Vans	Small	Gasoline	251.7	0.633	0.022	0.033	0.196	0.059	-
		Diesel	243.3	0.39	0.039	0.004	0.556	0.007	0.064
		LPG	190.2	1.717		0.032	0.447	0.026	-
	Midsize	Diesel	315.1	0.513	0.231	0.019	2.494	0.007	0.069
	Large	Diesel	1382.4	2.424	0.719	0.041	6.647	0.095	0.154
Trucks	Small	Gasoline	247.3	0.627		0.032	0.135	0.058	-
		Diesel	245.5	0.364	0.051	0.012	0.536	0.008	0.061
		LPG	187.9	1.642		0.031	0.397	0.025	-
	Midsize	Diesel	334.9	0.252	0.491	0.034	0.573	0.007	0.06
	Large	Diesel	1388.2	3.068	0.824	0.036	10.305	0.075	0.331

2.1.2 Estimating GHG Emissions

A. Methodology for Estimating GHG Emissions from Stationary Combustion

- CO_2 emissions are directly related to fuel consumption. The method to estimate CO_2 emissions is presented below.

- Estimating CO_2 Emissions

  - CO_2 Emission
    = Fuel Consumption × Heat Value × Carbon Content Coefficient
    × Fraction of Carbon Oxidized × 44/12
  - Data: fuel consumption by fuel type (kg), heat value (kcal/kg), fuel efficiency (kW/kcal), and CO_2 emission (tCO_2)
  - Calculation:
    1) Determine fuel consumption by fuel type
    2) Calculate TOE (Ton of oil equivalent) by multiplying fuel consumption by fuel type and TOE conversion factor
    3) Determine tC (Ton of Carbon) by multiplying TOE and CEF (Carbon Emission Factor)
    4) Emission = tC × 44/12

Table 2-3. TOE Conversion Factors and Carbon Emission Factors

Fuel Type	TOE Conversion Factor	Unit	Carbon Emission Factor (Ton C/TOE)
Bituminous coal (ton) lower than 0.3%	0.66	kg/kg	1.132
Cokes (ton)	0.65	kg/kg	1.132
Wood (ton)	0.45	kg/kg	1.132
Diesel (kL)	0.92	kg/L	0.832
Kerosene (kL)	0.87	kg/L	0.812
Distillate oil (kL)	0.99	kg/L	0.875
LSWR (kL) lower than 0.3%	0.99	kg/L	0.875
Naphthenic oil (kL)	0.80	kg/L	0.829
Reduced crude oil (kL)	0.99	kg/L	0.875
B-C Oil (kL)	0.99	kg/L	0.875
Lower than 4.0%	0.99	kg/L	0.875
Lower than 1.0%	0.99	kg/L	0.875
Lower than 0.5%	0.99	kg/L	0.875
Lower than 0.3%	0.99	kg/L	0.875
LNG ($1000m^3$)	1.05	kg/Nm^3	0.637
LPG ($1000m^3$)	1.50	kg/Nm^3	0.713
Refinery gas ($1000m^3$)	1.50	kg/Nm^3	0.713

Data: Korea Energy Management Cooperation (KEMCO) and Intergovernmental Panel on Climate Change (IPCC)

B. Methodology for Estimating GHG Emissions from Mobile Sources

- Daily emissions of CO_2 from a vehicle (g/day-vehicle) were calculated by multiplying vehicle kilometer traveled (VKT) and emission factors (g/km).
- Annual emissions of CO_2 from all the vehicles (ton/yr) were then computed as below[2].

$$\textit{Annual } CO_2 \textit{ Emission} = N_i \times M_i \times EF_i \times 10^{-6} \times 365$$

Where
EF_i = Emission factor for vehicle type *i* at average speed (g/km)
N_i = Number of vehicles of vehicle type *i*
M_i = kilometer traveled for vehicle type *i* (km)

o Emission Factor

[2] Prospective air pollutant emissions from vehicles, Ecofrontier

- Emission factors at average speed of 20km/hr, 60km/hr and 80km/hr were derived from the method presented in CAPSS (Table 2-4).

Table 2-4. Estimating CO_2 Emission Factors by Vehicle Type

Vehicle Type		Emission Factor (g/km)	R^2
Passenger Cars	Extra-Small	y = 595.32 * V^(-0.404)	0.87
	Small	y = 937.56* V^(-0.4506)	0.93
	Midsize	y = 1248.4 * V^(-0.4845)	0.97
	Large	y = 1563.9 * V^(-0.5194)	0.99
Taxies		y = 1397.4 * V^(-0.5475)	0.98
Passenger vans	Small (Diesel)	y = 1103.7* V^(-0.413)	0.89
	Midsize	y = 1086.2* V^(-0.3249)	0.91
	Large	Intra-city buses (< 50km/hr) y = 2804.7 * V^(-0.3105)	0.88
		Other than intra-city buses, use emission factors for large trucks	
Trucks	Small (Diesel)	y = 1073.8 * V^(-0.4009)	0.86
	Midsize	y = 0.1029 * V^(2) -14.937 * V + 798.9	0.89
	Large	y = 624.04 * V^(-0.3829)	0.97

Reference: NIER. 2005. Measures for Reduction of GHG Emissions from Vehicles; V = velocity in km/hr

Table 2-5. CO_2 Emission Factors by Vehicle Type

Vehicle Type		Emission Factor by Speed (g/km)		
		20 km/hr	60 km/hr	80 km/hr
Passenger Cars	Extra-Small	177	114	101
	Small	243	148	130
	Midsize	292	172	149
	Large	330	186	161
Taxies		271	149	127
Passenger Vans	Small (Diesel)	320	203	181
	Midsize	410	287	262
	Large	1106		
		Other than intra-city buses, use emission factors for large trucks		
Trucks	Small (Diesel)	323	208	185
	Midsize	541	273	263
	Large	1982	1301	1166

- The ratios of vehicle speeds differ by the region. Thus, average emission factors were derived by multiplying the ratios of vehicle speeds for each region (Urban (20km/hr), Rural (60km/hr), Highway (80km/hr)) (data from CAPSS) and weighted average of emission factors at each speed[3].

  - For small passenger cars in Kyonggi, 20km/hr 36.3%, 60km/hr 37.5%, 80km/hr 26.2%
  - Average emission factor = [(weighted average emission factor at 20km/hr × 36.3%) + (weighted average emission factor at 60km/hr × 37.5%) + (weighted average emission factor at 80km/hr × 26.2%)] / 100

[3]MOE. Estimation of Air Pollutant Emissions from Vehicles

Table 2-6. VKT Ratios by Region and Vehicle Type

Vehicle type	Seoul			Incheon			Kyonggi		
	20 km/hr	60 km/hr	80 km/hr	20 km/hr	60 km/hr	80 km/hr	20 km/hr	60 km/hr	80 km/hr
Extra-Small Cars	79.5	16.2	4.2	50.2	18.5	31.3	37.3	38.5	24.2
Small Passenger Cars	82.2	14.1	3.7	50.2	18.2	31.6	36.3	37.5	26.2
Midsize Passenger Cars	85.2	11.8	2.9	47.6	19.8	32.7	35.1	38.2	26.7
Large Passenger Cars	85.3	11.8	2.9	45.3	21.3	33.4	35.3	38.1	26.7
Taxies	98.7	1.3	0.0	87.0	0.6	12.5	100.0	0.0	0.0
Small Rvs	85.3	11.8	2.9	45.3	21.3	33.4	35.3	38.1	26.7
Midsize RVs & Passenger Vans	84.2	12.9	3.0	58.1	13.6	28.2	41.9	35.0	23.2
Midsize Passenger Vans	33.7	53.0	13.4	17.6	32.4	50.0	2.1	59.0	38.8
Intra-city Buses/Diesel	98.8	1.2	0.0	87.1	0.6	12.3	100.0	0.0	0.0
Intra-city Buses/CNG	98.8	1.2	0.0	87.1	0.6	12.3	45.9	48.3	5.8
Intercity Buses	14.6	82.5	3.0	0.0	50.0	50.0	45.9	48.3	5.8
Chartered Buses	23.3	63.2	13.5	33.2	16.8	50.0	2.1	56.9	41.0
Express Buses	52.4	0.0	47.6	0.0	50.0	50.0	3.2	0.0	96.8
Other Buses	33.7	53.0	13.4	17.6	32.4	50.0	2.1	59.0	38.8
Diesel/Small Trucks	81.6	13.6	4.8	44.5	21.4	34.0	31.2	39.5	29.3
Midsize Trucks	67.7	20.9	11.5	29.2	35.4	35.4	18.1	34.4	47.5
Large Trucks	25.8	45.8	28.4	5.8	47.1	47.1	2.3	38.5	59.1
Special Vehicles	25.8	45.8	28.4	5.8	47.1	47.1	2.3	38.5	59.1

Data: CAPSS internal data, Ecofrontier

Table 2-7. Average CO_2 Emission Factors for Gasoline Passenger Cars by Vehicle Type and Model year

Gasoline vehicle type	Model year	Average emission factor (g/km)		
		Seoul	Incheon	Kyonggi
Extra-Small	All	164	142	135
	< 1996	152	132	125
	1997 - 2001	167	144	136
	2002 <	162	142	135
Small	All	226	190	178
	< 1996	223	188	176
	1997 - 2001	226	189	176
	2002 <	224	200	189
Midsize	All	274	222	203
	< 1996	272	218	204
	1997 - 2001	262	211	197
	2002 <	303	256	244
Large	All	308	243	230
	< 1996	264	205	194
	1997 - 2001	323	254	240
	2002 <	314	250	238

Table 2-8. CO_2 Emission Factors by Vehicle Type (g/km)

Vehicle type		Fuel Type	Seoul	Incheon	Kyonggi
Passenger Cars	Extra-Small	Gasoline	164	142	135
		LPG	131.2	113.6	108
	Small	Gasoline	226	190	178
		LPG	180.8	152	142.4
	Midsize	Gasoline	274	222	208
		Diesel	205.5	166.5	156
		LPG	219.2	177.6	166.4
	Large	Gasoline	308	243	230
		Diesel	231	182.3	172.5
		LPG	246.4	194.4	184
Taxies	Midsize/Large	LPG	269	253	271
Passenger Vans	Extra-Small	Gasoline	251.7	251.7	251.7
		LPG	190.2	190.2	190.2
	Small	Gasoline	251.7	251.7	251.7
		Diesel	301	265	247
		LPG	190.2	190.2	190.2
	Midsize	Diesel	326	296	247
Large Passenger Vehicles	Intracity buses	Diesel	1106	1106	1106
		LPG	34.35 (ton/yr-vehicle)		
	Intercity buses	Diesel	143.8	1277	123.5
	Chartered buses	Diesel	143.8	1277	123.5
	Express buses	Diesel	143.8	1277	123.5
	Other buses	Diesel	143.8	1277	123.5
Trucks	Extra-Small	Gasoline	247.3	247.3	247.3
		LPG	187.9	187.9	187.9
	Small	Gasoline	247.3	247.3	247.3
		Diesel	301	251	237
		LPG	187.9	187.9	187.9
	Midsize	Diesel	454	348	317
	Large	Diesel	1438	1277	1235

- Number of Registered Vehicles
  - Projected numbers of registered vehicles by year, vehicle type and vehicle age were used to estimate CO_2 emissions.

- Annual Vehicle Kilometer Traveled
  - Annual vehicle kilometer traveled was calculated by multiplying daily vehicle kilometer traveled (VKT) by number of registered vehicles and 365 days.

Table 2-9. Daily VKT in Seoul by Year (km)

Vehicle type	Year										
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Extra-Small Passenger Cars	37.2	37.1	37.1	37.0	36.9	36.8	36.8	36.7	36.6	36.6	36.6
Small Passenger Cars	37.2	37.1	37.1	37.0	36.9	36.8	36.8	36.7	36.6	36.6	36.6
Midsize Passenger Cars	38.3	38.2	38.1	38.1	38.0	37.9	37.8	37.8	37.7	37.7	37.7
Large Passenger Cars	42.7	42.6	42.5	42.4	42.3	42.2	42.1	42.1	42.0	42.0	42.0
Midsize Taxies	221.0	220.6	220.1	219.7	219.2	218.8	218.3	217.9	217.5	217.5	217.5
Large Taxies	161.3	161.0	160.9	160.3	160.0	159.7	159.3	159.0	158.7	158.7	158.7
Small RVs	42.7	42.6	42.5	42.4	42.3	42.2	42.1	42.1	42.0	42.0	42.0
Midsize RVs/ Passenger Vans	62.9	62.8	62.6	62.5	62.4	62.3	62.1	62.0	61.9	61.9	61.9
Midsize Passenger Vans	50.9	50.8	50.7	50.6	50.5	50.4	50.3	50.2	50.1	50.1	50.1
Intra-city Buses	210.9	210.9	210.9	210.9	210.9	210.9	210.9	210.9	210.9	210.9	210.9
Intercity Buses	342.6	341.9	341.3	340.6	339.9	339.2	338.5	337.8	337.1	337.1	337.1
Chartered Buses	189.8	189.4	189.0	188.6	188.2	187.9	187.5	187.1	186.7	186.7	186.7
Express Buses	525.1	524.0	522.9	521.9	520.8	519.8	518.7	517.7	516.6	516.6	516.6
Other Buses	117.3	117.0	116.8	116.5	116.3	116.1	115.8	115.6	115.4	115.4	115.4
Extra-small/ Small Trucks	61.5	61.4	61.3	61.1	61.0	60.9	60.8	60.6	60.5	60.5	60.5
Midsize Trucks	67.8	67.6	67.5	67.3	67.2	67.1	66.9	66.8	66.7	66.7	66.7
Large Trucks	102.4	102.2	102.0	101.8	101.5	101.3	101.1	100.9	100.7	100.7	100.7

Data: MOE. 2004. Total Allowable Emissions System in Seoul Metropolitan Area

2.2 CURRENT STATUS OF AIR POLLUTANT AND GHG EMISSIONS IN SEOUL METROPOLITAN AREA

The emissions of air pollutants and GHGs by source in the Seoul metropolitan area were analyzed to identify major sources and to characterize emissions from those sources. Emissions of air pollutants and GHG by source are presented in Table 2-10.

Table 2-10. Emissions of Air Pollutants and GHGs in year 2003 (ton)

Source		NO_X	SO_X	PM10	CO_2
Combustion For Energy	Public Power Plants	35,951	11,316	299	8,603,583
	District Heating Facilities	2,037	1,830	33	1,468,538
	Oil Refineries	789	1,204	17	
	Private Power Plants	1,847	4,748	151	
	Subtotal	40,624	19,098	501	10,072,122
Nonindustrial Combustion	Commercial/Municipal Buildings	11,350	5,341	43	7,312,125
	Residential Buildings	23,483	6,616	697	8,569,342
	Agricultural/ Animal Farming/ Fishing Facilities	1,517	926	78	925,088
	Subtotal	36,350	12,884	818	925,087
Industrial Combustion	Combustion Facilities	12,863	17,749	1,185	10,514,850
	Industrial Furnaces	6,446	7,523	179	
	Subtotal	19,309	25,272	1,364	16,806,553
Industrial Processes		6,764	4,865	257	5,663,898
Road Mobile Sources		144,968	3,182	9,058	33,206,684
Non-road Mobile Sources		51,514	6,757	2,054	10,578,091
Waste Management		7,135	788	32	1,901,888
Total		306,664	72,846	14,084	88,741,086

Note: Values are rounded off to the nearest integer. Total numbers may not be the same as the summation of values from difference sources.

2.3 PROJECTED EMISSIONS OF AIR POLLUTANTS AND GHG IN SEOUL METROPOLITAN AREA

Statistical data from the government as well as materials on socio-economic projections were used to project future fuel demand. Socio-economic indices influencing energy demand were adjusted to the year of the project. Projected fuel demand was estimated by multiplying energy demand for base-year by a growth factor.

$$\text{Projected Fuel Consumption} = \text{Fuel Consumption for Base-year} \times \text{Growth Factor} \times \text{Control Factor}$$

Fuel consumption by sector and the corresponding GHG emissions for the year 2014 were estimated using CAPSS data, projected emissions from MOE (Korean Ministry of Environment, 2005) and growth factors.

2.3.1 Methodology for Projection

A. Industrial Combustion for Energy, Nonindustrial Combustion, Industrial Combustion and Industrial Process

□ Setting Socio-Economic Indices

The socio-economic indices used to project future energy demand were from the report titled the Countermeasures against Convention on Climate Change and Kyoto Protocol. The socio-economic indices are presented below.

1) Economic Growth Rate

The economic growth rate in the report, Countermeasures against Convention on Climate Change and Kyoto Protocol, was determined from data in the reports (short-term economic outlook by The Bank of Korea, projected potential economic growth rate and economic outlook in basic plan for national energy demand phase II by Korea Development Institute) and historical trends.

Table 2-11. Projected Economic Growth Rates

Period (year)		Projected economic growth rates
2001 ~ 2010	2001 ~ 2005	5.1%
	2006 ~ 2010	5.1%
2011 ~ 2020	2011 ~ 2015	4.5%
	2015 ~ 2020	4.0%
2001 ~ 2020		4.7%

Data: Korean Ministry of Commerce, Industry and Energy, Korea Energy Economics Institute, 2003, Counter Measures against Convention on Climate Change and Kyoto Protocol

2) Industrial Structure

In the report of Countermeasures Against Convention on Climate Change and Kyoto Protocol, the industrial structure was projected by using a long-term outlook of industrial structure by the Korea Institute for Industrial Economics and Trade[4], the 2nd year report of Countermeasures against Convention on Climate Change and Kyoto Protocol and historical trends. When the industrial structure was projected, upper and lower limits were set (Table 2-13) to reflect the difference in decrease rate for share of manufacturing industry in total GDP as presented in Table 2-12.

Table 2-12. Comparison of Two Reports on Projection of Industrial Structure

Reference	Projected industrial structure	
	Similarity	Difference
A	Share of manufacturing industry in total GDP has consistently decreased. Share of service industry in total GDP has consistently increased	Share of manufacturing industry in total GDP has decreased relatively slowly.
B		Share of manufacturing industry in total GDP has decreased relatively fast.

A: Prospect and Vision of Industrial Development in 2010
B: Basic plan for National Energy, Phase II

Table 2-13. Projected Industrial Structure (proportion, %)

Industry		2001	2005	2010	2015	2020
Agricultural and fishing industry	Upper	5.2	4.2	3.3	2.7	2.2
	Lower	5.2	4.2	3.0	2.4	2.0
Mining and manufacturing industry	Upper	34.1	33.6	33.0	32.4	31.8
	Lower	34.1	32.7	31.0	29.0	28.0
(Manufacturing industry)	Upper	33.8	33.4	32.8	32.3	31.7
	Lower	33.8	32.5	30.8	28.9	27.9
Service industry	Upper	60.7	62.2	63.7	64. 9	66. 0
	Lower	60.7	63.1	66.0	68.6	70.0
GDP	Upper	100.0	100.0	100.0	100.0	100.0
	Lower	100.0	100.0	100.0	100.0	100.0

Reference: Korean Ministry of Commerce, Korea Energy Economics Institute. 2003. Counter measures against convention on climate change and Kyoto Protocol

[4] MCIE, Korea Institute for Industrial Economics and Trade. 2001. Prospect and Vision of Industrial Development for the Year 2010

3) Projected Residential Energy Demand

GDP, population, total number of households, and number of capita per household are the key elements for projection of residential energy demand (Countermeasures Against Convention on Climate Change and Kyoto Protocol). Future population was projected using population estimates by Korea National Statistical Office under the assumption that increase rate of total number of households was consistent with that of number of general households by Korea Institute for Health and Social Affairs.

Table 2-14. Projections of Key Elements in Residential Energy Demand

	Year 2001	Year 2005	Year 2010	Year 2015	Year 2020	Annual Increase (%)	
						2002 ~2010	2011 ~2020
GDP (1995 constant, 1000 won)	493.0	614.8	786.9	980.7	1,193.1	5.3	4.2
Population (million)	47.3	48.5	49.6	50.4	50.7	0.5	0.2
Household (million)	14.7	15.9	17.7	18.1	18.7	1.7	0.9
Number of People per Household	3.2	3.0	2.9	2.8	2.7	-1.2	-0.7

Reference: Korean Ministry of Commerce, Korea Energy Economics Institute. 2003. Counter measures against Convention on Climate Change and Kyoto Protocol

4) Projected Commercial Energy Demand

Key elements used to project commercial energy demand are presented in Table 2-15. Commercial building area was projected using data by Korea National Statistical Office and applying the correlation between GDP and building area.

Table 2-15. Projection of Key Elements in Commercial Energy Demand

	2001	2005	2010	2015	2020	Annual increase (%)	
						2002 ~2010	2011 ~2020
GDP (1995 constant value, trillion won)	216.4	276.4 ~ 280.4	356.8 ~ 369.9	455.1 ~ 480.5	562.3 ~ 596.6	5.7 ~ 6.1	4.7 ~ 4.9
Area of Buildings (million m^2)	281.3	353.7 ~ 358.6	446.3 ~ 461.5	523.3 ~ 547.9	589.2 ~ 618.6	5.3 ~ 5.7	2.8 ~ 3.0

Reference: Korean Ministry of Commerce, Korea Energy Economics Institute. 2003. Counter measures against Convention on Climate Change and Kyoto Protocol

 Determining Growth Factor

The growth factor was derived from growth rate of future energy demand (excluding public electricity generation sector). A Top-down method of breaking projected national energy demand by sector into energy demand by region, sector and fuel type was adopted.

- Steps to Determine Growth Factor

1) Aggregate data on energy demand by sector and fuel type from 1997 till 2001 in a country, Seoul, Incheon and Kyonggi using annual report on regional energy statistics[5].
2) Assess ratios of energy demand by sector and fuel type to national energy demand
3) Compute increase/decrease rate of regional energy demand by sector and fuel type from 1997 till 2001 to reflect the characteristics of energy demand by sector and fuel type
4) Calculate ratios of national to regional energy demand by sector and fuel type for the period of 2002 to 2015 by applying the increase/decrease rate for the same period to the ratios of regional to national energy demand in 2001
5) Project national energy demand by sector and fuel type for the period of 2005 to 2014 using projections of national energy demand for the year 2001 (base-year), 2005, 2010 and 2015 as presented in the report, countermeasures against convention on climate change and Kyoto Protocol[6]
6) Project energy demand for the period of 2005 to 2014 by applying results from step 4 to results from step 5
7) Project energy demand growth by region, sector and fuel type for the period of 2005 to 2014

B. Industrial Combustion for Energy, Nonindustrial Combustion, Industrial Combustion, Industrial Process

Increase rate of energy demand by sector, fuel type and region was considered as growth rate.

C. Industrial Process

Growth rate was derived from projected energy demand for each corresponding industry.

D. Petrochemical Industry

Growth rate of energy demand was determined by considering all the fuel types of petroleum, coal, LNG and etc.

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[5] Korea Institute of Commerce, Industry and Energy, Korea Energy Economics Institute. 1998. 1999. 2001. 2004. Annual Report on Regional Energy Statistics

[6] Korea Institute of Commerce, Industry and Energy, Korea Energy Economics Institute. 2003. Counter Measures against Convention on Climate Change And Kyoto Protocol

E. Other Industries than Petrochemical Industry

Only growth rate of petroleum energy demand was used for growth rate.

- Control Factor

  - Regulations and policies related to air may have great impacts on future emissions. It is necessary to review acts on national air quality fuel control, acts on factory location regulation, acts and regulations on industrial complex (applied only to regulations and policies approved by December 31, 2005)
  - Factors that may influence on emissions of air pollutants in the future: act on air quality management (regulations on air pollutant concentrations from emission facilities), mandatory green fuel use

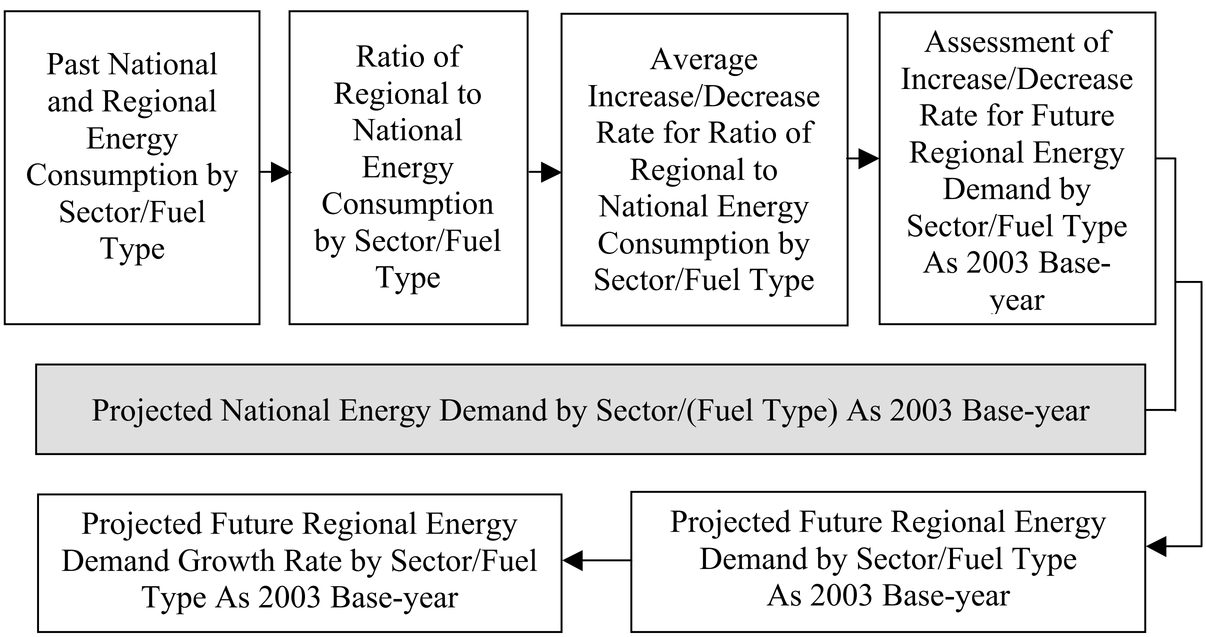

Figure 2-1. Flowchart for Growth Rate

Table 2-16. Steps to Estimate Fuel Consumption

Source	Facilities	Steps
Combustion for Energy	Public Power Plants	Emissions from historical data × Growth of electricity generation
	District Heating Facilities	1) Determine past average increase/decrease rate for the share of regional (Seoul, Kyonggi and Incheon) heat generation in national heat generation 2) Determine future regional share of heat generation 3) Future national petroleum energy demand × regional share of heat generation projection on petroleum production in Incheon (oil refineries) 4) Determine regional growth rate
Nonindustrial Combustion	Commercial and Municipal Buildings	1) Determine average increase/decrease rate for the share of regional (Seoul, Kyonggi and Incheon) fuel consumption in national fuel consumption for commercial sector in the past 2) Determine future share of demand by region and fuel type 3) Future estimates of national fuel demand is multiplied by value from 2) to obtain future regional fuel demand by fuel type for commercial sector 4) Determine regional growth rate
	Residential Buildings	1) Determine average increase/decrease rate for the share of regional (Seoul, Kyonggi and Incheon) fuel consumption in national fuel consumption for residential sector in the past 2) Determine future share of demand by region and fuel type 3) Future estimates of national fuel demand is multiplied by value from 2) to obtain future regional fuel demand by fuel type for residential sector 4) Determine regional growth rate
	Agricultural, Animal Farming and Fishing Facilities	1) Determine average increase/decrease rate for the share of regional (Seoul, Kyonggi and Incheon) fuel consumption in national fuel consumption for agricultural/animal farming/fishing sector in the past 2) Determine future share of demand by region and fuel type 3) Future estimates of national fuel demand is multiplied by value from 2) to obtain future regional fuel demand by fuel type for agricultural/animal farming/fishing sector 4) Determine regional growth rate
Industrial Combustion		1) Determine average increase/decrease rate for the share of regional (Seoul, Kyonggi and Incheon) fuel consumption in national fuel consumption for manufacturing sector in the past 2) Determine future share of demand by region and fuel type 3) Future estimates of national fuel demand is multiplied by value from 2) to obtain future regional fuel demand by fuel type for manufacturing sector 4) Determine regional growth rate

2.3.2 Projected Emissions of Air Pollutants and GHG in Seoul Metropolitan Area

Projected emissions of air pollutants and GHG for the year 2014 are presented in Table 2-17.

Table 2-17. Projected Emissions of Air Pollutants and GHG by Source and Region for the Year 2014 (ton/yr)

Source	District	NO_X	SO_X	PM10	CO_2
Combustion for Energy	Seoul	1,284	689	18	570,846
	Incheon	20,780	9,671	1,129	3,968,972
	Kyonggi	25,037	19,242	409	5,065,463
	Subtotal	47,101	29,601	1,556	9,605,281
Nonindustrial Combustion	Seoul	17,022	660	187	4,140,498
	Incheon	10,181	4,968	77	3,554,054
	Kyonggi	32,479	2,911	465	8,415,033
	Subtotal	59,682	8,539	729	16,109,585
Industrial Combustion	Seoul	6,057	4,836	41	3,467,719
	Incheon	16,981	18,332	854	2,886,278
	Kyonggi	7,507	8,260	1,696	5,720,517
	Subtotal	30,545	31,428	2,591	12,074,514
Industrial Processes	Seoul	0	0	0	0
	Incheon	8,508	5,422	343	1,325,059
	Kyonggi	952	742	33	488,148
	Subtotal	9,460	6,164	376	1,813,207
Road Mobile Sources	Seoul	46,694	1,696	3,137	17,164,965
	Incheon	16,701	203	1,175	5,035,621
	Kyonggi	66,678	2,937	5,195	21,733,498
	Subtotal	130,073	4,836	9,507	43,934,084
Non-road Mobile Sources	Subtotal	64,179	9,183	2,572	13,178,186
Waste Management	Seoul	1,582	282	8	614,562
	Incheon	1,214	66	5	387,007
	Kyonggi	10,107	1,016	41	2,368,401
	Subtotal	12,903	1,364	54	3,369,970
Total		353,943	91,116	17,385	103,084,826

Emissions of air pollutants and GHG by source for the year 2003 and the year 2014 are presented in Table 2-18.

Table 2-18. Emissions of Air pollutants and GHG for the Year 2003 and Year 2014 (ton/yr)

Source	Year	NO_X	SO_X	PM10	CO_2
Combustion for Energy	2003	40,624	19,098	501	10,072,122
	2014	47,101	29,602	1,556	9,605,281
Nonindustrial Combustion	2003	36,350	12,884	818	16,806,553
	2014	59,682	8,539	729	16,109,585
Industrial Combustion	2003	19,309	25,272	1,364	10,514,850
	2014	30,545	31,428	2,591	12,074,514
Industrial Processes	2003	6,764	4,865	257	5,663,898
	2014	9,460	6,164	376	1,813,207
Road Mobile Sources	2003	144,968	3,182	9,058	33,203,684
	2014	130,073	4,836	9,507	43,934,084
Non-road Mobile Sources	2003	51,514	6,757	2,054	10,578,091
	2014	64,179	9,183	2,572	13,178,186
Waste Management	2003	7,135	788	32	1,901,888
	2014	12,903	1,364	54	3,369,970
Total	2003	306,664	72,846	14,084	88,741,086
	2014	353,943	91,116	17,385	103,084,826

Emissions of air pollutants and GHG by source in Seoul metropolitan area for the year 2003 are illustrated in Figure 2-2.

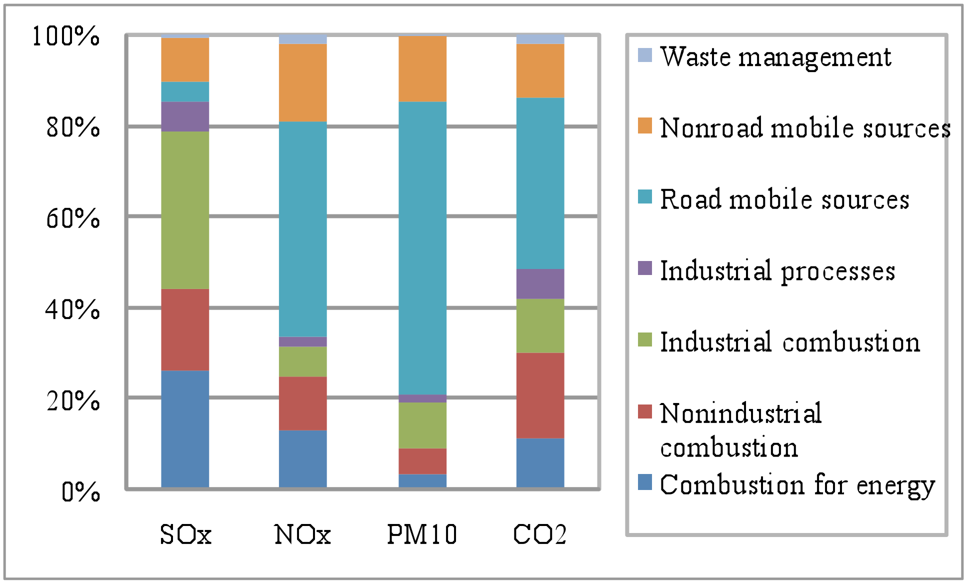

Figure 2-2. Emissions of Air Pollutants and GHG in Seoul Metropolitan Area for the Year 2003

For the year 2003, industrial combustion constituted 35% of SO_X emissions, and road mobile sources were the most significant sources for emissions of NO_X and PM10 that accounted for 47% and 64% of emissions, respectively. Road mobile sources also contributed to GHG emissions the most.

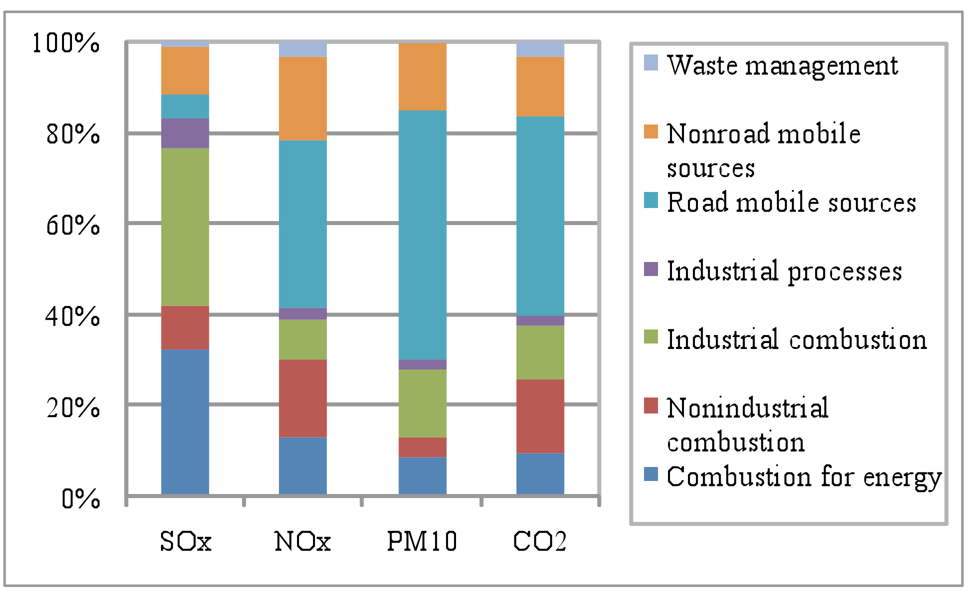

Figure 2-3. Projected Emissions of Air Pollutants and GHG in Seoul Metropolitan Area for the Year 2014

Emissions of air pollutants and GHG for the year 2014 were not much different from those for the year 2003. However, while the contribution of road mobile sources to PM10 emissions decreased slightly, road mobile sources had greater impact on CO_2 emissions.

A comparison of emissions between year 2003 and year 2014 is illustrated in Figure 2-4.

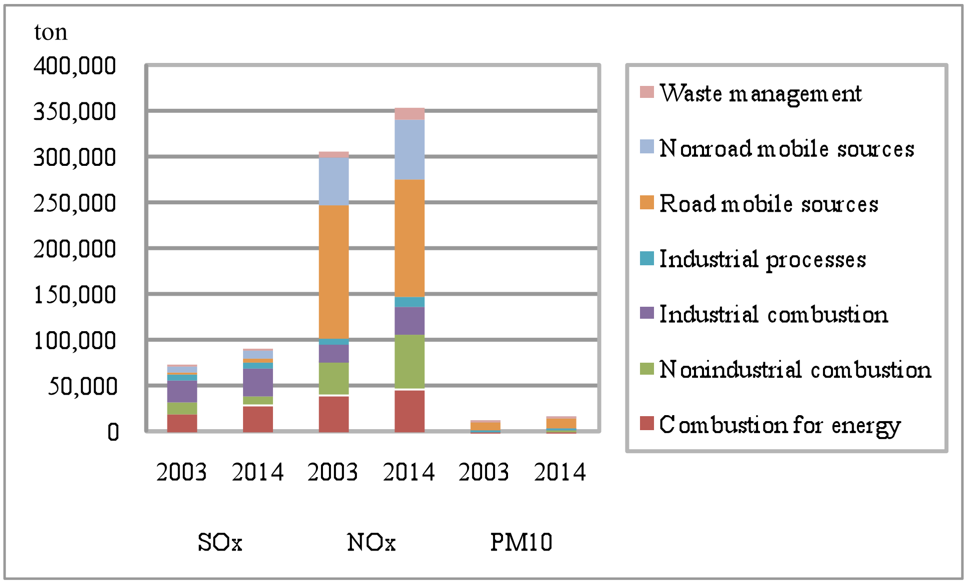

Figure 2-4. Comparison of Air Pollutant Emissions in Seoul Metropolitan Area for the Year 2003 with Those for the Year 2014

As presented in Figure 2-4, it was anticipated that emissions of air pollutants for the year 2014 would not be much different from those for the year 2003. For both years 2003 and 2014, industrial combustion accounted for the most SO_X emissions, and on-road mobile sources were the most important contributors for both NO_X and PM10 emissions.

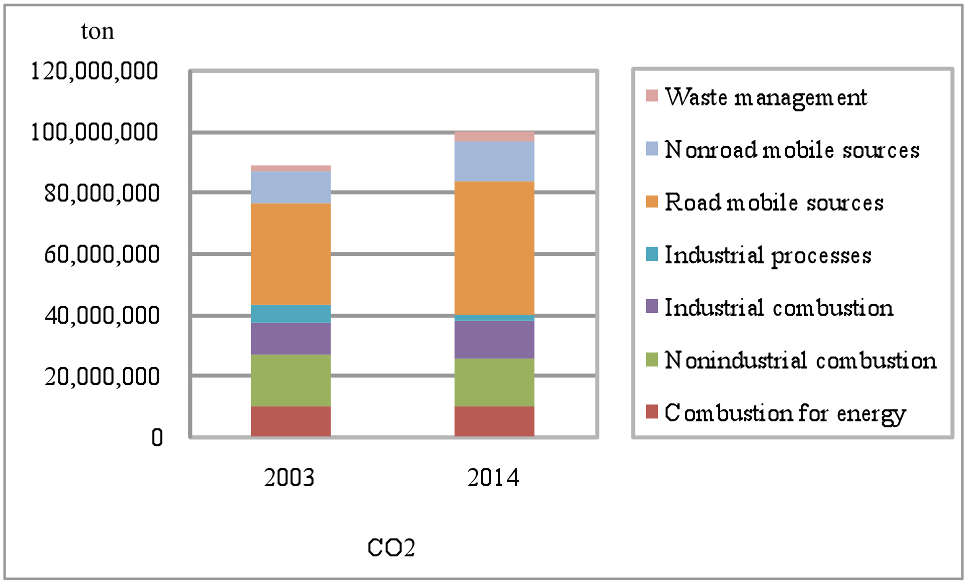

Figure 2-5. Comparison of GHG Emissions in Seoul Metropolitan Area for the Year 2003 with Those for the Year 2014

Like air pollutant emissions, GHG emissions for year 2014 slightly increased, and road mobile sources contributed to GHG emissions the most.

CHAPTER 3
SEOUL METROPOLITAN AREA AIR QUALITY MANAGEMENT PLAN (SAQMP) AND GHG EMISSION MITIGATION PLAN (GHG): EFFECTS ON EMISSION REDUCTIONS AND COST ANALYSIS

Air pollutant emission reductions as well as the associated costs were analyzed to evaluate the efficiencies of specific measures under Seoul metropolitan area Air Quality Management Plan (SAQMP) and GHG emission mitigation plan (GHG).

Unit cost is the summation of equipment cost and fuel cost savings. Equipment cost was converted to Equivalent Annual Value (EAV) with equipment longevity to estimate future unit cost more accurately. The equation for converting equipment cost to EAV is presented below. Fuel cost savings can be estimated from differences in fuel consumption of each measure.

Unit Cost = Equipment Cost + Fuel Cost Saving

$$\text{Annual Equipment Cost} = \frac{C_{Total} \times r}{1-(1+r)^{-n}}$$

C_{Total}: Total Equipment Investment Cost
r: Discount Rate
n: Equipment Longevity

Discount rate (r) of 0.05 was used in this study[1].

3.1 ESTIMATING EMISSION REDUCTIONS AND COSTS FOR SAQMP

3.1.1 Area Sources

A. Switching from Anthracite for Residential Use to Clean Fuels

 Summary

A regulation on fuel use like mandatory use of clean fuels is underway in Korea. Facilities obliged to use clean fuels (Notification of Clean Fuel Use No 13) are apartments and row houses whose sizes are bigger than those specified in annexed list 6 in district heating facilities among integrated energy supply facilities based on Integrated Energy Supply Act, Article 2, business boilers with evaporation loss greater than 2 ton (including commercial and public boilers and excluding industrial boilers) and power plants (excluding industrial cogeneration plants). Regulation on fuel use by some apartments and row houses in Seoul, Incheon and Kyonggi is presented in Table 3-1.

Table 3-1. Fuel Use of Apartments and Row Houses with Central Heating or District Heating

District		Status	Boiler Capacity	Fuel
Seoul Metropolitan Area	Seoul	–	– ≥25 pyeong[a] – >12.1 pyeong and <24 pyeong	Clean Fuel Clean Fuel or Diesel
	Incheon, Suwon, Bucheon, Gwacheon, Seongnam, Gwangmyeong, Anyang, Uiwang, Gunpo, Siheung, Guri, Goyang	Current	– ≥25 pyeong – >18 pyeong and <25 pyeong	Clean Fuel Clean Fuel or Diesel
		New	– ≥25 pyeong (Building permits approved before Jan. 1st, 1991 for apartments and before April 11th, 1991 for row houses) – >18 pyeong and <25 pyeong (Building permits approved after May 1st, 1994)	Clean Fuel Clean Fuel or Diesel
	Pyeongtaeg, Osan, Yongin	Current	– ≥18 pyeong	Clean Fuel or Diesel
		New	– >12.1 pyeong (Building permits approved after Jan. 1st, 1997)	Clean Fuel or Diesel

Data: Notification on Clean Fuel Use, Annexed List 6

Note: [a] Pyeong is a unit of area commonly used for buildings in Korea and it's equivalent to $3.3058m^2$

Major Sources

This is one of fuel control methods and the major emission sources impacted by this measure are all the facilities using anthracite for nonindustrial combustion in residential buildings in Seoul metropolitan area.

Air Pollutant Emission Reductions

Anthracite for residential heating is switched to urban gas to reduce air pollutant emissions in the Seoul metropolitan area. CO_2 emission reductions are achieved by switching from anthracite with high C content to gas fuels such as LNG with lower C content. Emission factor for a fuel per calorie was calculated by multiplying emission factor by the amount of fuel consumed to produce the same amount of heat as anthracite for residential use did when anthracite for residential use was assumed to have consumption of 1.

Projected anthracite consumption for nonindustrial combustion/residential buildings for the year 2014 is presented in Table 3-2.

Table 3-2. Projected Anthracite Consumption for Nonindustrial Combustion/Residential Buildings

District	Year 2014 (toe)
Seoul	6,770
Incheon	0
Kyonggi	6,177
Seoul Metropolitan Area	12,947

Data: MOE. 2004. Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

Table 3-3. Emission Factors for Residential Use of Anthracite and LNG (kg/4,600Kcal)

Fuel	NO_X	SO_X	PM10
Anthracite for Residential Use	1.300	10.300	0.402
LNG	1.148	0.0004	0.013

Data: MOE. 2004. Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

Note: 1) Based on anthracite for residential energy use

2) CAPSS Data, Sulfur content of kerosene used for boilers was assumed to be 0.1%.

When the same amount of heat is produced from two fuels, emissions vary as much as the ratio of emission factors does. Emission reduction is the difference in emissions from anthracite for residential use and a clean fuel.

$$Ef:EFc = En:EFn$$

Ef: Projected Emission in 2014
EFc: Emission Factor per Calorie for Anthracite for Residential Use
En: Emission from New Fuel
EFn: Emission Factor per Calorie for New Fuel

Emission Reduction (ER) = Projected Emission in 2014 (Ef) – Emission from New Fuel (En)

The results are presented in Tables 3-4 and 3-5.

Table 3-4. Emissions from Anthracite for Residential Use and Urban Gas (kg/yr)

	NO_X	SO_X	PM10
Business As Usual 2014 (No Control)	30,301	240,069	9,370
Switching to Urban Gas (2014)	26,754	10	296

Data: MOE. 2004. Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

Table 3-5. Emission Reductions from Fuel Switching (kg/yr)

	NO_X	SO_X	PM10
Reduction (2014)	3,547	240,059	9,074

Data: MOE. 2004. Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

With projected anthracite consumption of 12,947 toe for nonindustrial combustion/residential buildings in 2014, air pollutant emission reductions are computed as:

NO_X Reduction: 3,547 kg/12,947 TOE = 0.27 kg/toe
SO_X Reduction: 240,059 kg/12,947 TOE = 18.54 kg/toe
PM10 Reduction: 9,074 kg/12,947 TOE = 0.7 kg/toe

CO_2 Emission Reductions

Steps to evaluate CO_2 emission reductions from fuel control are

- Project anthracite consumption for nonindustrial combustion/residential buildings
- Convert a fuel consumption unit of kg/yr to toe
- Ton Oil Equivalent (toe) – calculate the converted value by setting heat value of crude oil of 10,000 kcal to 1
- Estimate emission using emission factor by fuel type.

Table 3-6. Toe by Fuel Type

Crude Oil: 1	LNG: 1.03
Gasoline: 0.83	Anthracite: 0.45
Diesel: 0.87	Bituminous coal: 0.66
Kerosene: 0.92	Electricity: 0.25

Table 3-7. CO_2 Emission Factors for Anthracite for Residential Use and LNG

Fuel Type	CO_2 (kg C/GJ)	CO_2 (ton C/toe)
Anthracite for Residential Use (Primary Solid Fossil Fuel)	26.80	1.100
LNG (Gas Fossil Fuel)	15.30	0.637

Data: IPCC Carbon Emission Factor (CEF)

The same amount of heat is produced from the two fuels being used, emissions vary by the ratio of emission factors per calorie, and the emission reduction is the difference in emissions.

Emission Reduction = CO_2 Emission from Anthracite for Residential Use
– CO_2 Emission from Switched Fuel of LNG

- CO_2 Emission from Anthracite for Residential Use in 2014
  12,947 TOE × 1.100 TonC/toe × $44CO_2/12C$ = 52,220 Ton CO_2

- CO_2 Emission from Fuel Switching in 2014
  12,947 TOE × 0.637 TonC/toe × $44CO_2/12C$ = 30,240 Ton CO_2

- CO_2 Emission Reduction from Fuel Switching in 2014
  (Anthracite for Residential Use →LNG)
  52,220 Ton − 30,240 Ton = 21,980 Ton CO_2

When 12,947 TOE of fuel is consumed in 2014, CO_2 emission is reduced by 21,980 Ton. Thus, unit CO_2 emission reduction from switching fuel is 1.7 ton per 1 toe.

Air Pollutant Emission Reductions from Fuel Control (kg/toe)

	NO_X	SO_X	PM10	CO_2
Fuel Control	0.27	18.54	0.7	1,700

Unit Cost

Equipment cost for this measure includes the price of a gas boiler as well as installation cost. Prices of residential gas boilers are summarized in Table 3-8, and boiler longevity is assumed to be 10 years.

Table 3-8. Equipment Prices of Gas Boilers by Manufacturer (won/equipment)

Manufacturer	Price [a]
Kiturami Gas Boiler	400,000
Rinnai Gas Boiler	410,000
Daesung Gas Boiler	380,000
Average	397,000

Note: [a] Cost includes both equipment price and installation cost. The values for a building space of 32 pyeong or smaller is adopted. Pyeong is a unit of area and equivalent to 3.3058m^2.

With boiler longevity of 10years, EAV for a boiler was estimated to be 51,413 won. EAV for investment cost was divided by annual household fuel consumption of 1.247 toe/household[7] to obtain investment cost per toe of 41,229 won/toe. The same amount of heat is generated with each fuel type, and fuel cost saving is the difference of fuel cost between anthracite for residential use and urban gas. The price of anthracite for residential use is 81won/kg and that of urban gas is 629.59 won/m^3. Fuel cost saving can be calculated from the difference in fuel costs after they are converted to a unit of won/toe using TOE conversion factor; fuel cost of anthracite for residential use (=81won/kg/0.45) and urban gas (=629.59 won/m^3/1.5) in won/toe. The EAV value for equipment cost was divided by annual fuel consumption and added to fuel cost saving to obtain unit cost for fuel switching from anthracite for residential use to urban gas.

Unit Cost for Fuel Control (Anthracite for Residential Use → Urban Gas) (won/TOE)

Measure	Cost
Fuel Control (Anthracite for Residential Use → Urban Gas)	280,960

[7] Korea Energy Economics Institute. 2004. First Year Report on Mid- and Long-Term Strategies to Cope with Convention on Climate Change

B. Low-Sulfur and Green Fuels

 Summary

This is a measure of fuel control. The summary of switching from anthracite for residential use to clean fuels applies to this section as well. Diesel and heavy oil (B-A oil, B-B oil and B-C oil) are commonly used for nonindustrial combustion (commercial and municipal buildings, residential buildings and agricultural, animal farming and fishing facilities) in Seoul, Incheon and Kyonggi. SO_X emission can be reduced by switching from diesel and heavy oil to low-sulfur fuel. Sulfur contents of diesel, B-A oil, B-B oil and B-C oil supplied in Seoul metropolitan area are lower than 0.1%, 0.5%, 0.5% and 0.3% respectively.

 Major Sources

The main emission sources impacted by this measure are industrial combustion/combustion facilities/others according to CAPSS classification.

 Air Pollutant Emission Reductions

Other than SO_X and PM10, emission factors don't change according to sulfur content of fuel. Thus, emission reductions from different sulfur contents were determined only for SO_X and PM10.

Table 3-9. Emission Factors for NO_X, SO_X and PM10 by Fuel Type (kg/kL)

Fuel type	NO_X	SO_X	PM10
Diesel (1.0%)	2.400	17.000	0.105
B – A Oil (1.0%)	2.400	18.000	0.521
B – A Oil (2.0%)	2.400	36.000	0.521
B – B Oil (1.0%)	6.600	18.840	0.744
B – B Oil (3.0%)	6.600	56.520	0.744
B – C Oil (0.5%)	6.630	9.420	1.017
B – C Oil (1.0%)	6.630	18.840	1.569
B – C Oil (4.0%)	6.630	75.360	2.970
Diesel (0.1%)	2.400	1.700	0.105
B – A Oil (0.5%)	2.400	9.000	0.521
B – B Oil (0.5%)	6.600	9.420	0.744
B – C Oil (0.3%)	6.630	5.652	1.017

Data: CAPSS, Phase III: Methodology for emission estimation

Table 3-10. Emissions from Nonindustrial Combustion with No Control (kg/yr)

Fuel type	SO_X	PM10
Diesel (1.0%)	1,945,695	3,386
B – A Oil (1.0%)	97,103	489
B – A Oil (2.0%)	1,239,122	3,688
B – B Oil (1.0%)	32,937	680
B – B Oil (3.0%)	657	12
B – C Oil (0.5%)	368,948	18,662
B – C Oil (1.0%)	530,039	35,712
B – C Oil (4.0%)	1,559,698	46,030
Total	5,774,199	108,659

Data: MOE. 2004. Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

Table 3-11. Emissions from Nonindustrial Combustion with Low-Sulfur Fuel (kg/yr)

Fuel Type	SO_X	PM10
Diesel (0.1%)	194,570	3,386
B – A Oil (0.5%)	358,332	4,177
B – B Oil (0.5%)	16,578	692
B – C Oil (0.3%)	497,358	57,572
Total	1,066,837	65,827

Data: MOE. 2004. Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

Table 3-12. Emission Reductions from Low-Sulfur Fuel (kg/yr)

	SO_X	PM10
Emission Reductions from Supply of Low-Sulfur Fuel	4,707,362	42,832

When fuel was switched to low-sulfur fuel, SO_X emissions were reduced by the difference in emission factors.

Table 3-13. SO_X Emission Reductions from Fuel Switching to Low-Sulfur Fuel (kg/kL)

Fuel Switching	SO_X Emission Factor	SO_X Emission Factor for Low-Sulfur Fuel	Difference in Emission Factors (Reduction)
Diesel 1.0% → 0.1%	17.000	1.7000	15.3
B – A Oil 1.0% → 0.5%	18.000	9.000	9
B – A Oil 2.0% → 0.5%	36.000	9.000	27
B – B Oil 1.0%→ 0.5%	18.840	9.420	9.42
B – B Oil 3.0% → 0.5%	56.520	9.420	47.1
B – C Oil 0.5% →0.3%	9.420	5.652	3.8
B – C Oil 1.0% → 0.3%	18.840	5.652	13
B – C Oil 4.0% → 0.3%	75.360	5.652	69.7

For PM10, only emissions from B-C oil are reduced by the differences in emission factors.

Table 3-14. PM10 Reductions from Switching to Low-Sulfur Fuel (kg/kL)

Fuel Switching	PM10 Emission Factor	PM10 Emission Factor for Low-Sulfur Fuel	Difference in Emission Factors (reduction)
B – C Oil 1.0% → 0.3%	1.569	1.017	0.55
B – C Oil 4.0% → 0.3%	2.970	1.017	1.95

Air Pollutant Emission Reductions from Fuel Switching to Low-Sulfur and Clean Fuels (kg/kL)

Fuel Switching	NO_X	SO_X	PM10	CO_2
Diesel 1.0% → 0.1%	0	15.3	0	0
B – A Oil 1.0% → 0.5%	0	9	0	0
B – A Oil 2.0% → 0.5%	0	27	0	0
B – B Oil 1.0%→ 0.5%	0	9.42	0	0
B – B Oil 3.0% → 0.5%	0	47.1	0	0
B – C Oil 0.5% →0.3%	0	3.8	0	0
B – C Oil 1.0% → 0.3%	0	13	0.55	0
B – C Oil 4.0% → 0.3%	0	69.7	1.95	0

Unit Cost

There is no equipment cost associated with fuel switching. Thus, total costs for this measure were computed from differences in fuel prices between current fuel and switched fuel. Average values of prices by oil refineries (March, 2007) are used to estimate costs.

Table 3-15 Wholesale Prices by Oil Refinery (won/l)

Fuel Type	SK	GS Caltex	Hyundai Oilbank	S-Oil
Diesel (0.003%)	1,165	1,169	1,173	0
Diesel (0.05%)	1,165	0	0	0
Diesel (1.0%)	1,140	1,144	1,140	0
B – A Oil (0.5%)	588.68	591.14	595.00	579.70
B – A Oil (1.0%)	580.28	582.72	586.07	571.30
B – A Oil (2.0%)	571.13	573.42	575.87	562.10
B – B Oil (0.5%)	528.69	527.60	533.03	522.30
B – B Oil (1.0%)	513.14	514.17	517.53	508.10
B – B Oil (3.0%)	495.33	496.00	497.53	490.30
B – C Oil (0.3%)	489.86	491.82	489.42	487.40
B – C Oil (0.5%)	469.57	466.82	471.42	464.80
B – C Oil (1.0%)	452.51	452.77	454.72	450.50
B – C Oil (4.0%)	421.95	421.70	420.72	418.70

Unit Cost for Fuel Control (Low-Sulfur and Clean Fuel Use) (won/kL)

Fuel Switching	Unit Cost
Diesel 1.0% → 0.1%[8]	25,667
B – A Oil 1.0% → 0.5%	8,538
B – A Oil 2.0% → 0.5%	18,000
B – B Oil 1.0%→ 0.5%	33,115
B – B Oil 3.0% → 0.5%	14,670
B – C Oil 0.5% →0.3%	21,473
B – C Oil 1.0% → 0.3%	37,000
B – C Oil 4.0% → 0.3%	68,858

[8] Total cost is calculated from the difference between 1.0% diesel price and average of 0.003% and 0.05% low-sulfur diesel prices.

C. District Heating and Cooling Expansion

 Summary

District heating and cooling systems provide commercial and residential buildings and offices heating, air conditioning, hot water and electricity from a central plant to individual buildings. 1,177,000 households used district heating and cooling systems nationally in 2002, which constituted 9.5% of the total number of households (12,358,000). According to the report on integrated energy systems by Korea Energy Management Cooperation (2002), 939,000 households in Seoul metropolitan area were served by district heating systems in 2001. The Korean government plans to expand district heating and cooling systems to 1,590,000 households by the year 2006, a 36.5% increase compared to year 2002. By the year 2010, 2 million households, 11.3% of total households, will be served by district heating and cooling systems according to the government plan.

 Major Sources

Major emission sources impacted by this measure are industrial combustion for energy use/district heating systems and nonindustrial combustion/residential buildings.

 Air Pollutant Emission Reductions

The plan is to replace existing heating systems with district heating systems for 90,000 households per year in the Seoul metropolitan area until reaching 2,109,000 households served by district heating systems by the year 2014. This estimate was derived from the national plan on supply of integrated energy systems (Public Notice 2002-240) by the Korean Ministry of Commerce, Industry and Energy (MCIE), and the annual plan of expanding district heating and cooling system supply by year for Korea is presented below (Table 3-16). The average annual increase of number of households provided by district heating systems is 105,000 household/yr.

Table 3-16. District Heating and Cooling Systems Expansion Plan by Year (Basic plan for Supply of Integrated Energy Systems)

Year	2002	2003	2004	2005	2006
Increase of Number of Households with District Heating and Cooling Systems (1000 households)	101	79	117	152	78

Data: MOE. 2004. Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

Average annual increase of number of households in Seoul metropolitan area was estimated from percentage of integrated energy systems in Seoul metropolitan area (88%) (Status of district heating system supply in 2001, References in integrated energy systems business (2002)). However, this value needed to be modified to consider the ratio of residential area (0.0464) in

Kyonggi not under air quality management. The modified percentage became 86%. Annual increase in households served by district heating systems in the Seoul metropolitan area became 105,000 household/yr × 86% = 90,000 household/yr. If additional 90,000 households were served by integrated energy systems every year, a total of 2,109,000 households (=939,000 + (90,000×13)) would be served by the integrated energy systems by the year 2014.

Emissions were estimated based on the data in year 2001. 939,000 households were served by district heating systems among 4,966,000 total households in Seoul metropolitan area in 2001. The number of households utilizing current heating systems was calculated by subtracting the number of household with district heating systems (939,000) from the total number of households in Seoul metropolitan area (4,027,000). When emissions were assessed, the contribution from local power plants (13% of power plant output was used for residential heating in 2001) was also included.

Table 3-17. Emission Comparison between District Heating and Existing Heating (kg/yr 2001)

		NO_X	SO_X	PM10
District Heating Systems	Industrial Combustion for Energy/District Heating Facilities [1]	2,267,478	1,685,162	30,249
	Electric Power Plants [2]	10,067,673	31,752	80,147
	Total (Total = [1] + [2] × 0.13)	3,576,276	1,689,290	40,668
Existing Heating Systems	Nonindustrial Combustion/Residential Buildings	21,233,407	7,839,950	742,510

Air pollutant emission per household by heating type was estimated from dividing emissions by the number of households by heating type (939,000 households of district heating systems and 4,027,000 households of existing heating systems) in year 2001.

Table 3-18. Emission Reductions from Switching to District Heating Systems in 2001 (kg/1000 households)

	NO_X	SO_X	PM10
District Heating Systems [1]	3,809	1,799	43
Existing Heating Systems [2]	5,723	1,947	184
Emission Reduction (=[2]-[1])	1,464	148	141

Data: MOE. 2004. Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

By the year 2014, 1,170,000 households will be served by district heating systems. Air pollutant emissions reductions (kg/1000 household) were multiplied by the number of households switching to district heating systems to obtain emission reduction in 2014.

Table 3-19. Projected Emission Reductions from District Heating Systems Expansion (kg/yr)

	NO_X	SO_X	PM10
Emission Reduction (2014)	1,713,067	172,944	165,055

□ CO_2 *Emission Reductions*

The steps to estimate CO_2 emission reductions from expansion of district heating systems are:

- Estimate CO_2/toe, toe/household, and CO_2/household due to fuel consumption from existing heating system
- Calculate CO_2/toe, toe/household, and CO_2/household due to fuel consumption from district heating system
- Project toe by fuel type → CO_2 emissions from existing heating systems in year 2014
  CO_2 emissions from district heating systems in year 2014
- Compute emission reductions by multiplying unit emission reduction by number of households with district heating systems

Emission Reduction = Unit Reduction × Number of Households Converting to District Heating Systems

Table 3-20. Comparison of CO_2 Emissions from District Heating Systems and Existing Heating Systems in 2001 (kg)

Year 2003	Emission (kg)
District Heating [1]	110,991
Electric Power Facility [2]	26,363,322
Total Heating Emissions (Total =[1]+[2]×0.13)	3,441,661
Unit Emission from District Heating (per 1000 households) [4]	3,665
Total Emissions Existing Heating System	63,764,851
Unit Emission from Existing Heating System (per 1000 households) [5]	15,834
Unit Emission Reduction (per 1000 households) ([5]-[4])	12,169

Data: MOE, 2004, Action Plan for Total Allowable Emissions System in Seoul Metropolitan Area

Unit emission reduction ([5]-[4]) of 12,169kg/yr per 1000households was multiplied by number of households converting to district heating systems by 2014 of 2,109 (1000 households) to obtain CO_2 emission reduction of 25,664 tons. The unit emission reduction per household is 12 kg/household. Emission reductions from switching to district heating systems are presented in Table 3-21.

Table 3-21 Emission Reductions from Switching to District Heating (kg/household)

	NO_X	SO_X	PM10	CO_2
Emission reduction	1.5	0.15	0.14	12

Emission Reductions from Expansion of District Heating and Cooling Systems (kg/household)

	NO_X	SO_X	PM10	CO_2
Converting to District Heating and Cooling Systems	1.5	0.15	0.14	12

 Unit Cost

District heating and cooling in residential and commercial buildings and offices were considered for cost estimation. Equipment cost was evaluated by dividing annual investment cost by annual supply plan (Integrated energy system supply by MCIE (2002)). Total equipment cost[9] was estimated to be 1,530,000 won/household in 2005. With heating and cooling system longevity of 15 years[10], EAV for this measure became 147,404 won.

[9] Total Equipment Cost = Annual Investment ÷ Annual Supply Plan = 2321000000000won/152000household = 15300000won/household (2005)

[10] Yunho Song and etc.. 2006. Cost-Benefit Analysis of Utilization of the Heat of the Earth from Private and Public Perspective, The Korean Society for Geosystem Engineering

Table 3-22. Annual District Heating Cooling System Supply Plan (1000 household)

Year	2002	2003	2004	2005	2006
Household (Increase)	101	79	117	152	78
Household (Cumulative Total)	1,166	1,245	1,362	1,514	1,592
Percentage (%)	9.4	9.7	10.3	11.0	11.3

Data: MCIE. 2002. Basic Plan for Integrated Energy Supply

Table 3-23. Investment Costs by Year (100 million won)

Year	2002	2003	2004	2005	2006
Investment Cost (Increase)	3,103	4,683	3,026	2,321	1,000
Investment Cost (Cumulative Total)	3,103	7,786	10,812	13,133	14,133

Data: MCIE. 2002. Basic Plan for Integrated Energy Supply

Fuel cost savings for this measure were based on number of district heat supplied residences in 2005 as well as energy cost savings from switching existing heating systems to district heating systems. Number of residences served by district heat in the Seoul metropolitan area in 2005 was 670,425 households, and the energy cost difference between two heating systems was 453,510 million won. Therefore the energy cost savings[11] became 680,000won/household[12].

Table 3-24. Number of Households with District Heating Systems in 2005

Location	Residential Building (household)
Jungang	49430
Bundang	100723
Goyang	152963
Gangnam	144695
Suwon	94472
Sangam	6929
Yongin	108568
Hwaseong	12645
Total	670425

Data: Korea District Heating Corp. 2006. Energy Consumption Reduction and Its Effects on Environmental Improvement

[11] Korea Heating Corp. 2005. Energy Saving and Effects on Environmental Improvement
[12] Energy Cost Saving = (Energy Cost for District Heating – Energy Cost for Existing Heating) ÷ Number of Heat Supply = -453,510,000,000won/679,425household = -680,000won/household.
Note: Negative value means saving of energy cost.