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CO_2 Emissions and Their Abatement Measures in the Transportation Sector of Korea

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Contents

Contents of Tables

Contents of Figures

Abstract

As concerns on global warming by the greenhouse effect escalate, national efforts to respond to climate changes are growing in Korea. This study was, by an integrated simulation framework, to address the emission of CO_2 , which is the most contributing greenhouse gas to global warming, and assess the policy options to abate CO_2 emissions in the transportation sector of Korea.

The applied model of this study was AIM(Asia-Pacific Integrated Model for Evaluating Policy Options to Reduce GHG Emission and Global Warming Impacts) originally developed by the National Institute for Environmental Studies of Japan. Based on AIM, the conditions of new energy-saving technologies selection was assessed under the various scenarios regarding different rates of carbon taxes, subsidies and the existence of a driving restriction system.

There are 3 major findings of the study. First, the carbon tax may not play any tole in promoting the market entry of energy-saving or low CO_2 emitting vehicles in the future since the cost savings made by new low CO_2 emitting vehicles alone are large enough to allow themselves to enter into the market. Second, while the energy consumption in the transportation sector is expected to grow very rapidly and high, the appropriate policy measures to curtail CO_2 emissions in the transportation sector are very limited under the present technology development pace. Thus, various approaches other than the just imposition of carbon tax such as the nationwide driving restriction system, are required. Third, when the carbon tax may not be effective, subsidies, which are given to the buyers of energy-saving vehicles, could be another option to reduce CO_2 emissions in the transportation sector. However, it requires a huge amount of financial sources and moderate rates of carbon taxes can not cover all the necessary funds. Also, subsidies are considered to be incompatible with polluter-pays-principle. Therefore, subsidies to R&D on electric cars, energy-saving vehicles and other CO_2 abatement equipments are recommended.

Ⅰ. Introduction

1. Background of the Study

Global warming by the greenhouse effect is the most pressing global environmental issue of the 1990's. The scientific debates on actual occurrence of global warming, which are expected to continue beyond 2000, have already created an international convention on climate change in 1992. This convention, the Framework Convention on Climate Change, will function as the international regulatory tool to slow down the speed of climate change in the near future. Then, the Korean economy will face another major obstacle to economic growth in which the growth of production and export in energy-intensive industries has been significant. In 1992, carbon dioxide(CO_2) emission, which was responsible for over half the increased greenhouse effect from 1980 to 1990, was 77.7 million TC(tons of carbon) in Korea. Korea's CO_2 emissions was the 18th largest in the world. It is projected to be 158.0 million TC in 2010, which is twice that of 1992's, and will be within the 10th largest in the world(Lee, 1994). Thus, concerns on the necessary of building socio-economic and scientific response strategies grow in Korea and various government-affiliated research institutes are involved in developing the response strategies on climate change.

When the use of economic instruments are considered as tools to ease increasing CO_2 emissions, or a "no-regret policy" option, cost-effectiveness should be the main criterion for adopting the policies. Considering the cost-effectiveness of economic instruments, the carbon tax or tradeable permits for emissions could be appropriate economic instruments. However, the use of these kinds of economic instruments affects the performance of the economy and international trade. Thus, various studies, such as the ones based on a "top-down approach," "bottom-up approach" and "mixed bag approach", should be advanced. The "top-down approach" provides an economy-wide analysis based on macro-economic model(Dean, 1993) while the "bottom-up approach" analyzes the details of technologies, different energy sources and specific production processes by a micro-economic benefit-cost analysis(Johansson and Swisher, 1993). The "mixed bag" is a set of policy instruments that can be used to control energy conservation and the reduction of CO_2 emissions(Lenstra and Bonney, 1993). Then, the priority of each economic instrument in implementing the response strategies should be given.

One of the efforts to make these kinds of approaches more legitimate and acceptable is the development of integrated assessment models which can analyze, in a simulation framework, the emissions of greenhouse gases, the degree of climate change by the change of greenhouse gas concentrations in the atmosphere, the impact of climate change on the ecosystem and socio-economy, etc.(Morita, et al., 1994).

2. Objectives of the Study

The emissions of CO_2 from the transportation sector were 11.5 million TC in 1990 and 17.2 million TC in 1993 and their share of total emissions was 20.9% in 1990 and 24.5% in 1993(KEEI, 1994b). It is one of the major sources of CO_2 emission in Korea. Thus, this study focuses on the transportation sector of Korea. Its main objective is to estimate the CO_2 emissions in the transportation sector and to assess appropriate policy options to abate the emissions in an integrated simulation framework. More specifically, this study is to assess the effects of carbon tax on the supply of energy-saving technologies and the resulting degree of CO_2 emissions abated. Also, this study is to analyze the effects of subsidies and the driving restriction system. The driving restriction system in Korea prohibits driving on the days where the last digit of the vehicle license plate number coincides with the last digit of the date.

To achieve these goals, the analytical framework adopted is AIM(Asia-Pacific Integrated Model for Evaluating Policy Options to Reduce Greenhouse Gas(GHG) Emission and Global Warming Impacts). AIM is modified and adjusted for Korea and is named "AIM/KOREA." The present AIM/KOREA only covers the emission model of the original AIM.

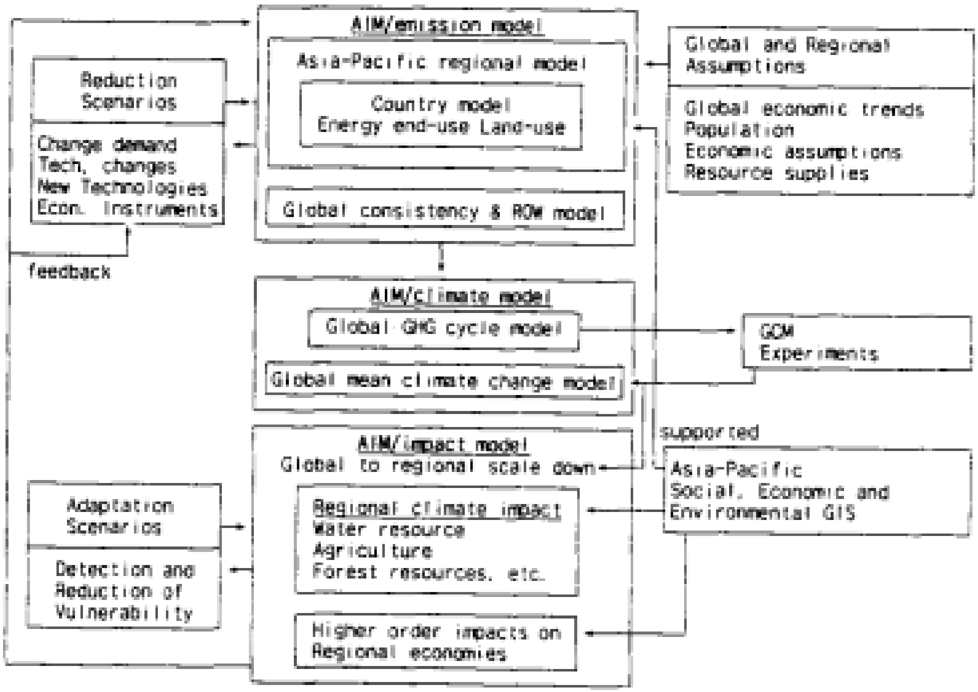
Based on AIM/KOREA, the conditions of new energy-saving technologies selection would be assessed under various scenarios regarding different rates of carbon taxes, subsidies and the existence of the driving restriction system. This process includes the estimation of abated amounts of CO_2 emissions by the introduction of new energy-saving technologies into the market. Then, the effect of carbon taxes, subsidies and the driving restriction system on those relationships are analyzed.

Ⅱ. Structure of AIM/KOREA

1. Structure of AIM

AIM is an integrated simulation model developed to assess the emissions of greenhouse gases(GHG), their abatement options, and environmental impacts of global warming in the Asia-Pacific area(Figure 1).

<Figure 1> A Summary of AIM



Source: Morita, T., Y. Matsuoka, M. Kainuma, K. Kai, H. Harasawa and D. K. Lee, 1994, *Asian-Pacific Integrated Model for Evaluating Policy Options to Reduce Greenhouse Gas Emmissions and Global Warming Impacts*, p.3

AIM is an integrated 'top-down, bottom-up' model with regional models and a major global model. It is interlinked with an emission model, a climate model and an impact model. The emission model consists of an end-use energy model and a technological selection model. The climate model is developed to link other emission and impact models. The impact model, having a spatial water balance model, an ecological matching model and a malaria distribution model, is used to estimate the in creased risks of droughts, floods, vegetation changes and malaria(Morita, et al., 1994).

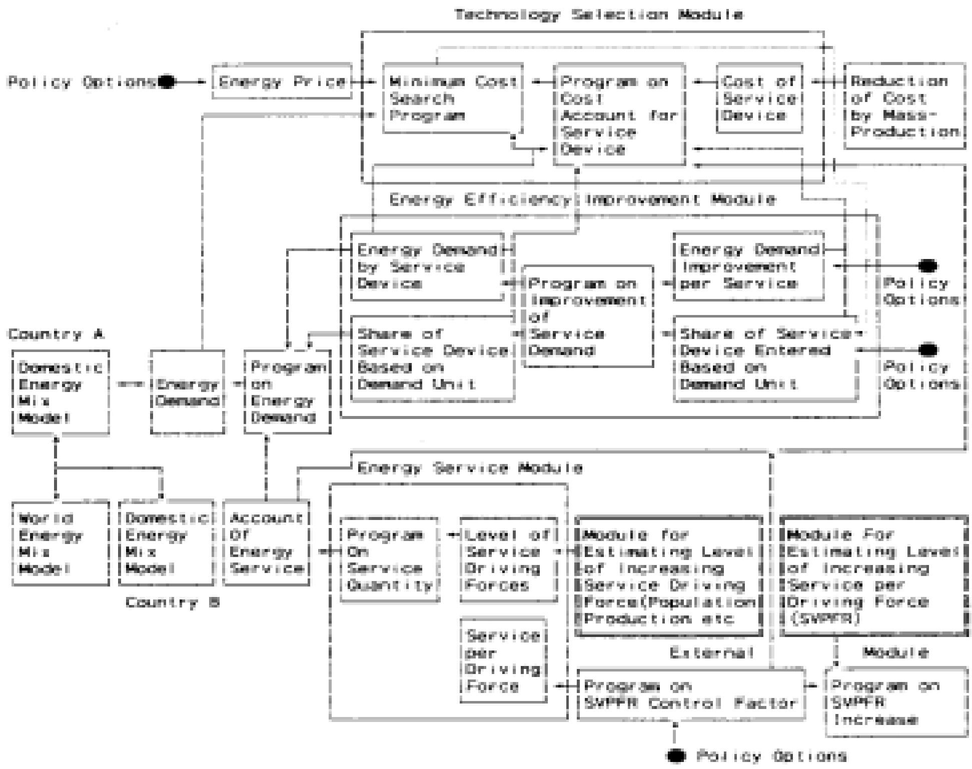
Among the 3 models, the AIM emission model is utilized for the study. It combines the technological selection model with the energy demand model. It could simulate the energy-saving mechanism and resulting CO_2 abatement mechanism by making certain assumptions on energy service demand and energy-saving technologies.

2. Components of AIM/KOREA

The AIM emission model, which integrates the technological selection model into the end-use energy demand model, is modified to be adopted to the Korean case. The resulting AIM/KOREA could simulate the interrelationships among the energy-saving technology selection, energy efficiency improvement, energy service demand, their related socio-economic variables and the amounts of energy consumption and CO_2 emissions.

As shown in Figure 2, AIM/KOREA is composed of 3 modules. The first module is the energy service module. It estimates the amount of energy service in terms of energy service units, such as "ton・Km" and "seat・Km", under given scenarios which reflect the changes of consumption patterns, economic activities, lifestyles or other major economic variables. The second module is the energy efficiency improvement module which calculates the extent of energy efficiency improvement. The last one is the technology selection module, in which the most cost-effective technology is selected by assessing the comparative advantages of different energy-saving technologies.

<Figure 2> Outline of AIM End-use Energy Demand Model



Source: Morita, T., Y. Matsuoka, M. Kainuma, K. Kai, H. Harasawa and D. K. Lee, 1994, *Asian-Pacific Integrated Model for Evaluating Policy Options to Reduce Greenhouse Gas Emissions and Global Warming Impacts*, p.4

AIM/KOREA is a "bottom-up" model. Thus, in the model, the energy efficiency improvement is evaluated by introducing the various energy-saving technologies and the substitutions among the technologies, taking place according to the levels of energy price, are analyzed. Therefore, detailed evaluation of different CO_2 abatement options are possible in the model. Also, future energy efficiency improvement can be predicted since the technology selection behavior is integrated into the end-use energy demand model. Furthermore, this model could be extended to analyze the regional or global cases since it can be easily linked to the AIM World model. AIM/KOREA can be integrated in the "top-down" model at the final stage of modeling and the prices of technologies and the structure of the changes of energy consumption pattern are determined endogeneously within the integrated model.

3. AIM/KOREA for the Transportation Sector

AIM/KOREA covers industry sectors of steel manufacturing, cements manufacturing and petrochemicals manufacturing, the households and commercial sector and the transportation sector. However, the present study focuses on the transportation sector. AIM/KOREA is used to estimate the amounts of fuel consumption and CO_2 emitted by estimating present and future sizes of energy services and introducing technology selections for passenger transportation modes and land freight modes.

4. Data Requirements

The data required for the simulation is described in Table 1. The data regarding energy sources calories of different fuel types, prices of fuels and CO_2 emission factors. Energy services represent the utilities resulting from energy consumption and their units are defined according to the types of energy use. The units of energy services in the transportation sector are ton · km for freights and seat · km for passengers.

Energy service technologies indicate the equipments and appliances which consume energy. For the transportation sector, they represent "vehicles" in the present study. The required data are initial costs(purchase prices) of vehicles, number of vehicles driven(owned), amounts of fuel consumed and saved, the duration period(replacement period or vintage), market shares, the years that the specific type of vehicle is introduced in the market and disappears for different types of vehicles.

<Table 1> Input Data for the Transportation Sector in Aim/Korea

Data items	Contents
Energy consumption	amounts of energy consumption by vehicle types
Energy consumption per unit of energy services	energy consumption divided by energy services
Energy conservation technologies	duration period, prices, energy efficiency, fuel types used by different vehicle types
Energy services	ton · km, seat · km

5. Simulation Procedure

5.1. Overall procedure

The overall simulation is done by the following procedure.

(1) The amounts of energy services in the base year are given by the actual consumption data and those in the future are given according to the scenarios externally set.

(2) Energy service technologies, i.e. new and existing vehicle models, are selected to meet the energy services. the selection of technologies(vehicles) and addition of new (energy-saving) technologies(vehicles) are based on a least cost principle in different production processes and means.

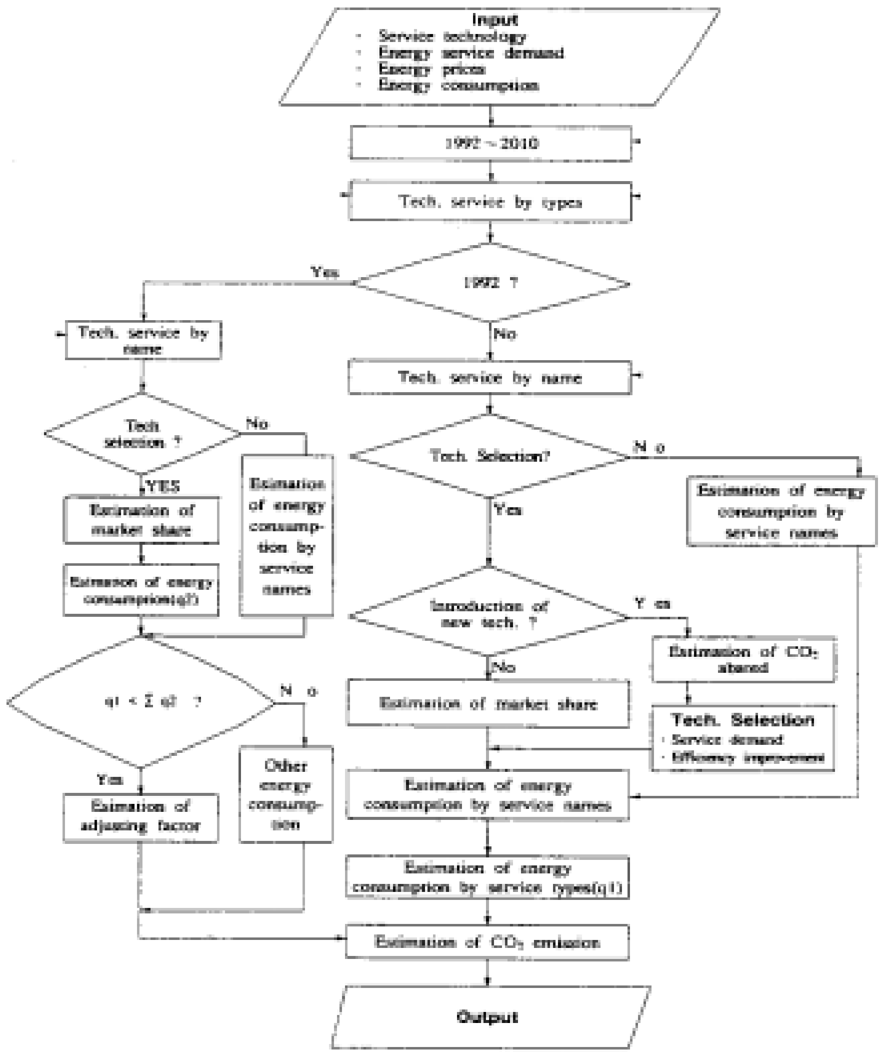
(3) The amount of energy consumption required to operate the adopted technologies (vehicle models) are estimated.

(4) Finally, the amounts of CO_2 emitted are estimated. At the same time, market shares of energy saving technologies and existing technologies in the future market are identified numerically.

This procedure can be illustrated by the flow chart for the simulation(Figure 3). The details of service technologies classification mentioned in Figure 3 are shown in Table 7 of the next chapter.

5.2. Technology selection

One of the special features of AIM is the inclusion of technological selection model in it. In AIM, the technology selection criterion is different when the replacement is needed, i.e., the duration time of vehicles is exhausted, and when the replacement period is still left. When the vehicle replacement time is close, the consumer should decide whether he or she buys the same model or a new energy saving model. For this, the model selects the less-cost vehicle by comparing the initial costs and maintenance costs(mainly fuel and repairing costs) of two alternative vehicles. When the vehicle replacement time is still left, the model selects the case where the costs of vehicle modification or additional installation of new parts are less than the energy costs when the same vehicle is still used, regardless of partial or whole retrofit or repairment. Partial retrofit indicates the cases where the same technologies are applied to vehicle modification and whole retrofit the cases where the different technologies are applied to vehicle modification. In the former case, the remained duration period of the vehicle is maintained as it was. These cases can be summarized by table 2(Morita, et al., 1994).



Source: Morita, et al., 1994, *An Energy-technology Model for Forecasting Carbon Dioxide Emissions in Japan*, F-64-'94/NIES, p.13

<Table 2> Conditions of Technology Selection

Cases	Conditions	Decisions
1) Replacement	$F_a + E_a \leq F_b + E_b$	selects a, otherwise b
2) Whole retrofit	$E_a \leq F_b + E_b$,	selects a, otherwise b
3) Partial retrofit	$E_a \leq {}_mF_b + E_b$	selects a, otherwise b

Notes : Subscript a represents the same(old) model, subscript b energy-saving model, F the annual fixed capital cost, E the annual fuel cost and ${}_mF$ the annual retrofit cost

In the simulation model, the technology selection can also be made by the introduction of carbon taxes or subsidies. Then energy consumption and the CO_2 emissions change. For example, if carbon taxes are introduced, the energy prices go up and the consumption of energy declines. As a result, the relatively more expensive energy-saving technology is selected in the market. Also, if subsidies to the development costs of energy-saving technologies are introduced, initial development costs decrease and the less-cost technology is newly selected.

As discussed in the previous section, when a specific vehicle model is selected, AIM/KOREA tries to find a least-cost option for energy consumption and CO_2 emissions by assessing the initial costs, fuel costs, and taxes of the various energy-saving technologies(vehicles). However, there are a few points to be carefully reviewed.

First of all, there are factors other than economic efficiency which affect the technology selection, such as incomplete information on technology selection, uncertainty of future energy prices and expectations on future technology development. The above factors induce higher discounts rates and as a result, low energy-efficiency technologies are selected since they cost less. Matsuhashi, et al(1991) has estimated the future discount rates of the investment of energy-saving facilities in terms of a pay-back period in Japan. In was 2 years in Japan. This higher discount rate also applies to the United States and many other countries. It is less than 2 years in energy-intensive industries of the United States(ASE, 1983)and 1 to 5 years in many IEA membership countries(IEA,1987).

Although the economic efficiency criteria may not be realistic in some aspects, the discrepancy between theory and the actual behavior of consumers may also come from the variety of individual preferences on characteristics of cars such as engine power, safety and appearence or irrational choice behavior on vehicle types. The deficiency of economic efficiency criteria may be overcome by extending the economic efficiency criteria while the discrepancy between theory and practice could be resolved by defining new socio-economic variables and developing the normative models reflecting the institutional arrangements for moving toward an energy-saving society and behavioral hindrance(Morita, et al., 1994).

Ⅲ. Simulation Period and Input Data

1. Projection Period

Based on 1992 data, the simulation is done up to the year 2010. The reason for setting the year 1992 as the base year came from the data availability. That is, the Report on Energy Census by the Korea Energy Economics Institute provides the most appropriate data for the present simulation and the most recent survey for the Report on Energy Census was for 1992. On the other hand, the year 2010 was selected as the ending year for the simulation since the technology development for energy-saving vehicles could be minimally predicted until 2010 and it was assumed that at least some new energy service technologies reducing CO_2 emission could be developed in 2000 and the vehicles with developed technologies could run for about 10 years.

2. Details of Input Data

2.1. Classification of energy services demand in the transportation sector

Energy services in the transportation sector are separately measured for passenger and freight transportation. Their service measurement units are "seat · km"and"ton · km"respectively. Service types set in the model reflect the ways of energy services and sizes of energy-use. Details are shown in Table 3 and the classification of service types in the one used in the Report on Energy Census. Right column in Table 3 indicates whether technological selection is made or not in each service types.

<Table 3> Classification of Energy Services Demand in the Transportation Sector

Types of Energy Services	Technological Selection
1. Private Passenger Cars less than 1500cc	○
2. Private Passenger Cars less than 2000cc	○
3. Private Passenger Cars more than 2000cc	○
4. Taxis less than 1500cc	○
5. Taxis more than 1500cc	○
6. Jeeps	○
7. Buses less than 16 persons(Privately owned)	○
8. Buses more than 16 persons(Privately owned)	×
9. Buses more than 16 persons(Transportation industry)	○
10. Inter Urban Railway(Passenger)	×
11. Subway	×
12. Coastal Water Passenger	×
13. Air Transport(Domestic Passenger)	×
14. Trucks less than 1.0 ton	○
15. Trucks less than 3.0 tonnes	○
16. Trucks less than 5.0 tonnes	○
17. Trucks less than 8.0 tonnes	○
18. Trucks less than 12.0 tonnes	○
19. Trucks more than 12.1 tonnes	○
20. Railway(Freight)	×
21. Coastal Water Freight	×
22. Air Transport(Domestic Freight)	×

2.2. Energy prices and CO_2 emission factors by fuel types

The data on energy calories of different fuel types, prices of fuels and CO_2 emission factors by fuel types are required for the simulation and they are shown in Table 4.

2.3. Energy services and energy consumption

<Table 5>shows the total amounts of energy consumed in calories for different fuel types and the amount of energy consumed per service unit, i. e. seat · km and ton · km. In Table 5, the data on the upper level is the consumption by energy calories and the data on the lower level is for energy

<Table 4> Fuel Types

No.	Name(unit)	Average Heat (Kcal/unit)		Price		CO_2 Emmission Unit (1.0E-10 TC/kcal)	
		Korea	Japan	Won/kcal	Yen/kcal	Korea	Japan
1	Imported Coal(kg)		6,200		0.00116	1,080.2	1,042.2
2	Anthracite(kg)	4,500		0.00905		1,080.2	
3	Bituminous(kg)	6,600		0.00518		1,080.2	
4	Fire Wood(kg)	4,500				1,080.2	
5	Cokes(kg)	6,500	7,200	0.01280	0.00337	1,080.2	1,061.2
6	Furnace Gas(m^3)		2,000		0.00337		1,061.2
7	Gasoline(l)	8,300	8,400	0.04494	0.01321	816.4	765.8
8	Kerosene(l)	8,700	8,900	0.02138	0.00481	837.4	777.5
9	Diesel(l)	9,200	9,200	0.01946	0.00662	845.7	783.9
10	Bunker-C(l)	9,900	9,800	0.00857	0.00259	883.4	818.0
11	Bunker-A(l)	9,400		0.01384		720.1	
12	Bunker-B(l)	9,700		0.01075		720.1	
13	Other Pet(l)		10,100		0.01321		773.7
14	LPG(kg)	12,000	12,000	0.03458	0.00730	837.4	688.3
15	Gas(m^3)		10,000		0.01071		563.9
16	Butane(kg)	11,800		0.02458		837.4	
17	Town Gas(kg)	10,500		0.02713		640.6	
18	LNG(m^3)	13,000		0.01157		791.3	
19	Solar Heat						0
20	Electric.(Res:Kwh)	860	860	0.03570	0.02894	1,212.8	1,212.8
	Electric.(Com:Kwh)	860	860	0.06337	0.02000	1,212.8	1,212.8
	Electric.(Ind:Kwh)	860	860	0.04384	0.01538	1,212.8	1,212.8
21	Steam(kg)		639		0.02758		-
22	Jet Oil(l)	8,700	8,700	0.01877	0.00777	845.7	766.5
23	JP-4(l)		8,500		0.00220		1,061.2
24	Naphtha(l)	8,000	8,000	0.01060	0.00289	837.4	760.5
25	Crude Oil(kg)	10,000	9,250	0.01102	0.00220	837.4	781.1
26	Limestone						0.12
27	Waste Heat				0.00000		

Sources: Internal data of KEEI, Morita, et al. 1994

consumption by service units. The data was cited from the "1993 Report on Energy Census"and the data year is 1992. Since the data on the "1993 Report on Energy Census"was compiled by TOE, 10^7Kcal of 1 TOE was assumed to convert the TOE data to energy calories data. The number of passengers for the private passenger cars is 1, and the data of seat・km for taxis was obtained by dividing the Energy census data by 4 since the data on taxis from the "1993 Report on Energy Census"was assumed to be 4 passengers. Since the number of "privately owned buses for more than 16 persons"was very small, they were included in "buses for more than 16 persons (transportation industry)." The data for "buses for more than 16 persons (transportation industry)"is the average for inter-urban, urban, charter buses and hearse transport buses. Unit energy services data for buses and trucks was calculated by the following formula.

Unit energy consumption=total energy consumption÷[No. of buses×annual driving distances×average No. of passengers (average load weight)]

Energy service levels per vehicle by service types, measured by seat・km and to n · km, are shown in Table 6. This energy service data in utilized to estimate the least cost option for technology selection. In table 6, new model indicate the vehicle model that has improved energy-efficiency significantly by replacing the initial engine types and bodies.

The data for old models in table 6 is also for 1992 and provided by the "1993 Report on Energy Census." The data for new models is obtained by using the energy consumption of different vehicle types and the numbers of licensed cars. "Seat · km"and "ton · km"for different vehicle types were calculated by the following formula.

Passenger transportation:

seat · km/year=total energy consumption(Kcal)÷

[unit energy consumption(Kcal/seat · km)×No. of cars×Average No. of passengers];

<Table 5>Energy consumption by Calories and Service Units

units : Kcal, Kcal/seat · km, Kcal/ton · km

Service Types	Gasoline	Diesel	Bunker-C	LPG	Electricty	Jet-oil
1. Private Pass. Cars less than 1500cc	2.671E+13 603.3	-	-	-	-	-
2. Private Pass. Cars less than 2000cc	1.144E+13 789.5	-	-	-	-	-
3. Private Pass. Cars more than 2000cc	1.709E+12 1,039.1	-	-	-	-	-
4. Taxis less than 1500cc	-	-	-	2.755E+12 168.3	-	-
5. Taxis more than 1500cc	-	-	-	1.095E+13 200.9	-	-
6. Jeeps	-	2.068E+12 1,124.8	-	-	-	-
7. Buses less than 16 persons (Private)	-	8.533E+12 195.9	-	-	-	-
8. Buses more than 16persons (Private)	-	2.395E+12 76.7	-	-	-	-
9. Buses more than 16 persons (Trans. Ind.)	-	1.692E+13 69.5	-	-	-	-
10. Inter Urban Railway (Passenger)	-	1.653E+12 69.6	-	-	-	-
11. Subway	-	-	-	-	7.643E+11 30.3	-
12. Coastal Water Passenger	-	-	7.769E+11 1,479.8	-	-	-
13. Air Transport (Domestic Passenger)	-	-	-	-	-	3.987E+12 761.6
14. Trucks less than 1.0 tonnes	-	3.000E+13 2,566.4	-	-	-	-
15. Trucks less than 3.0 tonnes	-	1.003E+13 1,327.7	-	-	-	-
16. Trucks less than 5.0 tonnes	-	6.495E+12 841.0	-	-	-	-
17. Trucks less than 8.0 tonnes	-	1.898E+12 374.4	-	-	-	-
18. Trucks less than 12.0 tonnes	-	2.791E+12 181.6	-	-	-	-
19. Trucks more than 12.1 tonnes	-	3.865E+11 204.6	-	-	-	-
20. Railway(Freight)	-	1.425E+12 100.0	-	-	-	-
21. Coastal Water Freight	-	-	4.957E+12 137.8	-	-	-
22. Air Transport (Domestic Freight)	-	-	-	-	-	2.850E+10 303.2

Notes : 1. The data on the upper level is the consumption by energy calories and the data on the lower level is for energy consumption by service units.
2. Data source : 1993 Report on Energy Census(the data year is 1992).

Freight transportation:

ton · km/year=total energy consumption(Kcal)÷[unit energy consumption(Kcal/ton · km)×No. of cars ×Average No. of passengers],

where the data of unit energy consumption(Kcal/seat · km, ton · km) is obtained from Table 5.

<Table 6>Energy Sevices by Vehicle Types(units:seat · km, ton · km/year)

Service Types	Old Model	New Model	Avg. passengers & freight
1. Private Pass. Cars less than 1500cc	18,628.8	19,607.1	1.0
2. Private Pass. Cars less than 2000cc	20,338.4	21,408.8	1.0
3. Private Pass. Cars more than 2000cc	22,748.0	23,945.3	1.0
4. Taxis less than 1500cc	131,973.7	153,321.1	4.0
5. Taxis more than 1500cc	86,592.5	88,399.2	4.0
6. Jeeps	22,327.7	25,087.3	1.0
7. Buses less than 16 persons (Privately owned)	24,688.4	25,987.8	4.5
8. Buses more than 16 persons (Privately owned)	26,724.9	31,270.8	27.2
9. Buses more than 16 persons (Transportation Industry)	184,508.1	195,625.5	27.2
14. Trucks less than 1.0 tonnes	25,880.1	26,680.6	0.5
15. Trucks less than 3.0 tonnes	29,156.6	30,058.4	1.5
16. Trucks less than 5.0 tonnes	33,783.0	34,827.8	3.3
17. Trucks less than 8.0 tonnes	42,137.5	43,440.7	4.1
18. Trucks less than 12.0 tonnes	45,403.7	46,808.0	8.6
19. Trucks more than 12.1 tonnes	52,934.5	54,571.7	14.4

Data sources : Report on Energy Census(1993); Transportation News(1993).

2.4 New energy service technologies selection data

Table 7 describes the data set used for technologies(vehicles)selection in the study. The definition of new model in Table 8 is the same as that of Table 6. The representative cars of each categories are Excel(1), Sonata(2), Grandeur(3), small Stellar(4), medium Stellar(5), Korando(6), Besta(7), Hyundai Aero City 540 Bus(8), Bongo(14), Kia 2.5 ton truck(K-3000)(15), Kia Rhino 5 ton truck(K-6700)(16), Hyundai 8 ton cargo truck(17), Hyundai 11 ton cargo truck(18), and Hyundai 15 ton dump truck(19), Low emission vehicles represent the cars whose energy efficiencies and reduction of air pollutants emissions are improved significantly by new engine types and body modofication.

In Table 7, the fixed costs were calculated by dividing the vehicle prices by unit energy services of seat · km or ton · km per vehicle. Energy consumption data for old models of passenger cars, jeeps, buses and trucks is provided by Table 5. For the rest of the old model vehicles, the 1992 Energy Census data was applied. In calculating the energy consumption data for new model vehicles, the various assumptions on fuel efficiency rates were made. The government-published fuel efficiency rates were applied to private passenger cars for new models. For small business passenger cars(taxis less than 1500cc), 14% of the fuel efficiency improvement rate was applied to the actual fuel efficiency rates of 1992. 14% of the fuel efficiency improvement rate is the target fuel efficiency rate for 1994 in X-5 Project. X-5 Project was a cooperative strategy plan between the government and the automobile industry to develop high-techs for cars and expand the automobile manaufacturing industry in the 2000's. For taxis more than 1501cc and buses, 5% of the fuel efficiency improvement rates were applied to the actual fuel efficiency rates of 1992. 3% of the fuel efficiency improvement rate was assumed for trucks and 11% for jeeps. For electric passenger cars, the data was based on the pilot car. Thus, the exact data on fuel consumption(or fuel efficiency rate)could not be provided and the price was a rough estimate provided by the producer. Low emission car 1 is the methane and gasoline mixed engine car developed by Hyundai Motor Corporation and it is not commercially sold yet. Hyundai Corporation insists that this car made about 10% of the fuel efficiency rate improvement. Thus, the energy efficiency suggested in the table is assumed to be improved by 10% compared to actual fuel efficiency rates. Low emission

<Table 7>Technology Status and Casts by Vehicle Types

Service Types	Tech. name	Avg. duratn year	Fixed Cost (W/T·km seat·km)	energy consumptn (kcal/T·km, seat·km)	Fuel type	Market		Market Share in 1992 (%)
						Entry	Exit	
1. Private Pass. Cars less than 1500cc	Old	7	255.9	603.3	Gasoline	1986	1992	100
	New	7	250.9	573.2	Gasoline	1992	2010	0
	Electricity	7	858.9	95.3	Electricity	2000	2010	0
	Low emi 1	7	276.0	573.2	Gasoline: Ethanol=4:1	2000	2010	0
	Low emi 2	7	369.5	573.2	Methanole	2000	2010	0
2. Private Pass. Cars less than 2000cc	Old	7	539.4	789.5	Gasoline	1986	1992	100
	New	7	541.8	750.1	Gasoline	1992	2010	0
3. Private Pass. Cars more than 2000cc	Old	8	966.7	1,039.0	Gasoline	1986	1992	100
	New	8	1,040.0	987.1	Gasoline	1992	2010	0
4. Taxis less than 1500cc	Old	7	44.4	168.3	LPG	1986	1992	100
	New	7	34.6	144.8	LPG	1992	2010	0
5. Taxis more than 1500cc	Old	7	89.4	200.9	LPG	1986	1992	100
	New	7	77.5	190.9	LPG	1992	2010	0
6. Jeeps	Old	8	635.6	1,125.0	Diesel	1986	1992	100
	New	8	597.9	1,001.0	Diesel	1992	2010	0
7. Buses less than 16 persons (Privately owned)	Old	7	295.6	196.9	Diesel	1986	1992	100
	New	7	330.2	186.1	Diesel	1992	2010	0
	Methanol	7	414.4	203.1	Methanole	2000	2010	0
	Electricity	7	1,667.0	30.4	Electricity	2000	2010	0
9. Buses more than 16 persons (Trans. Industry)	Old	10	191.0	69.0	Diesel	1986	1992	100
	New	10	184.0	65.6	Diesel	1992	2010	0
14. Trucks less than 1.0 ton	Old	10	160.6	2,566.0	Diesel	1986	1992	100
	New	10	206.4	2,489.0	Diesel	1992	2010	0
15. Trucks less than 3.0 tonnes	Old	10	245.6	1,328.0	Diesel	1986	1992	100
	New	10	264.2	1,288.0	Diesel	1992	2010	0
16. Trucks less than 5.0 tonnes	Old	10	415.7	841.0	Diesel	1986	1992	100
	New	10	439.9	815.8	Diesel	1992	2010	0
17. Trucks less than 8.0 tonnes	Old	10	539.9	374.4	Diesel	1986	1992	100
	New	10	541.0	363.2	Diesel	1992	2010	0
18. Trucks less than 12.0 tonnes	Old	10	812.1	181.6	Diesel	1986	1992	100
	New	10	803.3	176.2	Diesel	1992	2010	0
19. Trucks more than 12.1 tonnes	Old	10	908.9	204.6	Diesel	1986	1992	100
	New	10	907.1	198.5	Diesel	1992	2010	0

car 2(methanole engine car) indicates methanole Scoupe and they are not commercially sold yet in Korea. This methanole car is assumed to give 5% of the fuel efficiency rate. There are two types of trucks according to ownership, i.e., privately owned trucks and company owned trucks. All the trucks are for industry uses. Due to data deficiency, the energy consumption data was calculated based on privately owned trucks.

The averaged market prices of cars were applied to obtain the fixed costs. However, the prices of buses and trucks more than 8 tonnes in 1992 were not aviailable. Thus, 1994 prices were applied to those vehicles. For the prices of new models, the personnel of the car manufacturing companies were interviewed and they insisted that the prices of large trucks and buses, without the additions of special options, have barely changed since the middle of the 1980′s. Thus, 1994 prices were applied to those cases. The electric car, a Pride model produced by Kia Motor Corporation, was sold at 18,300,000 Won in July of 1994 and this data was used to calculate the fixed cost. Kia Motor Corporation has also developed the electric Besta and the price is estimated to be 4 times that of the ordinary Besta.

Regarding the entry years of new model vehicles, it was assumed to be 1992. For the exit years of each new model, the year 2010 was applied to most cases.

The emission factor of gasoline is applied to the calculation of CO_2 emissions by gasoline-methanole mixed cars, and for methanole cars the LPG emission factor.

3. Data Limitations

The data format suggested in the AIM emission model does not exactly match the actual data existing in Korea. Therefore, the various assumption and corrections were made for the simulation. The main data limitations could be summarized as follows. First of all, in regard to the data on fuel efficiencies and energy consumption, many discrepancies between the fuel efficiencies of passenger cars published by the government and actual road fuel efficiencies exist. The fuel efficiency rates for other types of vehicles have not been measured by the government and are published by the vehicle manufacturing companies. Thus, they are also very different from actual road fuel efficiencies and the vehicle manufacturing companies admits this problem. Concerning the new model cars which are treated as higher fuel efficiency cars in this analysis, most of them are made experimentally and have not been commercially sold in market except for the electric cars. Even though the electric cars are not at the stage of commercial sale yet, a few cars were sold in 1994. Many experts say that the electric cars sold in 1994 were just to promote the image of the company. Due to these reasons, the fuel efficiency rates based on energy consumption and driving distances data provided by the "1993 Report on Energy Census" were used for the simulation. However, the vehicle type classification on the Report on Energy Census is different from the one that is used in the statistics for the number of vehicles owned and driving years by the Korea Automobile Manufacturers Association. As a result, some assumptions and adjustments were made to compile the appropriate fuel efficiencies and energy consumption. Another data problem concerns the distinction between new energy-saving(or higher fuel efficiency) models and existing models(lower fuel efficiency cars). That is, the entry of new energy-saving(CO_2 emission abating) mtechnology into the market is hard to tell. The introduction of new model cars are mainly done by modifying bodies and some parts of the existing models and for power-up. Somtmes, new engines, such as the Excel's, are developed. However, these activities do not significantly contribute to abating CO_2 emissions. No special technology developments to decrease the CO_2 emissions have been made. Adversely, CO_2 emissions by passenger cars may have increased due to the power-up of passenger cars. Furthermore, consumers tend to prefer large cars in Korea these days.

In future studies, these data limitations should be overcome for a more refined analysis.

Ⅳ.Outputs of Simulation

1. Scenario Setting

Various scenarios on future energy consumption can be made for the model simulation and the scenario set for the present analysis is shown in Table 8. In Table 8, the base year is 1992 and the energy consumption of 1992 on the second column was calculated by the following formula:

Total energy consumption(seat・km, ton・km)

=total energy consumption in calories(Kcal)÷[unit energy consumption per vehicle(Kcal/seat・km, ton・km)]

That is, total energy consumptions for each service types in 1992 were calculated through dividing the figures of the upper level by those of the lower level in Table 5. On the other hand, since the predicted data on annual increses of seat・km and ton・km is not available, they are replaced with the predicted annual increase rates of energy consumption in the transportation sector. This data was povided from the "Long-Term Energy Demand 2030"by the Korea Energy Economics Institute(KEEI, October 1994a) and is business-as-usual(BAU) data. therefore, this data would have some discrepancies from seat・km and ton・km data directly estimated.

As mentioned earlier, the 1992 prices of technologies and CO_2 emission factors are assumed to be the same in the future in this bottom-up analysis. This assumption can be modified when AIM/KOREA is integrated into the top-down model.

<Table 8>The Scenario on Future Energy Consumption in the Trasportation Sector

Service Types	Total Energy Consumption in 1992 (seat·km, ton·km)	1990~2000 Avg. Increasing Rates (%/year)	2000~2010 Avg. Increasing Rates (%/year)
1. Private Passenger Cars less than 1500cc	4.428 E+10	9.5	6.5
2. Private Passenger Cars less than 2000cc	1.449 E+10	9.5	6.5
3. Private Passenger Carsmore than 2000cc	1.644 E+09	9.5	6.5
4. Taxis less than 1500cc	1.637 E+10	3.4	1.4
5. Taxis more than 1500cc	5.452 E+10	3.4	1.4
6. Jeeps	1.839 E+09	8.9	2.2
7. Buses less than 16 persons (Privately owned)	4.356 E+10	8.9	2.2
8. Buses more than 16 persons (Privately owned)	3.122 E+10	8.9	2.2
9. Buses more than 16 persons (Transportation Industry)	2.435 E+11	8.9	2.2
10. Inter Urban Railway(Passenger)	2.374 E+10	8.9	2.2
11. Subway	2.522 E+10	9.9	5.5
12. Coastal Water Passenger	5.250 E+08	3.7	2.9
13. Air Transport (Domestic Passenger)	5.233 E+09	8.2	4.7
14. Trucks less than 1.0 ton	1.169 E+10	8.9	2.2
15. Trucks less than 3.0 tonnes	7.552 E+09	8.9	2.2
16. Trucks less than 5.0 tonnes	7.723 E+09	8.9	2.2
17. Trucks less than 8.0 tonnes	5.069 E+09	8.9	2.2
18. Trucks less than 12.0 tonnes	1.537 E+10	8.9	2.2
19. Trucks more than 12.1 tonnes	1.889 E+09	8.9	2.2
20. Railway(Freight)	1.425 E+10	8.9	2.2
21. Coastal Water Freight	3.597 E+10	3.7	2.9
22. Air Transport (Domestic Freight)	9.400 E+07	8.2	4.7

2. Outputs

2.1. CO_2 emissions by the BAU scenario

CO_2 emissions of base year(1992) in the transportation sector was 12.5 million TC and that of year 2010 is predicted to be 32.8 million TC, which is about 2.6 times that of 1992's. 32.8 million TC is not much different from the CO_2 emission predicted by the KEEI(1993), 33.8 million TC. The increase of CO_2 emission by gasoline cars is especially significant in 2010. CO_2 emission by gasoline cars in 1992 was 3.3 million TC and is predicted to be 12.0 million TC in 2010 which is about 3.6 times that of 1992's(Table 9 and Figure 4). This increase will be due to the increase of vehicle number whose incremental

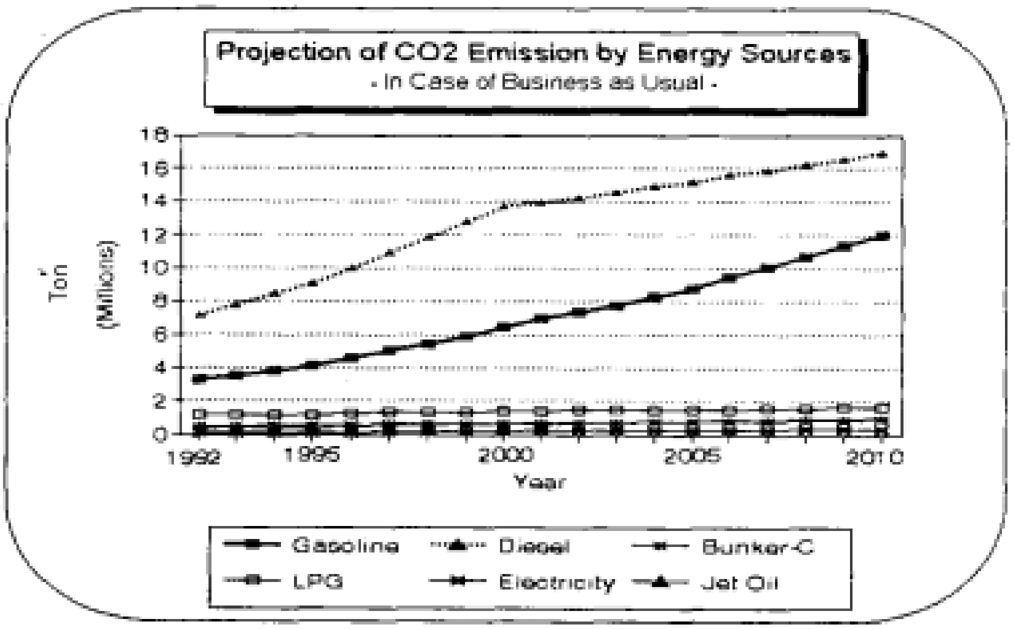
<Table 9>Predicted CO2 Emissions in the Transportation Sector under the BAU Scenario(unit:TC)

	Total	Gasoline	Diesel	Bunker-C	LPG	Electricity	Jet oil
1992	12,495,380	3,254,354	7,154,453	506,533	1,147,920	92,694	339,422
1993	13,523,470	3,553,804	7,796,890	525,948	1,174,387	102,796	369,646
1994	14,551,660	3,853,254	8,439,421	545,384	1,200,855	112,914	399,832
1995	15,579,850	4,152,704	9,081,952	564,819	1,227,322	123,032	430,018
1996	17,053,260	4,595,895	10,001,320	587,345	1,259,274	137,878	471,547
1997	18,526,680	5,039,086	10,920,697	609,872	1,291,226	152,724	513,076
1998	20,000,090	5,482,276	11,840,060	632,398	1,323,178	167,570	554,606
1999	21,473,500	5,925,467	12,759,437	654,924	1,355,130	182,416	596,135
2000	22,985,400	6,390,861	13,683,967	677,450	1,398,206	197,262	637,664
2001	23,837,920	6,864,010	13,977,317	698,264	1,418,342	293,375	670,671
2002	24,690,440	7,337,159	14,270,677	719,077	1,438,478	221,487	703,571
2003	25,563,050	7,810,307	14,584,110	739,890	1,458,615	233,599	736,524
2004	26,435,660	8,283,456	14,894,560	760,704	1,478,751	245,711	769,478
2005	27,308,270	8,756,604	15,211,010	781,518	1,498,887	257,823	802,431
2006	28,408,950	9,404,686	15,560,820	805,538	1,520,441	273,647	843,817
2007	29,509,630	10,052,770	15,910,640	829,558	1,541,995	289,470	885,204
2008	30,610,310	10,700,850	16,260,450	853,578	1,563,549	305,294	926,590
2009	31,710,980	11,348,930	16,610,260	877,599	1,585,103	321,117	967,977
2010	32,811,660	11,997,010	16,960,070	901,620	1,606,657	336,941	1,009,363

<Table 10>Market Share Variation by Vehicle Types under the BAU Scenario

Service Types	Tech.	1992	1995	2000	2005	2010
1. Private passenger cars less than 1500cc	Old	100	43.6	0	0	0
	New	0	56.4	100	100	100
	Electricity	0	0	0	0	0
	Ethanol	0	0	0	0	0
	Methanol	0	0	0	0	0
2. Private pass. cars less than 2000cc	Old	100	43.6	0	0	0
	New	0	56.4	100	100	100
3. Private pass. cars more than 2001cc	Old	100	47.6	0	0	0
	New	0	52.4	100	100	100
4. Taxis less than 1500cc	Old	100	51.7	0	0	0
	New	0	48.3	100	100	100
5. Taxis more than 1501cc	Old	100	51.7	0	0	0
	New	0	48.3	100	100	100
6. Jeeps	Old	100	48.3	0	0	0
	New	0	51.7	100	100	100
7. Buses less than 16 persons	Old	100	44.3	0	0	0
	New	0	55.7	100	100	100
	Methanol	0	0	0	0	0
	Electricty	0	0	0	0	0
8. Buses more than 16 persons	Old	100	54.3	10.1	0	0
	New	0	45.7	89.9	100	100
14. Trucks less than 1.0 ton	Old	100	54.2	10.1	0	0
	New	0	45.8	89.1	100	100
15. Trucks less than 3.0 tonnes	Old	100	54.2	10.1	0	0
	New	0	45.8	89.9	100	100
16. Trucks less than 5.0 tonnes	Old	100	54.2	10.1	0	0
	New	0	45.8	89.9	100	100
17. Trucks less than 8.0 tonnes	Old	100	54.2	10.1	0	0
	New	0	45.8	89.9	100	100
18. Trucks less than 12.0 tonnes	Old	100	54.1	10.1	0	0
	New	0	45.9	89.9	100	100
19. Trucks more than 12.1 tonnes	Old	100	54.2	10.1	0	0
	New	0	45.8	89.9	100	100

<Figure 4> Predicted CO_2 Emissions in the Transportation Sector under the BAU Scenario by Fuel Types



CO_2 emission will exceed the reduced amount of CO_2 emitted by new energy-saving vehicles.

Most of the old technology vehicles will be replaced by new energy-saving or technology vehicles by the year 2000 under the BAU scenario(Table 10). That is, without carbon taxes, new energy-saving(high fuel-efficiency) vehicles, excluding 'electric cars', 'buses more than 16 persons' and all sizes of trucks, will enter the market by 100% in the year 2000 since their energy consumption and fixed costs are relatively low. In addition, all types of vehicles, excluding electric cars, will replace the old technology vehicles by the year 2005. The electric cars will not be introduced into the market even in the year 2010 due to high fixed costs. Also, 'buses less than 16 persons', 'trucks less than 1 ton', 'trucks less than 3 tonnes' and 'trucks less than 5 tonnes' have the same technology selection structure as that of the base year since the cost saving made by reduction of energy consumption is greater that that made by reduction of fixed costs(Table 7 and Table 10).

2.2. Effects of carbon taxes and subsidies

Carbon taxes are regarded as an effective economic instrument to abate CO_2 emissions. While several countries such as Finland, Norway, Sweden, Denmark and the Netherlands are imposing a carbon tax or energy/carbon tax, their rates vary across the countries. EU has proposed 22 US dollars per TC in 1993 and Japan is proposing 3,000 Yen per TC. In the case of the Korean transportation sector, the effect of a carbon tax is found to be insignificant since the reduction of CO_2 emissions has not been made with the imposition of carbon taxes by different rates. That is, with carbon taxes of 20,000 Won/TC, 50,000 Won/TC and 100,000 Won/TC, no reduction of CO_2 emission shave been made in the simulation. In addition, the technology selection structure under the BAU scenario did not change under carbon taxes. Thus, the details of the effects of carbon taxes are not reported here.

On the other hand, another simulation has been done to identify the effects of carbon taxes and subsidies by the carbon tax revenue on the reduction of CO_2 emission and technology selection. That is, it was assumed that 20,000 Won/TC of carbon tax would be imposed and all the carbon tax revenue would be directly redistributed to the purchasers of electric cars to encourage the adoption of electric cars. Redistribution by the carbon tax revenue is to prevent new financial burdens by the government. It was also assumed that the carbon tax would be imposed from 1996 and subsidies would be redistributed from 1997. Then, the simulation was made again. In the simulation, the total carbon tax revenue with 20,000 Won/TC was 429.5 billion Won in 2000, and 634.2 billion Won in 2010. About 13.6 million Won of subsidy per vehicle(small passenger car whose engine capacity is less than 1500cc) in 1992 price is required for the entry of electric cars after the year 2000. Only 4.0% of new small passenger cars in 2010 will enter into the market as electric cars with the subsidy of 634.2 billion Won and their resulting CO_2 reduction will be 0.24 million TC. In 2000, 4.7% of new small passenger cars will enter into the market as market as electric cars with the subsidy of 429.5 billion Won and their resulting CO_2 reduction will be 0.15 million TC. If all the small-size passenger cars that entered into the market in 2010 were subsidized, the size of total subsidy required would be 17,067.6 billion Won and 6.1 million TC of CO_2 would be reduced. This amount is 18% of the total CO_2 emission of the transportation sector in 2010(Table 11).

In principle, financial assistance or subsidy is incompatible with the polluter-pays-principle. Thus, subsidizing the purchasers of electric cars may not be a viable option for the government. However, it can be compatible with the polluter-pays-principle if the tax revenue goes to research and development on CO_2 abatement technologies(OECD, 1993). Therefore, an analysis of the effects of subsidies to research and development on CO_2 abatement technologies is recommended in the future study.

<Table 11> Comparison of CO_2 Emissions under Different Scenarios

unit : million TC

Scenario	1992	2000	2010
1) Business-As-Usual	12.50	22.99	32.81
2) 20,000 W/TC carbon tax	12.50	22.99	32.81
3) 20,000 W/TC carbon tax & subsidies	12.50	22.84	32.57
4) 20,000 W/TC carbon tax & subsidies to all small pass. cars	12.50	19.77	26.76

2.3. Effects of the driving restriction system

To measure the effect of the driving restriction system, which prohibits driving on the days where the last digit of the vehicle license plate is the same as that of the date, on fuel consumption, the following formulas were used.

Energy consumption by nationwide implementation = actual fuel consumption × (1 - reduction rate by system implementation)

Energy consumption by Seoul area implementation = actual fuel consumption in Seoul × (1 - reduction rate by system implementation) + actual fuel consumption in other than Seoul

Table 12 shows the changes of energy consumption when the restriction system is implemented in Seoul. Energy consumption is reduced by 22.79% for passenger cars, by 7.24% for diesel vehicles such as buses, trucks and jeeps, and by 14.26% for LPG taxis. The reduced rates of energy consumption in Table 12 were also applied to the case that the system is implemented nationally.

<Table 12> Changes of Daily Energy Consumption under the Nationwide Driving Restriction System

	Gasoline	Diesel	LPG	Total
Before	12,202,817.30	29,048,002.78	2,782,318.75	44,033,138.83
After	9,422,383.69	26,945,153.19	2,385,600.75	38,753,137.63
Abated consumption (reduction rate)	2,780,433.61 (22.79%)	2,102,849.59 (7.24%)	396,718.00 (14.26%)	5,280,001.20 (11.99)

Notes : 1. Investigation period was for Jan. 24, 1995 to Feb. 15, 1995.
2. Data Source : City of Seoul(Feb. 27, 1995). "The Results of Economic Benefit Analysis of the Driving Restriction System."

When the driving restriction system is implemented nationally, then total CO_2 emission in 2010 could be reduced by 12.6%(Table 13 and Figure 5) while 4% reduction is possible if the system is implemented only in Seoul(Table 14 and Figure 5).

<Table 13> Predicted CO_2 Emissions in the Transportation Sector under the Nationwide Implementation of Driving Restriction System

unit : TC

Year	Total	Gasoline	Diesel	Bunker-C	LPG	Electricity	Jet oil
1992	12,496,380	3,254,354	7,154,453	506,533	1,147,920	92,694	339,422
1993	12,951,430	3,245,313	7,589,541	525,948	1,118,186	102,796	369,646
1994	13,407,580	3,236,272	8,024,723	545,384	1,088,453	112,914	399,832
1995	13,863,720	3,227,230	8,459,904	564,819	1,058,719	123,032	430,018
1996	15,158,560	3,564,233	9,313,047	587,345	1,084,511	137,878	471,547
1997	16,453,400	3,901,236	10,166,190	609,872	1,110,304	152,724	513,076
1998	17,748,240	4,238,238	11,019,330	632,398	1,136,096	167,570	554,606
1999	19,043,080	4,575,241	11,872,470	654,924	1,161,889	182,416	596,135
2000	20,376,400	4,934,446	12,730,770	677,450	1,198,805	197,262	6376640
2001	21,096,610	5,299,680	13,002,600	698,264	1,216,074	209,375	670,617
2002	21,816,820	5,664,914	13,274,430	719,077	1,233,343	221,487	703,571
2003	22,557,130	6,030,149	13,563,360	739,890	1,250,612	233,599	736,524
2004	23,297,430	6,395,384	13,858,280	760,704	1,267,881	245,711	769,477
2005	24,037,740	6,760,618	14,150,200	781,518	1,285,149	257,823	802,431
2006	24,962,900	7,260,687	14,475,590	805,538	1,303,627	273,647	843,817
2007	25,888,070	7,760,756	14,800,980	829,558	1,322,106	289,470	885,204
2008	26,813,240	8,260,825	15,126,370	853,579	1,340,584	305,294	926,590
2009	27,738,400	8,760,894	15,451,760	877,599	1,359,062	321,117	967,977
2010	28,663,570	9,260,962	15,777,140	901,620	1,377,540	336,941	1,009,363

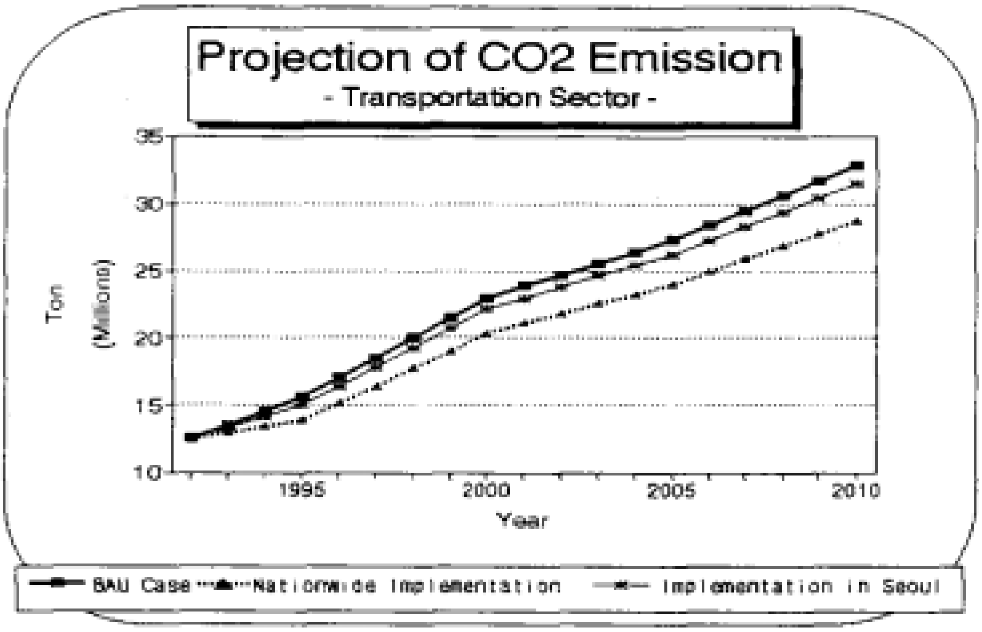
Notes: The driving restriction system in Korea prohibits the driving on the day which the last digit of vehicle licence plate number coincides with the last digit of the date.

<Table 14> Predicted CO_2 Emissions in the Transportation Sector under the Implementation of Driving Restriction System in Seoul

unit : TC

Year	Total	Gasoline	Diesel	Bunker-C	LPG	Electricity	Jet oil
1992	12,495,380	3,254,354	7,154,453	506,533	1,147,920	92,694	339,422
1993	13,343,200	3,437,337	7,751,855	525,948	1,155,618	102,796	369,646
1994	14,191,120	3,620,320	8,349,353	545,384	1,163,316	112,914	399,832
1995	15,039,040	3,803,303	8,946,850	564,819	1,171,015	123,032	430,018
1996	16,456,280	4,206,302	9,852,322	587,345	1,200,884	137,878	471,547
1997	17,873,520	4,609,301	10,757,790	609,872	1,230,753	152,724	513,076
1998	19,290,760	5,012,299	11,663,270	632,398	1,260,623	167,570	554,606
1999	20,708,000	5,415,298	12,568,740	654,924	1,290,492	182,416	596,135
2000	22,163,370	5,840,499	13,479,370	677,450	1,331,485	197,262	637,664
2001	22,969,920	6,272,944	13,768,100	698,264	1,350,629	209,375	670,617
2002	23,776,120	6,705,387	14,056,830	719,077	1,369,771	221,487	703,571
2003	24,602,410	7,137,830	14,365,650	739,890	1,388,914	233,599	736,524
2004	25,428,700	7,570,275	14,674,470	760,704	1,408,057	245,711	769,477
2005	26,254,990	8,002,719	14,983,300	781,518	1,427,200	257,823	802,431
2006	27,293,520	8,594,932	15,327,830	805,538	1,447,761	273,647	843,817
2007	28,332,060	9,187,149	15,672,360	829,558	1,468,322	289,470	885,204
2008	29,370,600	9,779,363	16,016,890	853,579	1,488,882	305,294	926,590
2009	30,409,130	10,371,580	16,361,420	877,599	1,509,443	321,117	967,977
2010	31,447,670	10,963,790	16,705,950	906,620	1,530,004	336,941	1,009,363

<Figure 5> Effects of the Driving Restriction System



2.4. Summary of outputs

The simulation outputs can be summarized in terms of the abated amounts of CO_2 emitted under different scenarios regarding the policy options. Table 15 is the summary of the simulation outputs. As seen in Table 15, the most effective measure to reduce CO_2 emissions from the transportation sector, in terms of the quantity of CO_2 abated, is the imposition of carbon tax and subsidizing all the purchasers of small passenger cars. However, this option requires a vast amount of financial sources and subsidizing the purchasers may not be acceptable to foreign countries. Then, the nationwide implementation of driving restriction system is the second-effective measure. Of course, combining both options will greatly enhance the reduction effect of CO_2 emissions from the transportation sector.

<Table 15> Abated Amounts of CO_2 Emitted under Different Scenarios

unit : million TC

Scenario\Year	2000	2005	2010
Carbon tax(20,000 W/TC)	0	0	0
Carbon tax(20,000 W/TC) & subsidy	0.15	0.18	0.24
Carbon tax(20,000 W/TC) & subsidy to all small pass. cars	3.22	4.19	6.05
Nationwide driving restriction	2.61	3.27	4.15
Driving restriction in Seoul	0.82	1.05	1.36

One thing to be noticed here is that the ineffectiveness of carbon tax in the transportation sector does not mean that the carbon tax is not effective in reducing CO_2 emissions. Much of this ineffectiveness of carbon tax is resulted from the characteristic of technology selection in AIM/KOREA. That is assuming that a medium-size passenger car emit about 1 tonne of carbon a year, even 100,000won/TC of carbon tax is a very low tax rate can not change the structure of technology selection. On the other hand, the implementation costs for the suggested options have not been assessed in this study. Eventually, the social costs induced by the implementation of these various policy options, together with the levels of CO_2 reduction, should be the important criteria for adopting the policy measures. This study did not cover the estimation of social costs induced by the introduced alternatives. AIM/KOREA should be integrated into the top-down model in the future study to identify these social costs and provide more reliable information for policy setting.

V. Conclusions and Future Research Orientation

In this study, CO_2 emissions under the BAU scenario have been projected for the year 2010, based on AIM/KOREA. Also, the conditions of new energy-saving technologies selection have been assessed under the various scenarios regarding the imposition of carbon taxes and the existence of subsidies or driving restriction system. This process included the estimation of abated amounts of CO_2 emissios by the introduction of new energy-saving technologies into the market. The major findings of the study could be summarized in three aspects.

First, as shown in Chapter IV, energy-saving or low CO_2 emitting vehicles, except electric cars, could be fully introduced in the market in 2010 even without the imposition of a carbon tax since the cost savings made by new low CO_2 emitting vehicles are large enough to allow themselves to enter into the market. Of course, this finding holds only if the consumers behave according to the assumption that they follow the least cost principle.

Second, the energy consumption in transportation sector is expected to grow very rapidly and high. However, the appropriate policy measures, which are designed to reduce the energy consumption in the transportation sector significantly, may not be readily available and the ways to curtail CO_2 emissions in the transportation sector are also very limited under the present technology development pace. Thus, the broader approaches such as conversion of land vehicle transportation to railway and subway transportation and changes of people's perception on technology(vehicle types) selection, e.g., making consumers purchase smaller and higher fuel efficiency cars, are required. At the same time, the natiowide implementation of the driving restriction system would enhance the CO_2 reduction effect.

Third, the carbon tax may not be effective under the given scenario. Thus, subsidies, which are given to the buyers of energy-saving vehicles, could be another option to reduce CO_2 emissions in the transportation sector. However, it requires a huge amount of financial sources and moderate rates of carbon taxes can not cover all the necessary funds. Futhermore, subsidies are considered to be incompatible with the polluter-pays-principle. Thus, subsides to R & D on electric cars, low emission vehicles and other CO_2 abatement equipments, which would require less financial sources than direct payment to the consumers, are recommended.

On the other hand, the study has some limitations which require extended future works. First, not all of the new energy-saving or low CO_2 emitting vehicles such as hybrid cars were introduced into the model analysis. Also, some data, e.g., the price and efficiency of electric cars, is not actual data. Second, it is necessary to incorporate the changes of vehicle prices into the analysis. If energy-saving technologies or vehicles are introduced into the market and their production costs decrease by economies of scale or the development of cost-saving technologies, then the prices of vehicles or technologies would decrease and this price decline should be reflected in the model. Third, although the implementation of driving restriction system has been assessed in this study, the more refined transportation model that reflects the congestion and changes of energy consumption by congestion should be utilized to simulate the effect. Also, the bus-driving-lane system and carpool system, which have been implemented in Korea, need to be studied in the future. Finally, the effects of subsidies to R & D on CO_2 abatement equipment and low emission vehicles have not been assessed in this study. The analysis on these types of subsidies may give us more interesting insights on the issue of technological selection.

< References >

1. Alliance to Save Energy, 1983, *Management Practices and Tax Incentives.*
2. City of Seoul, 1995, "The Results of Eonomic Benefit Analysis of the Driving Restriction System."
3. Dean, Andrew, "Costs of Cutting CO_2 Emissions:Evidence from "Top-Down" Models", *presented at the OECD/IEA International Conference on the Economics of Climate Change, Paris, 14-16 June, 1993.*
4. Dornbush, R. and J. M. Poterba, *Global Warming : Economic Policy Responses*, MIT Press, Cambridge, MA, 1991.
5. Hyundai Motors Corporation, 1993, *Automobile Industry.*
6. International Energy Agency(IEA), 1987, *Energy Conservation in IEA Countries*, OECD, Paris.
7. Johansson, T. B. and J. N. Swisher, "Perspectives on "Bottom-Up" Analyses of Costs of CO_2 Emissions Reductions", *presented at the OECD/IEA International Conference on the Economics of Climate Change, Paris, 14-16 June, 1993.*
8. Kia Economic Research Institute, 1994, *Automobile Economy.*
9. Ki-Choo, Lim, 1994, "Energy Consumption Status and Energy Saving Measures in Transportation Sector", KEEI.
10. Korea Automobile Manufacturers Association, 1994, *Automobile Industry in Korea.*
11. Korea Energy Economic Institute, 1993, *Study on Policy Measures to Prevent Global Warming in Energy Sector.*
12. Korea Energy Economics Institute, 1994a, "Long-Term Energy Consumption 2030".
13. Korea Energy Economics Institute, 1994b, *Study on National Report for the Framework Convention on Climate Change.*
14. Korea Transport Institute, 1992, *Reducing Energy Consumption and Air Pollution in the Transportation Sector.*

15. Lee, Hoi-Seong(ed.), 1994, *The Framework Convention on Climate Change and Korean Economy*, Korea Energy Economics Institute.

16. Lee, Seong-Keun and Chang-Bong Chung, 1993, "Survey Results on the Driving Practicies of Private Passenger Cars and Drivers' Perception on Driving Behavior", KEEI.

17. Lenstra, J. and M. Bonney, "The Merits of a Mixed Bag : National Plans, Agreements, and Policy Instruments", *presented at the OECD/IEA International Conference on the Economics of Climate Change, Paris, 14-16 June, 1993.*

18. Matsuhashi, R., et al., 1991, "Economic Assessment of CO_2 Abatement Options," *Energy and Resources Vol. 12, No. 5*, pp.62-69.

19. Ministry of Trade, Industry and Energy, 1987, *1987 Report on Energy Census.*

20. Ministry of Trade, Industry and Energy, 1990, *1990 Report on Energy Census.*

21. Ministry of Trade, Industry and Energy, 1993, *1993 Report on Energy Census.*

22. Morita, T., Y. Matsuoka, M. Kainuma, K. Kai, H. Harasawa and D. K. Lee, 1994, "Asian-Pacific Integrated Model for Evaluating Policy Options to Reduce Greenhouse Gas Emmissions and Global Warming Impacts." National Institute for Environmental Studies.

23. Morita, T., Y. Matsuoka, M. Kainuma, D.K. Lee, K. Kai, K. Yamabe, M. Yoshida and G. Hibino, 1994, "An Energy-technology Model for Forecasting Carbon Dioxide Emission in Japan", F-64-'94/NIES, pp.92.

24. Morita, T., Y. Matsuoka, M. Kainuma, K. Kai, H. Harasawa and D. K. Lee, 1995, "An Energy Technology Model for Forecasting Carbon Dioxide Emissions in Japan," National Institute for Environmental Studies.23. Investments in Energy Efficiency Opportunites, Washington, D.C.

25. OCED, 1993, Taxation and the Environment : Complementary Policies, OECD, Paris.