8. Application of AIM/Enduse Model to Korea

Tae Yong Jung[1], Dong Kun Lee[2], and Song Woo Jeon[3]

Summary. The AIM-Korea Model has been developed to analyze global environmental policies together with local ones in Korea. Various scenarios are considered for analyzing policy options to reduce CO_2 emissions. The major findings of this study can be summarized in terms of three aspects. Firstly, CO_2 emissions will continue to increase as long as energy demand increases. It could be difficult to introduce in the market by 2020 energy savings or devices with low CO_2 emissions in every sector without implementing any climate policy measures. Secondly, the policy implications of the mitigation of CO_2 emissions in Korea is that the adoption of energy-saving devices should be further encouraged, which is indicated by the simulation results showing that the scenario of providing subsidies leads to the most effective reduction in CO_2 emissions, as opposed to imposing only a carbon tax. Thirdly, the marginal cost of mitigating CO_2 emissions varies according to the sector. Hence, it is important to identify the potential sectors where CO_2 emissions reductions might be achievable at relatively low cost. According to the simulation results, the transportation, residential and commercial sectors could be potential candidates.

8.1 Introduction

In this study, the energy consumption patterns and the projection of these for the residential, commercial, transportation and industrial sectors were analyzed for Korea, and through this an attempt was made to find relevant CO_2 mitigation policies and measures for every end-use sector. For this purpose, AIM (Asia-Pacific Integrated Model), which was developed by the National Institute for Environmental Studies (NIES), Japan (Morita *et al.* 1994, 1995, 1996), was used. The present AIM-Korea Model is an application of the original AIM/End-use model. The application of a Mini-AIM in the residential sector is included. For the transport sector, further simulation was carried out to verify the possibility of introducing CNG buses into the market, which is one of the major climate policies of the Korean Ministry of the Environment. For the industrial sector, the business-as-usual (BaU) scenario was set up for other industries, such as food and beverages, pulp, and so forth. AIM-Korea is now run simultaneously for all sectors including power generation.

---

[1] Institute for Global Environmental Strategies, Hayama 240-0198, Japan
[2] Sangmyung University, San 98-20, An So-Dong, Chonan, Chung Nam, 330-180, Korea
[3] Office of Planning and Coordination, Korea Environment Institute, 613-2 Bulkwang-Dong Eunpyung-Gu, Seoul, 122-706, Korea

In Section 8.2, AIM-Korea Model and its data requirement are briefly described. In Section 8.3, the energy consumption patterns for every end use sector in Korea are analyzed according to various scenarios. The business-as-usual (BaU) CO_2 emissions projection and possible policy simulations are conducted to determine the potential mitigation of CO_2 emissions in Korea. A detailed analysis of the residential sector and the transportation sector is also presented in this section. Section 8.4 includes a discussion on policy implications.

8.2 AIM-Korea Model and Data

Table 1 summarizes the sectors and fields in the AIM-Korea Model. All end use sectors are included; residential, commercial, transport and industrial. Mini-AIM, which is a convenient tool for analyzing action programs to mitigate CO_2 emissions, is applied to the residential sector. The transport sector is classified into two fields; passenger and freight transport. In each field, the technical specifications for every specific transport mode are analyzed. The Korean Ministry of the Environment is particularly interested in introducing CNG vehicles into the market, which will contribute to mitigating CO_2 emissions: as well as SO_2 emissions. Further simulations are being made in this sector to assess the conditions that would allow the penetration of CNG vehicles in the transport market. In the industrial sector, energy intensive industries such as iron and steel, cement, and the petrochemical industry have been separated out. In this study, other industries, such as food and beverages, pulp, machinery, construction, and agriculture, so forth are also separated out for the BaU projections for CO_2 emissions. Since this model is an end use model, the CO_2 emissions from the energy conversion sectors, such as electric power generation and district heating, are distributed to each end use sector. This energy conversion sector is integrated into each end use sector, so that the AIM-Korea Model runs all sectors simultaneously. This model also reflects the unique circumstances of each end use sector. For example, in the residential sector, energy demand for primary heating and hot water are combined and account for almost 80% of all energy demand, since the winter in Korea is very cold and historically Koreans have had high levels of heating in winter. Hence, the combination of primary heating and hot water supply are separated out in the AIM-Korea Model.

The data for the AIM-Korea Model is quite detailed. Since this model assesses the selection of technologies, detailed data is required on energy sources, the calorific value of various types of fuel, the price of these fuels, and their CO_2 emission factors. Energy services represent the utility resulting from energy consumption and the units are defined according to the type of energy used.

Energy services technologies indicate the equipment and appliances that actually consume energy. In order to determine the dynamics of energy services, it is necessary to have detailed information. Two types of data are necessary. Firstly, basic data is required, such as the initial cost (purchase price) of energy services, number of units, number of households, and the amounts of fuel consumed or saved. Secondly, qualitative data is also required, such as the useful life of equipment (replacement period), market share, the introduction of specific types of equipment and appliances in the market, and the obsolescence of different technologies.

In the residential sector, one of the characteristics of the AIM-Korea Model is the separation of auxiliary heating from primary heating and the combination of primary heating with hot water supply. This change reflects the different situation in Korea compared with that of Japan, since the specific energy consumption patterns of any country are determined by the cultural and historical background, lifestyles and practices, as well as the weather conditions. The AIM-Korea Model therefore allows for more than one service to be included in the model from more than one service source simultaneously. For example, a kerosene pan heater provides auxiliary heating that requires both kerosene and electricity as energy sources. For example, Table 2 summarizes the factors that modify the requirement for energy services in the residential sector.

Table 1. Sectors and fields of the AIM-Korea model

Sectors	Field	
Residential	• Cooling • Primary heating and hot water • Auxiliary heating • Electricity/town gas	• Cooking • Lighting • Home appliances
Commercial	• Cooling • Primary heating and hot water supply • Auxiliary heating • Electricity/town gas	• Cooking • Lighting • Electrical appliances
Transportation	• Passenger transport	• Freight transport
Industrial	• Iron and steel industry • Cement	• Petrochemical industry • Other industries

Table 2. Factors that modify the requirement for energy services in the residential sector

Service	Factors
Cooling	Number of households × Floor area × Cooling intensity
Primary heating/Hot water supply	Number of households × Floor area × Heating/Hot water intensity
Auxiliary heating	Number of households × Floor area × Heating intensity
Cooking	Number of households × Floor area × Cooking intensity
Lighting	Number of households × Lux
Televisions	Number of households × Penetration × High technology
Refrigerators	Number of households × Penetration × High technology
Washing machines	Number of households × Penetration × High technology
Vacuum cleaners	Number of households × Penetration × High technology
Microwave ovens	Number of households × Penetration × High technology
Personal computers	Number of households × Penetration × High technology
Other end uses	Number of households

Table 3. Future energy services in the residential sector

Service	1995	2000	2010	2020
Number of households (thousand)	12501	13967	16561	18733
Number of households (1995=1.0)	1.0	1.117	1.325	1.490
Cooling	1.0	1.919	4.491	8.317
Primary heating/Hot water supply	1.0	1.150	1.490	2.002
Auxiliary heating	1.0	1.111	1.333	1.651
Cooking	1.0	1.156	1.390	1.651
Lighting	1.0	1.253	1.961	2.991
Televisions	1.0	1.297	1.843	2.318
Refrigerators	1.0	1.251	1.709	2.138
Washing machines	1.0	1.195	1.586	1.958
Vacuum cleaners	1.0	1.532	2.359	2.974
Microwave ovens	1.0	1.704	2.752	3.520
Personal computers	1.0	1.598	2.465	3.079
Other end uses	1.0	1.316	3.214	3.572

Table 3 shows the future energy services in the residential sector. Obviously, the most important factor determining the scale is the number of households, which will increase by more than 50% by 2020. The growth rate for this variable is much faster than that of the population, reflecting changing lifestyles. It is worthwhile noting that the intensity of cooling is becoming much greater due to the rapid diffusion of air conditioners, as family incomes rise.

In addition, primary heating and auxiliary heating will more than double, which is a greater increase than that of the number of households. Both cooling and heating services increase faster than the increase in the number of households, which implies that the cooling and heating intensity will increase as family incomes rise. As a home appliance, the personal computer will become more widely available, which is in accordance with one of the government's major policies so that Korea can become an ‘Information Society’ early in the new century.

Table 4 shows future energy services in the commercial sector, where the building floor area is the main factor determining the scale of energy consumption patterns. This variable will more than double by 2020, compared with the 1995 level.

Table 5 presents the transport sector. In this sector, various transport modes are considered. In particular, types of passenger vehicles are divided according to size. As per capita income rises, the demand for private vehicles will increase faster than other transport modes.

In Table 6, the data requirements are listed for the three energy intensive industries; iron and steel, cement and petrochemicals. In the iron and steel industry, the proportion of steel production using electric arc furnaces is important, besides the total production of crude steel, since the energy intensity of integrated steel making is much higher than that of the electric arc furnace. By the same token, in the cement industry, the proportion of ready mixed cement is important. In the petrochemical industry, ethylene production is the factor determining the scale of the various petrochemical products, for which the market is almost saturated.

Table 4. Future energy services in the commercial sector

Services	1995	2000	2010	2020
Building floor area (million m^2)	251.0	302.0	449.0	613.0
Building floor area (1995=1.0)	1.0	1.203	1.790	2.444
Cooling	1.0	1.203	1.790	2.444
Primary heating/Hot water supply	1.0	1.203	1.790	2.444
Auxiliary heating	1.0	1.203	1.790	2.444
Cooking	1.0	1.203	1.790	2.444
Lighting	1.0	1.203	1.790	2.444
Electrical appliances	1.0	1.203	1.790	2.444
Other end uses	1.0	1.203	1.790	2.444

Table 5. Future energy services in the transport sector (person km, ton km)

Service	Base Year	1995	2000	2005	2010	2020
Private passenger cars < 1500cc	1.06×10^{11}	1.000	1.274	1.925	2.453	3.075
Private passenger cars < 2000cc	4.57×10^{10}	1.000	1.278	1.928	2.451	3.085
Private passenger cars > 2000cc	5.52×10^{09}	1.000	1.277	1.920	2.464	3.080
Taxis < 1500cc (private)	5.09×10^{07}	1.000	1.202	1.424	1.542	1.554
Taxis < 1500cc (company)	2.25×10^{09}	1.000	1.204	1.427	1.542	1.556
Taxis > 1500cc (private)	3.15×10^{10}	1.000	1.203	1.425	1.543	1.556
Taxis > 1500cc (company)	4.63×10^{10}	1.000	1.203	1.425	1.542	1.555
Jeeps	8.92×10^{09}	1.000	0.980	1.233	1.413	1.379
Buses < 16 persons (private)	6.21×10^{10}	1.000	1.129	1.444	1.610	1.626
Buses > 16 persons (private)	2.85×10^{10}	1.000	1.130	1.446	1.614	1.625
Buses > 16 persons (company)	2.98×10^{11}	1.000	1.128	1.446	1.614	1.621
Inter urban railways (passenger)	2.03×10^{10}	1.000	0.709	0.685	0.719	0.818
Subways	2.47×10^{10}	1.000	1.522	1.721	2.142	2.696
Coastal water transport (passenger)	4.69×10^{08}	1.000	0.974	1.151	1.377	1.959
Air transport (domestic passenger)	4.56×10^{10}	1.000	1.180	1.496	1.853	2.982
Trucks < 1.0 ton	4.81×10^{09}	1.000	1.006	1.206	1.341	1.372
Trucks < 3.0 tons	3.56×10^{10}	1.000	1.006	1.205	1.340	1.371
Trucks < 5.0 tons	7.24×10^{09}	1.000	1.006	1.204	1.340	1.370
Trucks < 8.0 tons	6.49×10^{09}	1.000	1.005	1.203	1.339	1.370
Trucks < 12.0 tons	5.14×10^{09}	1.000	1.004	1.204	1.339	1.370
Trucks > 12.0 tons	1.17×10^{09}	1.000	1.009	1.205	1.342	1.376
Railway (freight)	1.38×10^{10}	1.000	1.174	1.254	1.312	1.377
Coastal water transport (freight)	4.38×10^{10}	1.000	1.132	1.288	1.429	1.751
Air transport (domestic freight)	8.18×10^{08}	1.000	1.169	1.443	1.724	2.274

Table 6. Future energy services in the industrial sector

	1995	2000	2010	2020
Iron and steel industry				
Crude steel production (1,000 tons)	36,772	39,200	42,700	42,700
Crude steel production (1995=1.0)	1.000	1.066	1.161	1.161
Proportion using the electric arc furnace (%)	37.8	38.8	35.6	35.6
Furnace (1,000 tons)	22871	24000	27500	27500

Electric arc (1,000 tons)	13901	15200	15200	15200

Table 6. Future energy services in the industrial sector (continued)

	1995	2000	2010	2020
Cement industry				
Cement production (1,000 tons)	51893	49310	63000	66200
Cement production (1995=1.0)	1.000	0.950	1.214	1.276
Proportion of ready mixed cement (%)	6.2	8.7	8.7	8.7
Petrochemical Industry				
Ethylene production (1,000 tons)	4,340	4,670	4,920	4,920
Ethylene production (1995=1)	1.000	1.076	1.134	1.134
Low density polyethylene	1,428	1,569	1,653	1,653
High density polyethylene	1,503	1,617	1,704	1,704
VCM	660	1,033	1,088	1,088
Polypropylene	2,602	3,176	3,347	3,347
PP	2,105	2,276	2,398	2,398
Octane	235	253	266	266
IPA	30	32	34	34
AA	160	172	181	181
BTX	5,114	5,518	5,813	5,813
Butadiene	601	687	932	932
Other petrochemicals	2,012	2,436	3,971	5,722

8.3 Simulation using AIM-Korea Model

8.3.1 Simulation setting and the BaU scenario

Based on the data for the year 1995, the simulations are set for up to the year 2020. The reason for setting the year 1995 as the base year is the availability of data. The Report on the Energy Census by the KEEI provides the most appropriate data for the present simulation and the most recent survey for this report is for the year 1995. (Ministry of Trade, Industry and Energy 1996). The year 2020 was selected as the end year for the simulation since the development of energy-saving technology could be predicted at least until this year.

The BaU scenario is one in which the current trends in energy consumption patterns will continue without any attempt to mitigate CO_2 emissions (KEEI 1998). However, expected new technologies, energy-saving, fuel switching, and existing plans are reflected in this scenario.

In Table 7 and Figure 1, CO_2 emissions by end use sector are shown. The total CO_2 emissions in 1995 amounted to 104.76 million tons of carbon (Mt-C), reaching 177.62 Mt-C in 2020 under the BaU scenario, which is a little higher than that of the previous study (Jung and Lee 1999), since the previous study reflected the financial crisis of Korea that occurred in December 1997. The GDP growth rate for 1998 was -5.9%. However, by 1999 the Korean economy had recovered with a more than 7% GDP growth rate. In this study, the current economic situation of Korea is considered, which results in a higher BaU projection for CO_2 emissions in this study. The proportion accounted for by the residential sector continues to increase from 17.4% in 1995 to 18.1% in 2020. The commercial sector shows the same trend. The proportion accounted for by this sector in 1995 was 8.3%, but it will reach 11.1% in 2020. It seems that the proportion of CO_2 emissions accounted for by the transport sector will be more or less stable after 2010, reflecting the saturation of the market for vehicle ownership. The transport sector will account for 22.1% of total CO_2 emissions in 2010.

In the industrial sector, CO_2 emissions are continuously increasing, but the proportion accounted for by this sector will decrease due to structural changes towards less carbon intensive industries. The proportion of CO_2 emissions accounted for by the industrial sector was 55.1% in 1995, while it will be 48.7% in 2020, which will be the lowest level. This trend is mainly due to the decrease in proportion of energy intensive industries. For example, the proportion accounted for by the iron and steel industry will drop from 17.8% in 1995 to 12.9%. The main reasons for the declining trend in this industry are production saturation and the change in the technology from the integrated process to the electric arc furnace. Obviously, energy efficiency improvements are also expected to occur. A similar trend is also observed in the cement and petrochemical industries. Hence, the share of CO_2 emissions accounted for by other industries will increase by more than 3% in 2020, compared with that of 1995. This type of industrial structural change in particular is rapidly developing in Korea. Among of the groups of booming industries in Korea are information technology (IT) related industries and the semiconductor industry, including computer parts, most of which are not energy intensive industries.

Table 7. Total CO_2 emissions by sector in Korea (BaU) (Mt-C, % in parentheses)

Sector	1995		2000		2010		2020	
Residential	18.21	(17.4)	20.39	(17.4)	25.73	(16.9)	32.16	(18.1)
Commercial	8.72	(8.3)	10.38	(8.9)	15.12	(9.9)	19.73	(11.1)
Transport	20.10	(19.2)	22.50	(19.2)	33.70	(22.1)	39.30	(22.1)
Industry	57.73	(55.1)	63.79	(54.5)	77.81	(51.1)	86.44	(48.7)
Iron and steel	18.60	(17.8)	20.28	(17.3)	22.62	(14.8)	22.95	(12.9)
Cement	11.59	(11.1)	11.17	(9.5)	14.26	(9.4)	14.99	(8.4)
Petrochemical	11.80	(11.3)	13.68	(11.7)	15.55	(10.2)	16.07	(9.0)
Other industries	15.75	(15.0)	18.67	(15.9)	25.38	(16.7)	32.43	(18.3)
Total	104.76	(100)	117.06	(100)	152.36	(100)	177.62	(100)

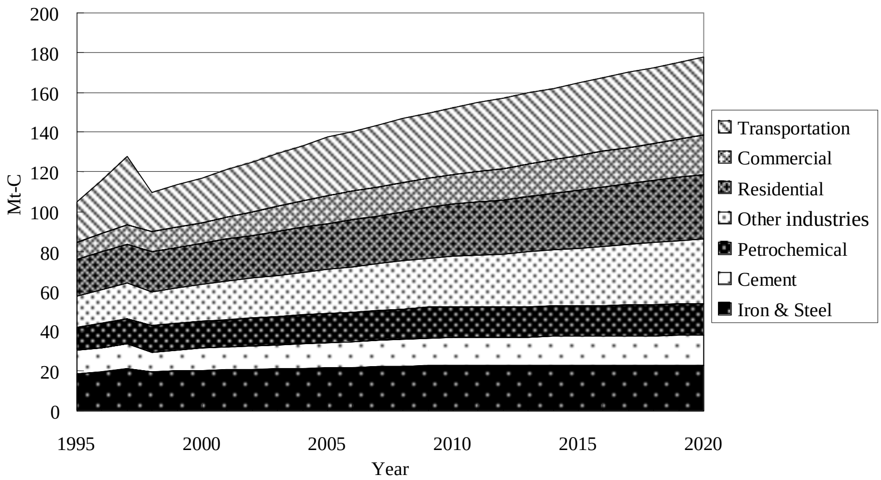

Fig. 1. Total CO_2 emissions by sector in Korea (BaU)

8.3.2 Policy scenarios and simulation results

Various scenarios on future energy consumption can be set up for the model simulation and the scenario sets for the present analysis are as follows.

The scenario for no technological changes (Scenario 1) is considered, which means that the current available technologies will continue to be used. This scenario seems to be unrealistic, but is necessary to calculate the upper bounds of CO_2 emissions. In Scenario 2 the introduction of a carbon tax (30,000Won/t-C) from 2000 is considered. In Scenario 3 a carbon tax (30,000Won/t-C) is collected, but is returned as subsidies to accelerate the introduction of solar energy for hot water or insulation, which is basically a form of tax recycling, starting from 2001. Since in AIM-Korea, the criteria for selecting technology is cost minimization, by extending the payback period, it is possible to reduce the annualized costs of energy-saving equipment, which usually requires high installation costs. These scenarios are applied to every end use sector. The scenarios mentioned above are summarized in Table 8. The results for these scenarios for all the end use sectors are presented next.

Table 8. Scenarios for all sectors

Scenario	Description	Short name
Scenario 0	Business as Usual	BaU
Scenario 1	No technological change	FIX

Scenario 2	Carbon tax: 30,000 Won/t-C from 2000 (1$ = 1,200 Won)	TAX
Scenario 3	Subsidy: 30,000 Won/t-C from 2001	SUBSIDY

Residential sector

Since the marginal costs of mitigating CO_2 emissions: in this sector are relatively low compared with the options in other sectors, it is concluded that mitigating options in this sector are feasible. Therefore, policy measures, such as energy labeling systems, rebates, and other incentives to encourage energy savings are highly recommended.

Figure 2 shows the projection of CO_2 emissions in this sector with the BaU scenario and others. In the BaU scenario, CO_2 emissions have an average annual growth rate of 2.3% (Table 7). By imposing a carbon tax of 30,000Won/t-C (about $25/t-C), CO_2 emissions mitigation is not expected in this sector (TAX). If a carbon tax of 30,000Won/t-C is imposed and returned as subsidies (SUBSIDY), further CO_2 emissions reductions would be feasible, in which case, 2.3 Mt-C in 2010 and 7.4 Mt-C in 2020 would be possible. Hence, it is found that carbon tax recycling is more effective than a simple increase in the carbon tax rate in this sector.

Commercial sector

The main driving force for energy services in this sector is obviously the increase in building floor area, which is expected to more than double by 2020 compared to that in 1995. Especially in Korea, the structural shift from the manufacturing sector to the services sector is now occurring especially rapidly in Korea. At the same time, the contribution of this sector to the GDP is consistently increasing.

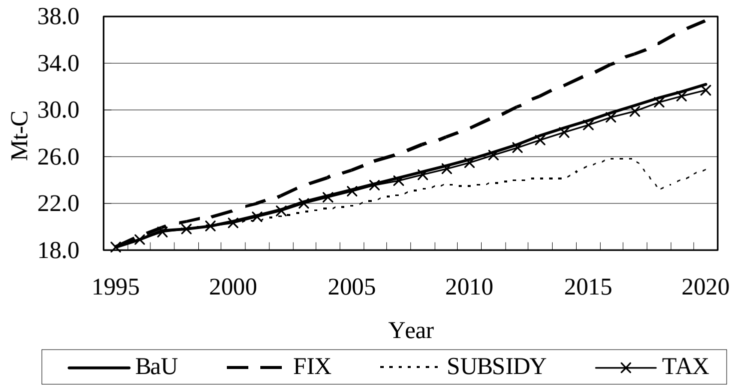

Fig. 2. CO_2 emissions projections in the residential sector

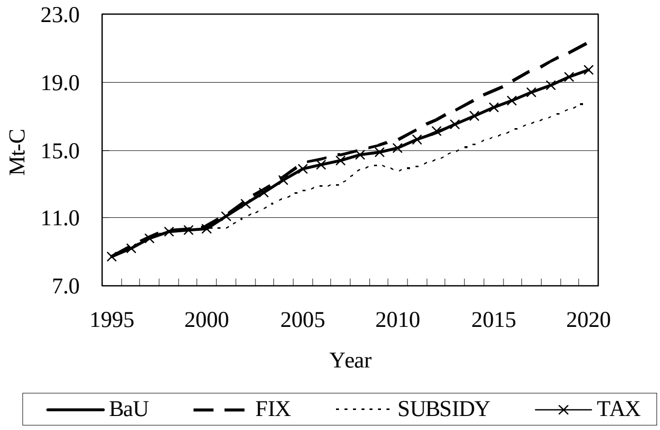

Fig. 3. CO_2 emissions projections in the commercial sector

Figure 3 shows CO_2 emissions projections for this sector with the BaU scenario and others. CO_2 emissions in 2020 with the BaU scenario would be 19.73 Mt-C, which is more than double that in 1995. In 2020, the proportion of CO_2 emissions accounted for by this sector will be 11.1% with the highest average annual growth rate of 3.3% between 1995 and 2020. By imposing a carbon tax of 30,000 Won/t-C (TAX), imposition of mitigation measures for CO_2 emissions in this sector is hardly effective, as with the residential sector. The introduction of a carbon tax is not sufficient to change technology selection in this sector. However, if the same amount of carbon tax is i mposed and then returned to this sector in the form of subsidies (SUBSIDY), further CO_2 emissions reductions would be expected, since energy efficient devices or LNG technologies, such as LNG boilers or co-generation, can be cost-effectively installed. It is expected that CO_2 emissions can be reduced by 1.9 Mt-C in 2020. Hence, the conclusion is that carbon tax recycling is more effective in this sector than increasing the tax rate. On the other hand, if current technologies are still in use in 2020, there will be an increase of 1.6 Mt-C in CO_2 emissions over the level under the BaU scenario.

Transportation sector

In the transportation sector, the demand for vehicles, especially passenger cars, has increased rapidly, as per capita income has increased. It is expected that this trend in increasing car ownership will continue, since it is projected that saturation of the passenger car market will not occur until around 2020. It is noted that due to the economic crisis, the energy demand and the demand for new passenger cars in 1998 temporarily declined, but in 1999 it rebounded with the recovery of the economy. Hence, in the long run, the trend towards increasing new car ownership

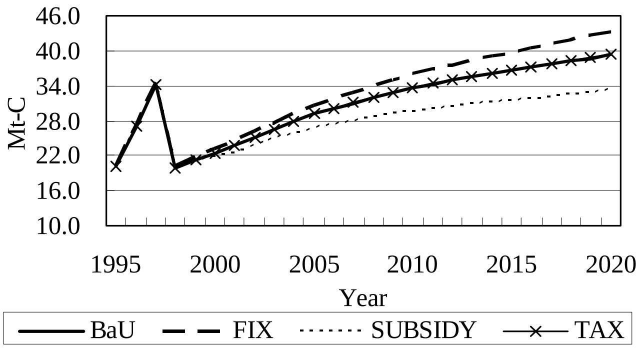

Fig. 4. CO_2 emissions projections in the transport sector

will continue until around 2020. Therefore, fuel substitution from carbon intensive to less carbon intensive fuels is an important option for mitigating CO_2 emissions in this sector. Also the secondary ben efits of reducing CO_2 emissions in this sector are important, since by reducing CO_2 emissions, it is also expected that SO_2 and other pollutants will be reduced, thus improving air quality, reducing congestion, and lowering related social costs.

Figure 4 shows CO_2 emissions projections in this sector with the BaU scenario and others. CO_2 emissions in 2020 for the BaU scenario would be 39.3 Mt-C, which is almost double than of 1995. The average annual growth rate of CO_2 emissions in this sector is 2.7% between 1995 and 2020. Again, the scenarios considered for this sector are to introduce a carbon tax and accelerate the introduction of new types of vehicles such as hybrid vehicles, as well as electric cars in the future. However, with a carbon tax of 30,000 Won/t-C (TAX), there can be no expectation of much reduction in CO_2 emissions in this sector, since the effect of this tax is not sufficient to change the cost structure, which is divided into fixed and variable costs. In other words, this tax scheme cannot ensure that new vehicles compete in the market, where the fixed costs of a new vehicle are still high. By imposing a carbon tax and providing subsidies (SUBSIDY), it is possible to mitigate CO_2 emissions by 5.9 Mt-C in 2020. It is found that the potential for CO_2 emissions reductions in this sector seems to be much greater than in other sectors. Therefore, policy measures in this sector should focus on how to slow down the trend towards car ownership, as well as to instigate fuel substitution and ensure that energy efficient vehicles are available in the market.

Industrial sector

In the industrial sector, the iron and steel, cement and petrochemical industries are examined. Since these three industries are energy-intensive and account for most of the CO_2 emissions in this sector, specific technologies in production processes of these industries are focused on. The share of the total CO_2 emissions accounted for by these three industries was about 40% for Korea in 1995. In this study, the BaU scenario was only included for other industries. The other industries are food and beverages, textiles, pulp, rubber, equipment assembly, machinery, electrical machinery, television production, automobiles, mining, construction and agriculture. The services included are boilers, district heating, electric power, and self-generated power.

Iron and steel industry. In the iron and steel industry, CO_2 emissions in 1995 were 18.6 Mt-C, which accounted for 17.8% of total CO_2 emissions in Korea. Figure 5 shows the CO_2 emissions projections for this industry for the BaU scenario and other scenarios. CO_2 emissions in 2020 with the BaU scenario would be 23.0 Mt-C, which is 1.2 times the level in 1995 with an average annual growth rate of 0.85%.

The results from the TAX scenario or the SUBSIDY scenario, assuming the introduction of a carbon tax from 2000, do not seem to be effective, since the facilities in this industry are too expensive for tax revenues to compensate for costs. Only 0.2 Mt-C of CO_2 emissions can be reduced in 2020. This finding implies that it is very difficult to reduce CO_2 emissions in this industry, as long as crude steel production keeps increasing and the share of production using the electric arc furnaces and integrated steel making processes is not reversed. According to the projections for crude steel production, the market will be saturated at around 47 Mt in 2010. Hence, after 2010, CO_2 emissions in this industry will be more or less stabilized.

Cement industry. In the cement industry, CO_2 emissions in 1995 were 11.59 Mt-C, which accounted for 11.1% of total CO_2 emissions in Korea. Compared with other sectors, various scenarios do not seem to be effective in mitigating CO_2 emissions in this industry, as long as cement production keeps increasing, which is similar to the situation for the iron and steel industry.

Figure 6 shows the CO_2 emissions projections in this industry for the BaU scenario and other scenarios. CO_2 emissions in 2020 with the BaU scenario would be 14.99 Mt-C, which would account for 8.4% of total CO_2 emissions in Korea. The average annual growth rate is 1.03% between 1995 and 2020. Like the iron and steel industry, the share of CO_2 emissions in this industry will be declining steadily, mainly due to the saturation of production. Figure 13 shows that with the SUBSIDY scenario, 1.18 Mt-C of CO_2 emissions can be reduced in 2020.

Petrochemical industry. In the petrochemical industry, the CO_2 emissions in 1995 were 11.8 Mt-C, which accounted for 11.3% of total CO_2 emissions in Korea. The CO_2 emissions in 2030 will be 16.07 Mt-C with an average annual growth rate of 1.24%. Scenarios such as a carbon tax of 30,000 Won/t-C (TAX) and carbon tax recycling (SUBSIDY) do not seem to be workable in reducing CO_2 emissions in this industry, compared with other sectors. For example, only 0.07 Mt-C of CO_2 can be reduced using subsidies in 2020. Figure 7 shows the CO_2 emissions projections in this industry for the BaU scenario and other scenarios. In the petrochemical industry as long as the production keeps increasing, there is little room for reducing CO_2 emissions, as in other energy-intensive industries.

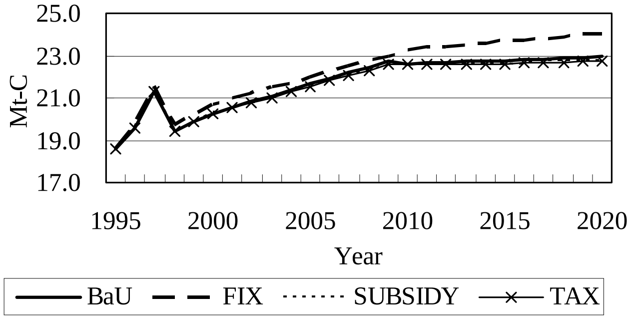

Fig. 5. CO_2 Emissions projections in the iron and steel industry

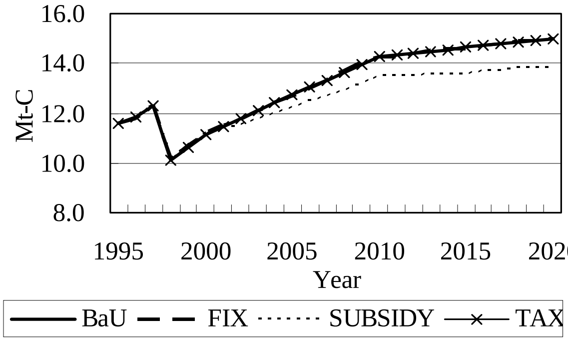

Fig. 6. CO_2 emissions projections in the cement industry

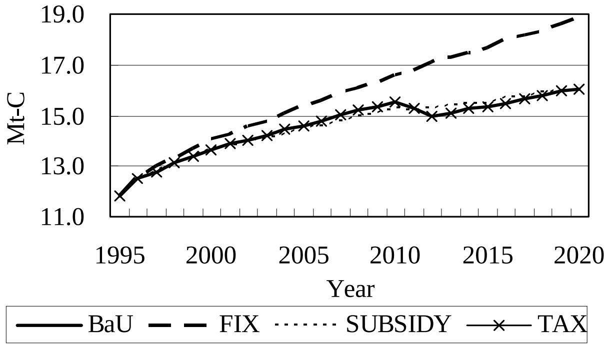

Fig. 7. CO_2 emissions projections in the petrochemical industry

8.3.3 Special scenarios for the sectors

Actions to reduce CO_2 emissions in the residential sector

Especially in the residential sector, there is a potential for CO_2 emissions reductions with changes in behavior and life style practices and the use of home appliances. This type of qualitative assessment can be applied to the Mini-AIM model*, which freezes technology selection in the BaU scenario and calculates the marginal change in CO_2 emissions due to possible action programs. For example, energy for cooking rice may be saved if pressure cookers are used to save cooking time. For dinner, if the whole family gets together, this also saves cooking time. The CO_2 emissions reduction potential of this type of action program is listed in Table 9. In Table 9, two cases are assumed, one in which the whole household undertakes the action program (100% action) and the other where 50% of households do (50%) so. This is compared with no action (0%, BaU scenario). For example, if the cooling temperature is increased by one degree or the filter is cleaned, a reduction of 34,000 t-C is possible with the full participation of households, which amounts to a reduction of 2.1% of CO_2 emissions for cooling services in the residential sector. It is worthwhile noting that for auxiliary heating, if insulation is installed, 20% of CO_2 emissions can be reduced, which is more than 60,000 tons of carbon. The marginal costs of these action programs are not so high, and most of them require minor changes to our behavior and practices.

Specific simulations in the transport sector

As pointed out, the transport sector is one of fastest growing sectors in terms of CO_2 emissions. Not only CO_2 emissions, but also other air pollutants cause local environmental problems. The Korean Ministry of the Environment has a special interest in mitigating emissions in this sector. Hence, in this study, more

Table 9. Actions in the Mini-AIM in the residential sector (Unit thousand t-C)

Action	50% Action	100% Action
Cooking	-69	-138
Cooling	-17	-34
Refrigeration	-22	-44
Auxiliary heating	-307	-614
TV	-27	-54
Lighting	-263	-525
Primary heating	-74	-149

* Mini-AIM is a part of AIM to assess the outcome of exogenously introducing certain technologies which are otherwise not chosen according to least-cost criteria. This model can simulate CO_2 emissions by changing the proportion accounted for by various technologies.

Table 10. Special scenarios for the transport sector

Scenario	Description	Abbreviation
Scenario 0	Business as Usual	BaU
Scenario 1	Extension of the Payback Period to 5 Years	Sc1
Scenario 2	Extension of the Payback Period to 8 Years	Sc2
Scenario 3	Carbon Tax - 300,000 Won/t-C from 2000	Sc3
Scenario 4	Subsidy - 15,000,000 Won per CNG Bus	Sc4
Scenario 5	Subsidy - 20,000,000 Won per CNG Bus	Sc5

simulations were set up in this sector to take into consideration the environmental policies of the Korean government. The scenarios considered for this simulation are different from the general scenarios, reflecting the particular features of the transport sector.

The BaU scenario is the same as the general one that assumes a payback period of three years. The next scenarios are extensions of the payback period to five years and eight years for all transport modes. These scenarios assume lower fixed costs for purchasing vehicles, which allows energy efficient vehicles to penetrate the market. Vehicles with advanced technologies are usually expensive, so the extension of the payback period can encourage consumers to select the new types of vehicles. The next scenario is to impose a carbon tax of 300,000 Won/t-C, which seems to be too high, but it is intended to be compared with a carbon tax of 30,000 Won/t-C. The last two scenarios are to apply a subsidy only for CNG buses of 15,000,000 Won per bus and then one of 20,000,000 Won. These scenarios are included to measure the effectiveness of the policy of the Koran Ministry of the Environment, which has a strong interest in introducing CNG buses as a form of mass transport with lower emissions. The scenarios mentioned above are summarized in Table 10.

Scenario 1 results in a reduction of CO_2 emissions by 5.02 Mt-C in 2020 which is a 12.7% reduction over the BaU scenario. This scenario allows all types of new vehicles into the market, as well as CNG buses. Scenario 2 makes an even further reduction possible. In 2020, the CO_2 emissions projection for this scenario is 3.30 Mt-C, which is a 16.0% reduction over the BaU scenario. The scenario involving imposition of a carbon tax of 300,000 Won/t-C (Sc 3) does not seem to be effective. As in the case of the 30,000 Won/t-C (TAX), the CO_2 emissions reductions do not occur.

Scenarios to provide subsidies for CNG buses (Sc4, Sc5) do not seem to be effective in reducing CO_2 emissions in this sector. These scenarios provide subsidies for CNG buses that carry more than 15 persons, which do not account for such a high proportion of transport modes. Hence, it is more critical to increase the actual proportion of CNG buses that meet passenger demand for this policy to be effective. Even with a subsidy of 20,000,000 Won, CO_2 emissions are only reduced by 0.64 Mt-C in 2020. However, in this scenario, the aspect of GHG emissions only was considered. If the benefits of reducing air pollutants are considered, this policy might be effective. In Figure 8, the CO_2 emissions projection of the further simulation is shown.

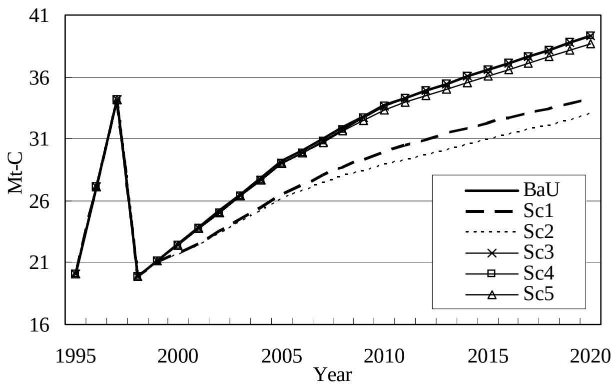

Fig. 8. CO_2 emissions projections in the transport sector (further simulation)
Note: For scenario names in the legend refer to Table 10.

8.4 Discussion

In this study, the CO_2 emissions projections for every end use sector in the Korean scenarios are conducted for the various scenarios, based on the AIM-Korea Model. Also, the conditions for the selection of new energy-saving technologies are assessed under the various scenarios in relation to the imposition of carbon taxes, the introduction of subsidies and all possible options. This process includes the estimation of the abated volume of CO_2 emissions due to the introduction of new energy-saving technologies into the market. This study is a further extension of research condu cted in fiscal 1998. The application of Mini-AIM in the residential sector is added. For the transport sector, further simulation was conducted to check the possibility of introducing CNG buses into the market, which is one of the major climate policies of the Korean Ministry of the Environment. For the industrial sector, a business-as-usual (BaU) scenario for other industries, such as food and beverages, pulp, and so forth has been set up. For every sector, power generation is included, which implies that AIM/Korea is now run simultaneously for all sectors.

The major findings of this study can be summarized from three aspects. Firstly, as shown in Section 8.3, in Korea, CO_2 emissions will continue to increase as long as the energy demand increases. Energy savings or low CO_2 emitting devices could be difficult to introduce into the market in every sector by 2020 without any climate policy measures. The marginally higher cost of new low CO_2 emitting devices is too large for them to penetrate the market. This finding holds only if consumers actually behave according to the assumption that they will follow the least cost principle.

Secondly, the policy implications of mitigating CO_2 emissions in Korea is to encourage the adoption of more energy-saving devices, which, as is shown from the simulation results, indicates that the scenario including subsidies ensures the most effective reduction of CO_2 emissions rather than imposition of a carbon tax alone. However, this involves a huge financial burden, and even moderate carbon tax rates cannot provide all the necessary funds. Furthermore, subsidies are considered to be incompatible with the polluter-pays-principle. Thus, it is recommended that subsidies for research and development on low emissions devices and other CO_2 abatement technologies, which would require a lower financial burden than direct payments to the consumers, are preferable to the sector. Hence, it is important to identify the sectors where CO_2 emissions reductions might be achievable at relatively low cost. Transport, residential and commercial sectors could be candidates, according to the simulation results, since not only is it possible to adopt new energy-saving technologies, but also the fuel switching may be possible in these sectors. The introduction of new devices alone is not effective in terms of climate policy as is shown in the case of the transport sector.

Finally, this study obviously has some limitations, which will require extensive CO_2 abatement devices and low emissions devices have not been assessed in this study. The analysis on these types of subsidies may provide more interesting insights into the issue of technological selection. Furthermore, this study does not cover the estimation of social costs incurred by implementing policy measures to mitigate CO_2 emissions. The AIM-Korea Model should be integrated into the top-down model in the future to identify the social costs of policy measures and provide more reliable information for policy formulation.

References

Jung TY, Lee DK (1999) Activities in Fiscal Year 1999 and Policy Design in Korea, National Institute for Environmental Studies, Japan

Korea Energy Economics Institute (1998) Action Plan for Mitigating GHG Emissions

Ministry of Trade, Industry and Energy (1987) Report on the Energy Census, Korea

Ministry of Trade, Industry and Energy (1990) Report on the Energy Census, Korea

Ministry of Trade, Industry and Energy (1993) Report on the Energy Census, Korea

Ministry of Trade, Industry and Energy (1996) Report on the Energy Census, Korea

Morita T, Matsuoka Y, Kainuma M, Lee DK, Kai K, Yamabe K, Yoshida M, Hibino G (1994) An Energy-technology Model for Forecasting Carbon Dioxide Emissions in Japan, F-64-'94/NIES, National Institute for Environmental Studies, Japan.

Morita T, Kainuma M, Harasawa H, Kai K, Lee DK, Matsuoka Y (1995) An energy technology model for forecasting carbon dioxide emissions in Japan. AIM Interim Paper, National Institute for Environmental Studies, Japan

Morita T, Kainuma M, Harasawa H, Kai K, Matsuoka Y (1996) A guide to the AIM/ENDUSE model. AIM Interim Paper, National Institute for Environmental Studies, Japan