J. KOSAE Vol. 19, No. E 1 (2003) pp. 41 ~ 50
Journal of Korean Society for Atmospheric Environment

An Analysis on the Ancillary Benefit of Greenhouse Gases Reduction in Korea

Yanghoon Song* **and Wha-Jin Han**[1)]
Dept of Agricultural Economics, Chungbuk National University, Cheongju, Korea
[1)]*Global Environment Research Center, Korea Environment Institute, Seoul, Korea*

Abstract

Greenhouse gases (GHG) could lead to global warming, which may bring about various disturbances to global ecosystem. Other than primary benefits that are too extensive, the ancillary benefit from GHG reduction has been estimated to provide justification for national actions. Five scenarios for 5 to 40% reduction of GHG were evaluated for the benefit/cost efficiency, using the cost estimates from a previous study. Their benefits were also estimated using a European model. As a result of this study, it can be concluded that lower reduction scenarios (5 ~ 10%) seem to be more efficient than higher reduction scenarios (30 ~ 40%).

Key words : Ancillary benefit, Greenhouse gases, Reduction strategies

1. INTRODUCTION

An excessive level of Greenhouse Gases (GHG)[1] in the atmosphere could contribute to global warming. Even though the global warming phenomenon has desirable effects such as expansion of arable land in low temperature regions and savings in heating, the negative effects overwhelm the positive effects by far. The major negative impacts include the rising of mean sea-level, more frequent outbreaks of epidemics, and climate change. Therefore, reduction of GHG emissions is believed to slow down the global warming and will reduce the cost associated with the negative impacts (thus increased benefits) at the cost of slowed-down economic development due to lower use of energy. The objective of this study is to compare the costs and the benefits of GHG reduction according to 5 GHG reduction scenarios and to suggest which scenario is more cost efficient in Korea.

The reduction in cost caused by reduced GHG emission damages is identified as the 'primary' benefit. However, the scale of the negative impacts of global warming is 'global' and the benefit of controlling the phenomenon accrues over time and space. This wide scope of the problem results in wide variation of benefit estimation, which makes acceptable estimation of the primary benefit impractical.

---

[1] Infrared (IR) active gases such as water vapor (H_2O), carbon dioxide (CO_2), and ozone (O_3), are present in the Earth's atmosphere. They absorb thermal IR radiation emission from the Earth's surface and atmosphere. This mechanism warms the atmosphere and makes the atmosphere emit back IR radiation. However, a portion of this energy warms up the surface and the lower atmosphere. As a result, the average surface air temperature of the Earth is about 30°C higher than it would be without atmospheric absorption and re-radiation of IR energy (Henderson-Sellers and Robinson, 1986; Kellogg, 1996; Peixoto and Oort 1992).

---

* Corresponding author.
Tel : 043-261-2588, Fax : 043-271-5920, E-mail : yhsong@cbucc.chungbuk.ac.kr

When reducing GHG emissions, other pollutants, primarily SO_x NO_x, PM (particulate matter) emissions[2] are also reduced due to less energy use. Scientists and economists relied more on this 'ancillary' or 'secondary' benefit estimation to justify the reduction of GHG emissions because these damages are relatively easier to quantify due to the fact that they occur locally and in shorter period of time.

Ancillary benefits include reduced medical cost due to reduced emission of other pollutants (and therefore less episodes of pollutant exposure) that are emitted along with GHG. Other non-health ancillary benefits include reduction in damage to buildings, agriculture and eco-systems. Nonetheless, the health benefit accrued by GHG emissions reduction is the most significant element of the ancillary benefit.

The reduction of GHG emissions is possible through less use of both fossil fuel and energy. Under the current global economic structure's dependence on energy, reduction in energy use translates into slower economic growth or lower GDP (Gross Domestic Product). Therefore, the cost of GHG emissions reduction is to be the decreased amount of GDP due to less energy use. This cost is frequently estimated through the Computable General Equilibrium (CGE) model, which is widely used to measure international and intra-national economic performance for policy changes or economic shocks. This study does not intend to estimate the cost of GHG reduction as it follows-up on a previous research project, conducted by the Korea Environment Institute and Korea Energy Economics Institute (2000), which already estimated the cost. Rather, the objective of this study is to estimate the ancillary benefit of GHG reduction and compare the benefit with the cost determined from the previous KEI/KEEI (2000) study and try to draw meaningful policy implications.

In the previous study (KEI/KEEI, 2000), 5 reduction scenarios were formulated and the associated reduction cost was estimated using a CGE model developed by the Korea Energy Economics Institute (KEEI). However, the previous study is lacking estimation of the ancillary benefit, which is subsequently supplemented in this study. Using the same scenarios from the previous study, for purposes of comparison, 5-year-interval estimates of energy use were assessed for scenarios from the years 2010 to 2030. Subsequently, the yearly total SO_x, NO_x, and PM emissions were estimated per scenario using domestic emission factors (emission amount per use of unit energy) and the IPCC (1996) emission factors in the case that domestic emission factors were unsuitable. It was assumed that the emission factors remain constant throughout the period analyzed.[3]

Once emission levels are known, the cost of damage (thus, benefit if the emission is reduced) and emission amount reported in Barker and Rosendahl (2000) were used to estimate the damage cost function. To enhance the estimation, additional variables such as population density, GDP per capita, and population were considered for inclusion in the model. Non-linear functional forms were also considered and found to be unsuitable. Therefore, a linear damage cost function of emission and population density was adopted and used to estimate the ancillary benefit (decreased cost) when the emission is decreased. The estimated benefit was compared with the cost and possible policy implications are discussed. In the following sections, estimation procedures are explained.

2. MODEL

2. 1 Estimated energy use by scenario

The GHG reduction scenarios from the previous study are as follows. BAU (Business As Usual) is a base scenario under which the current status will be

---

[2] These pollutants are believed to cause respiratory diseases and hamper lung functionality. Non-health effects include acidification of soil and soiling of buildings.

[3] Estimating emission factors for the period (2010 through 2030) was not a feasible task because it involved too many uncertainties like technological changes.

sustained in the future and the emission level will increase without respect to global warming. The year 1995 was selected as a base year because it is the year just before Korea joined international negotiations for GHG reduction. Reduction scenarios compared to the base year, 1995, are as the following.

Scenario 1: 5% reduction of GHG emissions in comparison to BAU after year 2010

Scenario 2: 10% reduction of GHG emissions in comparison to BAU after year 2010

Scenario 3: 20% reduction of GHG emissions in comparison to BAU after year 2010

Scenario 4: 30% reduction of GHG emissions in comparison to BAU after year 2010

Scenario 5: 40% reduction of GHG emissions in comparison to BAU after year 2010

These scenarios are illustrated in Figure 1.

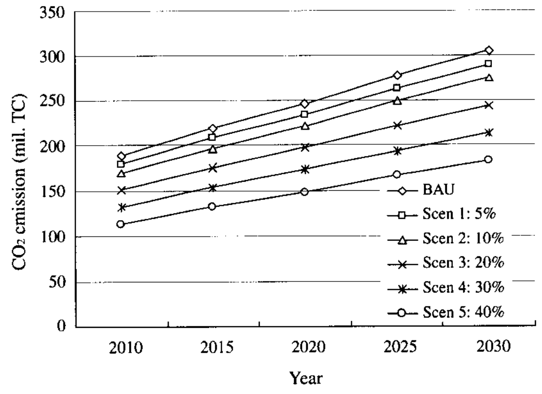

Fig. 1. CO₂ emission reduction by scenario.

The % change from A to B is defined as $\alpha = \frac{B-A}{A} \cdot 100$. The reduction rate is defined likewise, without multiplying 100.

In the previous study, δ_{ij}^{t} (rate of energy use reduction in year t, for energy type i and industry j) and $E_{ij}^{BAU,t}$ (energy use in year t under BAU scenario for i and j) are estimated (KEI and KEEI 2000, p. 250 and thereafter). Therefore, the energy use in industry sector j in year t for a scenario may be defined as

$$E_{ij}^{scen,t} = (1-\delta_{ij}^{t}) \cdot E_{ij}^{BAU,t} \tag{1}$$

and therefore, $TE_j^{scen,t}$, the total emission from industry i in year t is

$$TE_j^{scen,t} = \sum_i E_{ij}^{scen,t} \tag{2}$$

where, in detail, the variable t is year (1995 through 2030), i is energy type (electricity, petroleum, and, others), and j is industry sector (electricity generation; energy intensive industry such as chemical industry, cement, and steel industry; vehicle industry; transport; household and commercial). However, the energy use by type estimated in the previous study is not useful in estimating the emission inventory for SO_x, NO_x, and PM, because the emission factors are available for more specific types of fuel other than the broader categories of electricity, petroleum and others used in the previous study.

To be able to utilize the result (cost of GHG reduction) from the previous study and for our model to remain compatible with the model in the previous study, a dilemma emerges: we can either integrate the emission factors and estimate 3 weighted emission factors for electricity, petroleum, and others or disintegrate the energy use by industry sector under assumption.

The problem with the first option (weighted emission factors) will be that it undermines the specific emission behavior by energy type (the same coal in different types of combustion chamber will emit different level of SO_x, for example), which will lead to inaccurate emission estimation in the end. This is because the emission factors estimated and announced contain many stochastic variables and integration will add more variation to the emission factors. Using the second option, more specific energy use behaviors are addressed, although the issue of stochastic variables in the emission factors remains. However, in the course of disintegrating the energy use into more specific energy types, an assumption is necessary that the energy use pattern will remain the same under any scenario within the period of investigation. The second option is favored in this study in the sense that it simplifies the work when both approaches already bear a great deal of uncertainties.

To disintegrate the total energy use, it was assumed that the energy use structure in the base year 1995 would remain the same throughout the investigation period. That is, it is assumed that, in the given period, the ratio of energy use by type reported by the Korea Energy Economics Institute (1996) will remain the same. Formally,

$$\theta_{kj}{}^{1995} = \frac{E_{kj}{}^{1995}}{TE_j{}^{1995}} = \bar{\theta}_{kj}{}^{t} \quad \text{for all t,} \tag{3}$$

where $E_{kj}{}^{1995}$ is the use of energy type k (soft-bituminous coal and hard-anthracite coal; kerosene, gasoline, B-A, B-B, B-C; LPG; LNG) in industry j in 1995 and $\bar{\theta}_{kj}{}^{t}$ is the fixed ratio of the use of energy type k in industry sector j in year t. Therefore, the total emission in year t from k and j for a scenario is

$$E_{kj}{}^{scen,\,t} = \bar{\theta}_{kj}{}^{t} \cdot TE_j{}^{scen,\,t} \tag{4}$$

2. 2 Emission estimation

To estimate the emission using the total emission estimated in the previous section, emission factors are needed and most of them are available from NIER (National Institute of Environmental Research). For the transport sector, IPCC (1996) emission factors are used. Therefore, the emission of pollutant l (SO_x, NO_x, PM) from energy use of k in industry j in year t for a scenario is estimated as

$$M_{kjl}{}^{scen,\,t} = \bar{\varepsilon}_{kjl} \cdot E_{kj}{}^{scen,\,t} \tag{5}$$

where it is assumed that the emission factor, ε, is fixed over the investigation period. This may not be a reasonable assumption. However, predicting emission factor into a 30 year span is not possible within the scope of this study, considering the challenging task of estimating emission factors for only one year and the unpredictable development of emission-control/energy-use technologies. Then the total emission of pollutant l in year t for a scenario is

$$TM_l{}^{scen,\,t} = \sum_{k,j} M_{kjl}{}^{scen,\,t} \tag{6}$$

2. 3 Ancillary benefit estimation

2. 3. 1 Studies on ancillary benefit estimation

Burtraw and Toman (1997) estimate that the ancillary benefit of reducing GHG per 1 ton of carbon[4] in the United States ranges from USD3 to USD88. OECD (1997) reports that the benefit may range from USD3 to USD300, which covers most of the abatement cost or exceeds the cost estimated by Burtraw and Toman (1997).[5]

In a more recent study, Barker and Rosendahl (2000) used the Impact Pathway Approach of ExternE[6] and E3ME's[7] econometrics model to estimate the ancillary benefit of GHG reduction for the European Union. Following the notations in their study, the SO_2, NO_x, PM_{10} damages were assessed by a simple linear equation.

$$D_j = d_j{}^{SO_2} \cdot E_j{}^{SO_2} + d_j{}^{NO_x} \cdot E_j{}^{NO_x} + d_j{}^{PM_{10}} \cdot E_j{}^{PM_{10}} \tag{7}$$

where D_j is the total damage cost on all EU inflicted by region j[8], $E_j{}^k$ denotes the total emission of pollutant k

---

[4] Green House Gases (GHG) are a combination of various gases. It is known that the amount of Carbon is stable in the gases and is frequently used to represent the amount of GHG.

[5] Recent studies for Korea include Joh (2000) and Joh *et al.* (2001). In those studies, Impact Pathway Approach is used for Seoul-metropolitan area. They report that USD6.8 to USD7.5 of health benefit per carbon ton emission reduced. These are at the lower end of the benefit estimate ranges in other studies. Those studies were being executed simultaneously along with this study and at the beginning of this study those studies were in initiation stage, which made it hard for this study to benefit from those studies.

[6] ExternE Project (European Commission, 1995) is a comprehensive approach to assess the externalities related to fuel use (pollution cost of energy use). More than 30 teams from 9 EU countries are part of the project. ExternE utilizes the Damage Function Approach (or Impact Pathway Approach also called bottom-up approach in more general term) to relate emission of pollutants and damage cost.

[7] E3ME Model (http://www.camecon.co.uk/e3me/); developed by JOULE/THERMIE program of European Union to assess the energy-environment-economy problem. The E3ME model focuses on macro-economic problem or environment related policy and covers the whole Europe. The E3ME is modeled by region, by industry sector, which facilitates the analyses on Europe.

[8] The trans-boundary air pollution problem occurs in EU because the countries in EU share borders. Korea does not share borders except with North Korea. Even though the problem exists among China and Japan, it is assumed that the pollutants emitted in Korea affect Korea only to simplify the analysis.

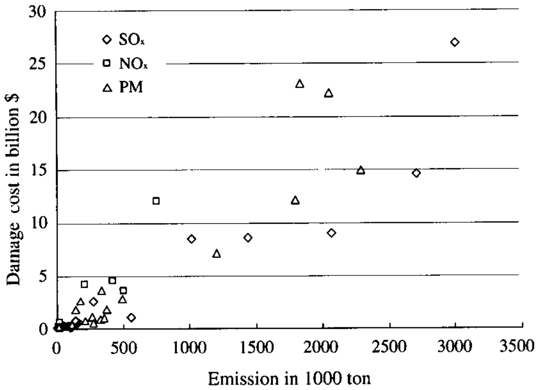

Fig. 2. Damage cost of pollutants emission in Europe.

in region j, and d_j^k denotes the damage cost coefficient of pollutant k in region j. Based on the above equation, they reported the relationship between the pollutant emissions and associated cost in Figure 2.

It is possible to utilize the unit damage cost from Barker and Rosendahl (2000) as illustrated above. A limitation of that approach is that the same unit damage cost per pollutant emission for Korea may be inappropriate. To make the estimation more plausible, population density, GDP per capita, population, and GDP for the European countries are considered for regression. Also, non-linear functional forms are considered to best-fit the data presented in Barker and Rosendahl (2000).

It may be more reasonable to assume a nonlinear functional form for the cost curve because the damage will increase at increasing rate when emission increases. However, non-linear functional forms are found to produce unreasonable coefficients such as negative coefficient for pollutants, implying that increase in emission decreases the damage. Therefore, non-linear functions were considered, but not used.

Variables other than population density were considered to estimate the damage cost function, but it was found that adding other variables also generates unreasonable signs of the coefficients. As results, only population density was included in the cost function. Therefore, the cost of the damage caused by emission of pollutant l in year t for a scenario is defined as

$$C_l^{scen,t} = \alpha_{0l} + \alpha_{1l} \cdot TM_l^{scen,t} + \alpha_{2l} PopDens^l \tag{8}$$

Then total benefit of reducing emission of pollutant l in year t for a scenario compared to BAU is

$$B_l^{scen,t} = C_l^{BAU,t} - C_l^{scen,t} \tag{9}$$

3. RESULTS AND POLICY IMPLICATION

3. 1 Emission estimation

Total Emissions of SO_x, NO_x, and PM[9] are presented in the following tables.

Damage cost functions are estimated and presented, using the damage costs and other data in Table 4.

Using the above equations and population density prediction into the year 2030, damage costs for each pollutant are estimated. For population estimates, data

Table 1. SO_x emission by GHG reduction scenario (ton/year).

Scenario Year	BAU	Scen1 (5%)	Scen2 (10%)	Scen3 (20%)	Scen4 (30%)	Scen5 (40%)
1995	1526139	1526139	1526139	1526139	1526139	1526139
2010	2870980	2738299	2583626	2343976	2067753	1773871
2015	3329038	3174757	2993968	2722225	2398947	2057651
2020	3805469	3599818	3426585	3115890	2751015	2364441
2025	4321130	4123392	3895838	3546588	3133629	2685132
2030	4792274	4561653	4323460	3936842	3484807	3001454

---

[9] Conventionally only the TSP (Total Suspended Particles) inventory has been recorded. Recent findings that the health effects of smaller particles are more detrimental led to monitoring of PM_{10} (particles less than 10 μm in diameter) inventory. More recently, it has been argued that even $PM_{2.5}$ inventory should be monitored on a national basis. Because of the lack of data on PM in Korea, it is assumed in this study that 50% of the TSP emission is PM emission, as in Pope *et al.* (1992).

Table 2. NO_x emission by GHG reduction scenario (ton/year).

Year \ Scenario	BAU	Scen1 (5%)	Scen2 (10%)	Scen3 (20%)	Scen4 (30%)	Scen5 (40%)
1995	1724274.64	1724274.64	1724274.64	1724274.64	1724274.64	1724274.64
2010	3064197.86	2926852.98	2767776.57	2617623.58	2350211.78	2063565.55
2015	3444350.64	3287643.91	3109105.52	2943897.58	2645096.80	2323072.70
2020	3822114.82	3638403.44	3450571.84	3267465.40	2938632.19	2579427.56
2025	4156290.17	3960606.10	3757284.73	3556517.77	3196619.62	2803776.15
2030	4464501.34	4252676.58	4040491.05	3821298.39	3437142.09	3018616.76

Table 3. TSP emission by GHG reduction scenario (ton/year).

Year \ Scenario	BAU	Scen1 (5%)	Scen2 (10%)	Scen3 (20%)	Scen4 (30%)	Scen5 (40%)
1995	387004.38	387004.38	387004.38	387004.38	387004.38	387004.38
2010	695097.94	658923.16	619280.96	562077.05	495497.04	425348.39
2015	797036.62	755238.91	709919.71	644855.36	568171.46	487958.33
2020	898911.58	846859.34	801547.11	727650.08	642336.42	552711.16
2025	1008935.77	956007.67	900637.01	817716.30	722158.25	618762.61
2030	1108419.00	1048265.07	989930.68	898337.19	794579.27	685356.72

Table 4. Estimated damage cost function.

SO_x cost	SO_x cost $=\alpha+\beta_1 SO_x+\beta_2$Pop density			$R^2=0.896$
	Variable	Coefficient	t	Significance
	Constant	-1.151		
	SOx	0.006826	10.349	0.000
	Pop/km^2	0.005087	0.824	0.424
NO_x cost	NO_x cost $=\alpha+\beta_1 SO_x+\beta_2$Pop density			$R^2=0.858$
	Variable	Coefficient	t	Significance
	Constant	-0.983		
	NO_x	0.009125	8.755	0.000
	Pop/km^2	0.0007532	0.098	0.923
PM_{10} cost	PM_{10} cost $=\alpha+\beta_1 SO_x+\beta_2$Pop density			$R^2=0.882$
	Variable	Coefficient	t	Significance
	Constant	-0.373		
	PM_{10}	0.01327	9.619	0.000
	Pop/km^2	0.001148	0.402	0.693

from the National Statistical Office (1996) are used and it is assumed that the total area of Republic of Korea is 99,352 km^2 (as of 1995) and it remains the same through 2030. Population density is calculated and used accordingly.

Total ancillary benefit of GHG reduction for the cost estimation is presented in Table 5.

It is expected that the reduction of GHG by 5% will lead to savings of USD2.4 billion a year in 2010 and the benefit will increase each year up to USD3.91 billion a year in 2030. The benefit under scenario 1 (5%) almost doubles in scenario 2 (10%) , increasing up to USD7.86 billion a year in 2030. In scenario 3 (20%), however, the increase in the benefit is minor, reaching USD8.55 billion in 2010 and USD13.1 billion in 2030. The same trend continues in scenarios 4 and 5, under which the benefit reaches up to USD28.22 billion a year in 2030 in scenario 5.

Table 5. Ancillary benefit estimation by reduction scenario (USD billion/Year).

Year \ Scenario	Scen1 (5%)	Scen2 (10%)	Scen3 (20%)	Scen4 (30%)	Scen5 (40%)
2010	2.40	5.17	8.55	13.32	18.41
2015	2.76	5.92	9.72	15.16	20.96
2020	3.43	6.62	10.90	16.96	23.47
2025	3.49	7.26	12.03	18.77	26.10
2030	3.91	7.86	13.10	20.38	28.22

3. 2 GHG reduction cost and net benefit

The GHG reduction cost estimated in the previous study is presented in Table 6.

In Table 6, GHG reduction cost increases at an escalating rate most likely due to increase of the marginal

Table 6. Cost estimation by GHG reduction scenario from the previous study by KEI and KEEI (2000) study (billion USD/year).

Year \ Scenario	Scen1 (5%)	Scen2 (10%)	Scen3 (20%)	Scen4 (30%)	Scen5 (40%)
2010	0.54	1.92	3.69	6.85	11.69
2015	0.77	2.31	4.77	9.31	15.92
2020	1.00	2.62	6.31	11.85	20.08
2025	1.31	3.08	7.85	15.08	25.46
2030	1.54	4.23	10.15	18.54	31.31

Table 7. Net benefit by GHG reduction scenario (billion USD/year).

Year \ Scenario	Scen1 (5%)	Scen2 (10%)	Scen3 (20%)	Scen4 (30%)	Scen5 (40%)
2010	1.86	3.25	4.86	6.48	6.72
2015	1.99	3.62	4.95	5.85	5.04
2020	2.43	4.01	4.60	5.12	3.40
2025	2.18	4.19	4.18	3.69	0.64
2030	2.37	3.62	2.95	1.84	−3.08

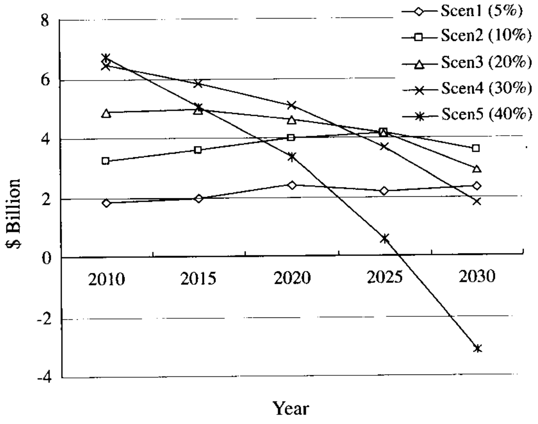

Fig. 3. Net benefit by GHG reduction scenario (USD billion/year).

cost of reducing GHG, as in other cost curves. Thus, the curve for each scenario is non-linear, which contributes to the non-linearity of the net benefit curves. The net benefit of GHG reduction is presented in Table 7.

As previously stated, the benefit increase is at constant rate but the cost increases at increasing rate. Thus, non-linear decreases of the net benefit are expected overall, which is illustrated in Figure 3.

Table 8. Net benefit GHG reduction per unit carbon by scenario (USD/TC/year).

Year \ Scenario	Scen1 (5%)	Scen2 (10%)	Scen3 (20%)	Scen4 (30%)	Scen5 (40%)
2010	197.93	172.67	128.98	114.62	89.20
2015	181.02	165.14	113.00	89.08	57.51
2020	195.61	162.24	93.05	69.13	34.41
2025	156.75	150.56	75.23	44.18	5.72
2030	154.76	118.45	48.18	20.08	-25.19

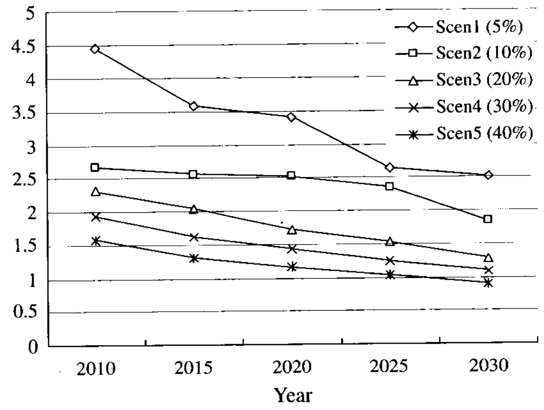

Fig. 4. Benefit per cost (benefit/cost ratio).

It is apparent that the net benefits for scenarios 4 and 5 are higher in the more near future. However, the net benefits decrease faster and end up lower than the net benefit in the more far future. It should be noted that under scenario 5, the net benefit becomes negative in 2030, which implies that too aggressive reduction strategy may not be useful in terms of the net benefit.

Another perspective on the efficiency of reduction strategy is that the net benefit per ton of carbon can be defined as the marginal net benefit with respect to the reduced carbon emission, which represents how much of the benefit can be realized per reduced carbon emission, and therefore benchmarks the efficiency of reduction strategies (Table 8).

Table 8 shows that the net benefits per carbon emitted are highest in lower GHG reduction scenarios (scenarios 1 and 2). For example, the net benefits per

Table 9. Comparison of reduction cost per carbon ton.

Previous study (p.248 KEI & KEEI 2000) <Table VI-7> in year 2020		Follow-up study (p.148 KEEI 2000) <Table 6-4> in year 2020		Adjustment ratio (B/A)
Reduction rate (%)	Reduction cost per TC (USD/TC) **A**	Reduction rate (%)	Reduction cost per TC (USD/TC) **B**	
5%	8.3	7.55%	53.9	6.49
10%	23.4	9.8%	87.9	3.76
20%	61.3	18.18%	255.2	4.16
30%	120.4	31.1%	851	7.07

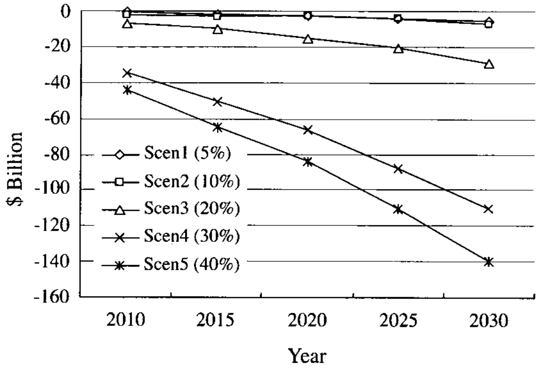

Fig. 5. Adjusted net benefit by GHG reduction scenario (billion USD/year).

carbon ton reduced in year 2010 are USD197.93 and USD172.67 for scenario 1 and scenario 2, but drop fast to USD128.98, USD114.62 and USD89.20 in scenarios 3, 4 and 5 respectively. Consistent conclusion can be drawn in the benefit/cost ratio (or benefit per cost) comparison (Figure 4).

In Figure 4, the benefit/cost ratio is higher in scenarios 1 and 2 even though the ratios are expected to decline over the period. The ratio decreases slowest in scenario 2, which can be an attractive option for policymakers.

If it is possible to assume that Korean people collectively prefer to maximize the accumulative net benefit during the period (dynamic optimization), a different interpretation of the result from Figure 3 is possible (Net Benefit by GHG reduction Scenario). That is, the areas under each net benefit curve represent the accumulative benefit over time. That is, integration of each net benefit curve from year 2010 to 2030 results in the total net benefit over time. The areas under scenarios 1 and 2 are the smallest and the area under scenario 5 is also small in comparison. Although it is hard to discern at first glance, the area under scenario 4 is larger than that of scenario 3. However, it is obvious that the areas under the net benefit curves are larger in the higher reduction scenarios. This indicates that higher reduction goals can provide higher net benefit over time, which contradicts the previous interpretation of the results.

3. 3 Adjusted GHG reduction cost and net benefit

The contradiction in the previous section may be caused by the underestimation of the cost in the previous study. In this section, different method of cost estimation/evaluation are used to consider the efficiency of policy scenarios.

In a follow-up study, KEEI updated the CGE model and reported that the cost of GHG reduction may be higher than that reported in the previous study. Comparison of the costs is presented in Table 9.

If we ignore the slight differences in reduction rates, the reduction costs per TC in the follow-up study (KEEI 2000) are 4 to 7 times higher than the previous study (KEI and KEEI 2000). It is implied that the reduction cost may have been underestimated.

When the costs of GHG reduction are adjusted using the ratios in Table 9, the contradiction of result interpretations vanishes. That is, with the adjusted reduction costs, lower reduction scenarios are consistently superior to higher reduction scenarios in terms of net benefit per carbon ton, benefit/cost ratio, and the area under the net benefit curves.[10] Supportive figure is provided in Figure 5.

In Figure 5, it is illustrated that the adjusted net benefits are negative, meaning that the reduction of GHG will lead to over all cost. The area above the adjusted net benefit curves represents the cost over time. Thus, the cost is smallest for scenarios 1 (5%) and 2 (10%). The cost is expected to be highest for scenarios 4 and 5. The same implications can be drawn for the adjusted net benefit GHG reduction per carbon ton and Adjusted Benefit/Cost Ratio, even though in these cases, scenario 2 (10%) is more efficient than scenario 1 (5%).

4. CONCLUSION AND FURTHER STUDY

The purpose of this study is to estimate the ancillary benefit of reduction in greenhouse gases (GHG), which follows up on a previous study conducted by the Korea Environment Institute and the Korea Energy Economics Institute (2000). Estimation of the ancillary benefit has been neglected compared to the cost of GHG reduction estimation, which was more frequently discussed in relevant global warming issues. Five reduction scenarios from the previous study (5%, 10%, 20%, 30%, 40% reduction from BAU emission level) were employed and emission levels for each scenario were assessed. Once emission levels were estimated, ancillary benefits were then estimated.

In estimating the ancillary benefit, the damage costs reported in Barker and Rosendahl (2000) were used in conjunction with population density and per capita GDP, and cost of GHG reduction from the previous study was used. In order to draw the policy implications, the benefit and the cost for each scenario were compared. It was found that, in terms of the net benefit per carbon ton and benefit per cost (benefit/cost ratio), lower reduction scenarios (5% and 10% reduction scenarios) may be more efficient than higher reduction scenarios. This result contradicts the dynamic implication that higher reduction scenarios (20% and 30% reduction scenarios) may result in higher net benefits over time. To resolve the contradiction and to ascertain more meaningful policy implications, the GHG reduction cost estimates had to be adjusted and the benefit/cost ratios were re-calculated. Once the reduction costs were adjusted, more consistent implications were drawn, supporting that lower reduction scenarios are more efficient.

There were three main limitations in this study. First, the damage costs were estimated using European data. Thus, it is necessary to assess the damage for Korea via the Impact Pathway Approach (IPA)[11], which is only possible through cooperative efforts among scientists and environmental economists. Secondly, there is limitations in the estimation of GHG reduction cost used in this study. A more accurate, full-dynamic, environment-specific, CGE model needs to be built to correctly assess the cost of reduction scenarios, which is still in progress. Third, it is necessary to develop more meaningful and plausible scenarios so that we better understand what we will be tackling with in the next few decades.

REFERENCES

Barker, Terry and Knut Einar Rosendahl (2000) Ancillary Benefits of GHG Mitigation in Europe: SO_2, NO_x, and PM_{10} Reductions from Policies to Meet Kyoto Targets using the E3ME model and EXTERNE valuations. Paper presented at the Expert Workshop on Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies, 27-29 March, Washington, DC. [http://www.oecd.org/EN/document/0, EN-document-8-nodirectorate-no-20-5396-8,00.html] (as of 3

---

[10] With the adjusted costs, the cost exceeds the benefit and the net benefits are negative. Therefore, net benefit curves that have smaller area *above* the curves are more efficient because they generate less cost.

[11] Recent studies for Korea via IPA include Joh (2000) and Joh, *et al.* (2001) and the scope of these studies is limited to the Seoul metropolitan area and related health effects.

June 2002).

Butraw, Dallas and Michael Toman (1997) The Benefits of Reduced Air Pollutants in the US from Greenhouse Gas Mitigation Policies, US EPA.

European Commission (1995) ExternE: Externalities of Energy, European Commission, DGXII, Science, Research and Development, JOULE, Vol. 1-6.

Henderson-Sellers, A. and P.J. Robinson (1986) Contemporary Climatology, 439pp., New York: John Wiley Sons, Inc.

Intergovernmental Panel on Climate Change (IPCC) (1996) Revised 1996 IPCC Guidelines for National Greenhouse Gases Inventories, UNEP, [http://www.ipcc.ch/] or [http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm] (1-16-02)

Joh, S. (2000) Studies on Health Benefit Estimation of Air Pollution in Korea, presented for Workshop On Assessing the Ancillary Benfits and Costs of Greenhouse Gases Mitigation Strategies, 27-29 March, Washington DC, US IPCC

Joh, S., Y. Nam, S. Shim, J. Sung, and Y. Shin (2002) Ancillary Benefit due to Greenhouse Gas Mitigation, 2000 to 2020, Korea Environment Institute.

Schneider, S.H eds. (1996) Greenhouse Effect, in Encyclopedia of Climate and Weather, pp. 368-371, New York : Oxford University Press.

Korea Energy Economics Institute (KEEI) (1996) Report on Energy Census, Dec., Ministry of Trade, Industry and Energy, Korea.

Korea Energy Economics Institute (KEEI) (2000) Spill-over Effect of Climate Change Conventions on Domestic Industry Structure and International Competitiveness, Dec. Korea Energy Economics Institute (KEEI).

Korea Environment Institute (KEI) and Korea Energy Economics Institute (KEEI) (2000) A Cost/Benefit Analysis of Greenhouse Gases Emission Reduction by Scenarios, Sep. Ministry of Environment, Korea.

National Intelligence Service (1996) Handbook of the World (Se-ge-gak-guk-pyon-rahm), Korea.

OECD (1999) Ancillary Benefits of Climate Change Policies, Working party on Economic and Environmental Policy Integration.

Peixoto, J.P. and A.H. Oort (1992) Physics of Climate, 520 pp New York : American Institute of Physics.

Pope III, C. Arden *et al.* (1992) Daily Mortality and PM_{10} Pollution in Utah Valley, Archives of Environmental Health, 47, 3.