Asian Journal of Atmospheric Environment
Vol. 5-4, pp.228-236, December 2011
doi: http://dx.doi.org/10.5572/ajae.2011.5.4.228

Evaluation of Green House Gases (GHGs) Reduction Plan in Combination with Air Pollutants Reduction in Busan Metropolitan City in Korea

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ABSTRACT

Since most Green House Gases (GHGs) and air pollutants are generated from the same sources, it will be cost-effective to develop a GHGs reduction plan in combination with simultaneous removal of air pollutants. However, effects on air pollutants reduction according to implementing any GHG abatement plans have been rarely studied. Reflecting simultaneous removal of air pollutants along with the GHGs emission reduction, this study investigated relative cost effectiveness among GHGs reduction action plans in Busan Metropolitan City. We employed the Data Envelopment Analysis (DEA), a methodology that evaluates relative efficiency of decision-making units (DMUs) producing multiple outputs with multiple inputs, for the investigation. Assigning each GHGs reduction action plan to a DMU, implementation cost of each GHGs reduction action plan to an input, and reduction potential of GHGs and air pollutants by each GHGs reduction action plan to an output, we calculated efficiency scores for each GHGs reduction action plan. When the simultaneous removal of air pollutants with the GHGs reduction were considered, green house supply-insulation improvement and intelligent transportation system (ITS) projects had high efficiency scores for cost-positive action plans. For cost-negative action plans, green start network formation and running, and daily car use control program had high efficiency scores. When only the GHGs reduction was considered, project priority orders based on efficiency scores were somewhat different from those when both the removal of air pollutants and GHGs reduction were considered at the same time. The expected action plan priority difference is attributed to great difference of air pollutants reduction potential according to types of energy sources to be reduced.

Key words: Greenhouse gas, Air pollutant, Reduction plan, Data envelopment analysis, Efficiency, Busan Metropolitan City

1. INTRODUCTION

Climate change is an important global issue and challenge nowadays. Global Green House Gases (GHGs) emissions have gradually increased since the Industrial Revolution, and are expanding at a pace of approximately 51 gigatonnes of carbon dioxide equivalents ($GtCO_2e$) per year. In Korea, the government has established a comprehensive plan to combat the climate change, has set 30% of the GHGs emission reduction target relative to the Business-As-Usual (BAU) by 2020, and is working with private and public sectors to meet the goal.

Since most GHGs and air pollutants are generated from the same sources, developing a reduction plan in combination with air pollutants reduction would be a way to save lots of redundant costs in developing and implementing the reduction plan. On the basis of the need for the integrated management of GHGs and air pollutants, Section 11 in the Clean Air Conservation Act regulates that an air quality improvement master plan including establishment of an integrated management system for simultaneous GHGs and air pollutants reduction be prepared. However, air pollutants mitigation plan and GHGs mitigation plan are currently devised separately and existing studies on the climate change mainly focus only on assessing current and future GHGs emissions, and evaluating reduction potential of GHGs abatement measures (Jong, 2010; Cheong *et al*., 2009; Cheong *et al*., 2007; Kim, 2006; Koh *et al*., 2006). Effects on air pollutants reduction according to implementing any GHG abatement plans have been rarely studied.

This study evaluated relative cost-effectiveness of

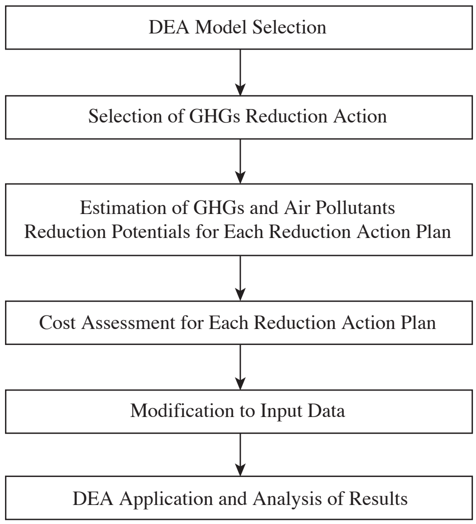

Fig. 1. Procedure of the study.

GHGs reduction action plans applicable to Busan Metropolitan City considering simultaneous air pollutants removal along with GHGs reduction when the GHGs abatement plans are implemented. For the assessment of the simultaneous reduction of air pollutants along with GHGs, we used the Data Envelopment Analysis (DEA), a methodology that evaluates relative efficiency of decision-making units (DMUs) producing multiple outputs with multiple inputs. The procedure of the study followed is presented in Fig. 1.

2. METHOD AND ANALYSIS OF RESULTS

2. 1 Selection of DEA Model

DEA which is an extension of Farrell's (1957) relative efficiency concept was initially proposed by Charnes *et al.* (1978) and was established as a basis for the efficiency analysis. DEA is a non-parametric method that measures the efficiency of multiple decision-making units (DMUs) which produce multiple outputs using multiple inputs.

Some of the advantages of DEA are:
(a) Capability of handling multiple inputs and outputs
(b) No need to explicitly specify a mathematical relation between inputs and outputs
(c) Direct comparison of a evaluated DMU with a peer group
(d) Outputs can have different units regardless of inputs unit

Some of the disadvantages of DEA are:
(a) Difficulty in measuring the absolute efficiency
(b) Results are sensitive to the selection of inputs and outputs (Berg, 2010)
(c) The number of efficient DMUs on the frontier tends to increase with the number of inputs and output variables (Berg, 2010)

Of the DEA methodology, a model developed by Charnes, Cooper and Rhodes (CCR model) defines the efficiency as a sum of weighted outputs to a sum of weighted inputs, where the weight structure is calculated by means of mathematical programming and constant returns to scale (CRS) are assumed (Charnes *et al.*, 1978). Other model developed by Banker, Charnes and Cooper (BCC model) considers variable returns to scale (VRS) (Banker *et al.*, 1984). Depending on efficiency assessment measures, the DEA methodology is divided into the input-oriented measures and output-oriented measures. There are other available models such as the super-efficiency model which overcomes drawbacks of the initial DEA models that are incapable of providing order information among efficient DMUs (Anderson and Petersen, 1993).

This study used the input-oriented super-efficiency CCR model to assess the order among efficient DMUs. The super-efficiency CCR model measures the radial distance from a target DMU to the efficient frontier which is estimated without the target DMU. The equation for the super-efficiency CCR model is expressed as follows (Cooper *et al.*, 2007):

$$Min\theta-\varepsilon\left[\sum_{i=1}^{m}s_i^- + \sum_{r=1}^{n}s_r^+\right]$$

subject to

$$\theta x_{ip} - \sum_{j=1,\, j\neq p}^{J} x_{ij}\lambda_j - s_i^- = 0 \qquad i=1, 2, \cdots, m$$

$$\sum_{j=1,\, \neq p}^{J} y_{rj}\lambda_j - y_{rp} - s_r^+ = 0 \qquad r=1, 2, \cdots, n$$

$$\lambda_j,\ s_i^-,\ s_r^+ \geq 0 \ \text{ for all } \ j, r, i \qquad \text{Eq. (1)}$$

where, x_{ij} is ith input of DMU j and y_{rj} is rth output of DMU j. θ, λ_j, s_i^-, and s_r^+ are model's decision variables. $\varepsilon > 0$ is the usual non-Archimedean element. m is number of inputs and n is number of outputs. J is number of DMUs. p is the index of target DMU. We can determine DEA efficiencies of all DMUs by solving Equation 1 J times, designating each DMU as a target DMU p in turn. Here, a DMU p with the optimum $\theta^* \geq 1$ is judged DEA efficient, while a DMU p with $\theta^* < 1$ is DEA inefficient. A DMU having greater θ^* is more efficient than a DMU having smaller θ^*. θ^* is termed as efficiency score.

We defined each GHGs reduction action plan as a DMU. We defined costs according to each GHGs reduction action plan as an input, and reduction potential of GHGs and air pollutants according to each GHGs reduction action plan as an output. Using these data, we calculated efficiency scores.

2.2 Selection of GHGs Action Plan

Referring to the *Guideline for Local Governments' Establishment of Green House Gases Reduction Master Plan (ver. 1)* by the National Institute of Environmental Research (Hong *et al.*, 2010) and *Master Plan for Climate Change Response in Busan Metropolitan*

Table 1. GHGs reduction action plans.

Sector	Reduction action plan	Participation or supply assumed (%)
Residential	Green home supply-insulation improvement	1.5% of new houses
	Solar light house supply	1.3% of total houses in Busan
	Reducing TV watching time[1)]	22% of TVs
	Reducing computer use time[2)]	20% of computers
	Keeping optimal capacity refrigerators[3)]	25% of refrigerators
	Reducing washing machine runs[4)]	21% of washing machine
	Reducing vacuum runs[5)]	31% of vacuums
	Reducing iron use time[6)]	9% of irons
	Reducing air conditioning time[7)]	31% of air conditioners
	Increasing air conditioner temperature[8)]	21% of air conditioners
	Periodic clean-up of air conditioner filers[9)]	33% of air conditioners
	Reducing heating time[10)]	20% of houses with natural gas
	Decreasing heating temperature[11)]	21% of houses with natural gas
	Cleaning up boilers regularly[12)]	36% of houses with natural gas
Commercial and Public	High efficiency LED lighting supply	30% of building gross floor area
	Stricter low carbon design standards	10% of building gross floor area
	Solar light generator installation	0.2% of building gross floor area
	Thermal energy supply	0.2% of building gross floor area
	Reasonable control of indoor temperature[13)]	20% of building gross floor area
	Light off after work hours	5% of building gross floor area
	Telecommute extension[14)]	1.2% of productive population
	Mokdo off-shore wind power development	–
	Small hydroelectricity power plant construction	–
	Utilization of methane from digesters	–
	Natural gas network expansion	95% of houses
	Saengok LFG to energy project	–
	Getting energies from municipal wastes and constructing heat-only boilers	–
	Utilizing extra heat from solid wastes incinerators	–
Transport	Integrated public transportation transfer center construction	–
	Intelligent transportation system (ITS) project	–
	Daily car use control program[15)]	25% of registered cars
Common	Green start network formation and running[16)]	–

[1)]Reducing TV watching time by 1 hour per day, 234 kwh saving per year per set
[2)]Reducing computer use time by 1 hour per day, 113 kwh saving per year per set
[3)]Filling contents in refrigerators up to 60% of the capacity (current practice: around 74%), 21 kwh saving per year per set
[4)]Reducing washing machine runs by 1 run per week, 105 kwh saving per year per set
[5)]Reducing vacuum runs by 1 run per week, 102 kwh saving per year per set
[6)]Reducing iron use time by 4 minutes per week, 52 kwh saving per year per set
[7)]Reducing air conditioner use time by 1 hour per day, 52 kwh per year per set
[8)]Increasing air conditioner temperature by 1°C, 13 kwh saving per year per set
[9)]Periodic clean-up of air conditioner filters, energy efficiency improvement by 4%, 8 kwh saving per year per set
[10)]Reducing heating time by 4 hours per day, LNG 85 Nm^3 saving per year per set
[11)]Decreasing heating temperature by 2°C, 13% energy saving
[12)]Cleaning up boilers twice a year, 5% energy efficiency improvement
[13)]1°C adjustment of building heating and cooling temperature, 6.5% emission reduction
[14)]Telecommuting at home once a week
[15)]Using public transportation or carpool once a week
[16)]Nationwide civil movement to reduce GHGs emissions in non-industrial sectors by voluntary participation and practice

Table 2. GHGs reduction and air pollutants reduction potentials according to action plans.

Sector	Reduction action plan	Reduction potential (unit: ton)					
		CO_2	CO	NO_x	SO_x	PM_{10}	VOC
Residential	Green home supply-insulation improvement	35,109	47	66	39	31	5
	Solar light house supply	23,002	31	43	25	20	3
	Reducing TV watching time	35,291	48	67	40	32	4
	Reducing computer use time	9,279	13	17	10	8	1
	Keeping optimal capacity refrigerators	2,615	4	5	3	2	0
	Reducing washing machine runs	10,555	14	20	12	9	1
	Reducing vacuum runs	12,123	16	23	13	11	2
	Reducing iron use time	2,330	3	4	3	2	0
	Reducing air conditioning time	20,854	28	39	23	18	3
	Increasing air conditioner temperature	1,333	27	39	23	18	3
	Periodic clean-up of air conditioner filers	1,257	42	59	35	28	4
	Reducing heating time	50,645	39	55	32	26	4
	Decreasing heating temperature	40,769	40	228	1	2	11
	Cleaning up boilers regularly	26,914	26	150	0	1	7
Commercial & Public	High efficiency LED lighting supply	16,374	22	31	18	15	2
	Stricter low carbon design standards	133,659	78	109	66	52	8
	Solar light generator installation	180	1	1	0	0	0
	Thermal energy supply	1,462	299	1,196	847	52	15
	Reasonable control of indoor temperature	51,806	29	41	25	20	3
	Light off after work hours	3,196	4	6	4	3	0
	Telecommute extension	8,283	1	0	0	0	0
	Mokdo off-shore wind power development	7,910	35	50	29	24	3
	Small hydroelectricity power plant construction	684	1	1	1	1	0
	Utilization of methane from digesters	3,604	5	7	4	3	0
	Natural gas network expansion	186,960	2	82	72	6	−5
	Saengok LFG to energy project	5,334	7	10	6	5	1
	Getting energies from municipal wastes andconstructing heat-only boilers	74,295	99	140	82	66	10
	Utilizing extra heat from solid wastes incinerators	42,479	10	40	287	4	1
Transport	Integrated public transportation transfer center construction	2,000	27	83	0	5	0
	Intelligent transportation system (ITS) project	80,000	887	993	0	59	0
	Daily car use control program	159,474	850	137	0	0	43
Common	Green start network formation and running	1,421,606	704	1,603	420	308	88

City-Establishment of Climate Change Response Master Plan and Yearly Implementation Plan (Yang *et al.*, 2010) to select GHGs reduction action plans, we chose GHGs reduction action plans from the residential, commercial and public, and transport sectors since these sectors have relatively high GHGs emissions and various reduction plans were already developed for these sectors. After further considering possibility of costs quantification along with GHGs and air pollutants reduction potential estimates, we chose 32 GHGs reduction action plans. The GHGs action plans selected for the study is presented in Table 1.

2. 3 GHGs and Air Pollutants Reduction Estimates

Estimates of GHGs and air pollutants reduction potentials in the target year, 2020, according to the reduction action plans in Busan are presented in Table 2. The GHGs and air pollutants reduction potential due to the electricity usage decrease was estimated by calculating indirect emissions reduction due to the decreased electricity usage.

2. 4 Cost Estimates Relative to Reduction Action Plans

Table 3 shows estimated total costs relative to the GHGs reduction action plans. Several papers and reports (Electric Power Statistics Information System, 2011; Korea City Gas Association, 2011; Hong *et al.*, 2010; Korea Electric Power Corporation, 2010; Ministry of Land, Transport and Maritime Affairs, 2010; Yang *et al.*, 2010; Kwon *et al.*, 2008) have been reviewed and consulted for the estimates of the costs relative to the GHGs reduction action plans. We considered installation and operation costs for the assessment of the reduction action plan costs, and obtained yearly

Table 3. Total costs relative to reduction action plans.

Sector	Reduction action plan	Total cost (1,000 won)
Residential	Green home supply-insulation improvement	926,452
	Solar light house supply	17,833,764
	Reducing TV watching time	−7,954,801
	Reducing computer use time	−2,091,441
	Keeping optimal capacity refrigerators	−589,380
	Reducing washing machine runs	−2,379,265
	Reducing vacuum runs	−2,732,635
	Reducing iron use time	−525,292
	Reducing air conditioning time	−4,700,736
	Increasing air conditioner temperature	−300,412
	Periodic clean-up of air conditioner filers	−283,246
	Reducing heating time	−15,448,456
	Decreasing heating temperature	−12,436,007
	Cleaning up boilers regularly	−8,209,751
Commercial and Public	High efficiency LED lighting supply	−95,915,487
	Stricter low carbon design standards	−16,384,883
	Solar light generator installation	326,101
	Thermal energy supply	−723,745
	Reasonable control of indoor temperature	−3,940,244
	Light off after work hours	−492,027
	Telecommute extension	−5,878,035
	Mokdo off-shore wind power development	1,911,987
	Small hydroelectricity power plant construction	−30,197
	Utilization of methane from digesters	−2,150,560
	Natural gas network expansion	−4,381,400
	Saengok LFG to energy project	−1,271,317
	Getting energies from municipal wastes andconstructing heat-only boilers	−15,580,085
	Utilizing extra heat from solid wastes incinerators	−2,360,500
Transport	Integrated public transportation transfer center construction	67,322
	Intelligent transportation system (ITS) project	1,322,892
	Daily car use control program	−112,882,596
Common	Green start network formation and running	−268,179,735

costs for equipment by dividing by running years. For action plans where construction period is more than 1 year, costs were converted to the present value. Action plans presented with negative costs are cases where financial profits are achieved with cost saving measures such as energy saving. Utility decrease which is difficult to express as monetary value was not considered in the study.

2.5 Modification to Input Data

In assessing effects of the GHGs reduction on the air pollutants reduction, each air pollutant to be reduced was assigned with its weighted fraction based on environmental characteristics of the pollutant in Busan since each air pollutant has different influences from other air pollutants, on the environment and public health. To assign the weighted fraction for each air pollutant, we calculated probability that each air pollutant would exceed 80% of the Standard in the Clean Air Conservation Act using mean, standard deviation, and the Standard, and compared the probability with the probabilities of the other air pollutants. Table 4 and 5 present data used to calculate the weighted fraction for each air pollutant and its results.

Since the level of CO was much less than the Standard and the probability to exceed 80% of the Standard was 0 as shown in the Table 4 and 5, CO was excluded from further analysis. In case of VOCs, since there was no data available, these compounds were also excluded from further analysis.

The GHGs reduction action plans having negative costs are relatively cost-effective comparing to the reduction action plans having positive costs. We applied the DEA model to cost-negative and cost-positive cases separately. For negative costs, the value was first converted to absolute value and then, converted to inverse value for application to the DEA model. In this case, priority order of profits (i.e., negative costs) times reduction potentials were evaluated using the DEA model. This is a good tool for this study since the ob-

Table 4. Air pollutants levels and standards (2008).

Air pollutant	Average	Standard deviation	Standard1)	Unit
PM_{10}	50.938	10.20890	50	μg/m^3
NO_x	0.022	0.00415	0.03	ppm
CO	0.416	0.06740	9	ppm
SO_x	0.006	0.00065	0.02	ppm

*From the Air Korea webpage posting real-time air quality in Korea (http://www.airkorea.or.kr)
1)The standard for CO is 8 hour standard and rest of standards are annual average standard. CO was excluded from the further analysis in this study.

Table 5. Weighted fraction adopted.

	Z value	Probability	Weighted fraction
PM_{10}	−1.07	0.86	0.86
NO_x	0.58	0.28	0.28
CO	100.65	0.00	0.00
SO_x	15.99	0.00	0.01 1)

1)For SO_x, the least number was assigned to the second digit from the decimal point.

Table 6. Priority oder of cost-positive cases - only for GHGs reduction.

Rank	DMU	Score
1	Intelligent transportation system (ITS) project	1.596
2	Green home supply-insulation improvement	0.627
3	Integrated public transportation transfer center construction	0.491
4	Mokdo off-shore wind power development	0.068
5	Solar light house supply	2.13E-02
6	Solar light generator installation-commercial and public	9.13E-03

Table 7. Priority order of cost-positive cases - for simultaneous GHGs and air pollutants removal.

Rank	DMU	Score
1	Green home supply-insulation improvement	3.183
2	Intelligent transportation system (ITS) project	1.713
3	Integrated public transportation transfer center construction	1.638
4	Mokdo off-shore wind power development	0.364
5	Solar light house supply	3.42E-02
6	Solar light generator installation-commercial and public	3.35E-02

Table 8. Priority order of cost-negative cases - only for GHGs removal.

Rank	DMU	Score
1	Green start network formation and running	21.178
2	Daily car use control program	4.72E-02
3	Stricter low carbon design standards	5.74E-03
4	High efficiency LED lighting supply	4.12E-03
5	Getting energies from municipal wastes and constructing heat-only boilers	3.04E-03
6	Natural gas network expansion	2.15E-03
7	Reducing heating time	2.05E-03
8	Decreasing heating temperature	1.33E-03
9	Reducing TV watching time	7.36E-04
10	Cleaning up boilers regularly	5.80E-04
11	Reasonable control of indoor temperature	5.35E-04
12	Utilizing extra heat from solid wastes incinerators	2.63E-04
13	Reducing air conditioning time	2.57E-04
14	Telecommute extension	1.28E-04
15	Reducing vacuum runs	8.69E-05
16	Reducing washing machine runs	6.59E-05
17	Reducing computer use time	5.09E-05
18	Utilization of methane from digesters	2.03E-05
19	Saengok LFG to energy project	1.78E-05
20	Light off after work hours	4.12E-06
21	Keeping optimal capacity refrigerators	4.04E-06
22	Reducing iron use time	3.21E-06
23	Thermal energy supply	2.77E-06
24	Increasing air conditioning temperature	1.05E-06
25	Periodic clean-up of air conditioner filers	9.34E-07
26	Small hydroelectricity power plant construction	5.42E-08

jective of this study is to obtain relative order among the GHGs abatement action plans.

2. 6 DEA Application and Analysis of the Results

Priority orders of the GHGs reduction action plans acquired using the DEA model are shown in Table 6 through Table 9. We put the costs of the GHGs action plans as inputs, and the GHGs and air pollutants reduction potentials as outputs. The results were obtained for cost-negative group and cost-positive group, separately, and we divided the results for each cost-negative and cost-positive group to GHGs reduction cases, and simultaneous GHGs and air pollutants reduction cases, respectively.

In case of cost-positive group, there were no differences of the priority orders between the GHGs reduction action plans, and the simultaneous GHGs and air pollutants reduction action plans except that the priority orders of "green home supply-insulation improvement" and "intelligent transportation system (ITS)" were switched with each other between the GHGs reduction action plans, and the simultaneous GHGs and air pollutants reduction action plans. When the simultaneous reduction of GHGs and air pollutants was counted, "green home supply-insulation improvement" appeared to be most cost-effective, and this indicates that the simultaneous GHGs and air pollutants reduction could be effectively achieved with relatively low costs for this category. Contrary to that,

Table 9. Priority order of cost-negative cases - for simultaneous GHGs and air pollutants removal.

Rank	DMU	Score
1	Green start network formation and running	80.576
2	Daily car use control program	4.72E-02
3	High efficiency LED lighting supply	1.70E-02
4	Getting energies from municipal wastes and constructing heat-only boilers	1.25E-02
5	Stricter low carbon design standards	1.03E-02
6	Decreasing heating temperature	6.59E-03
7	Utilizing extra heat from solid wastes incinerators	6.00E-03
8	Thermal energy supply	5.44E-03
9	Reducing heating time	4.88E-03
10	Reducing TV watching time	3.06E-03
11	Cleaning up boilers regularly	2.87E-03
12	Natural gas network expansion	2.80E-03
13	Reducing air conditioning time	1.05E-03
14	Reasonable control of indoor temperature	9.37E-04
15	Reducing vacuum runs	3.60E-04
16	Reducing washing machine runs	2.74E-04
17	Reducing computer use time	2.08E-04
18	Telecommute extension	1.28E-04
19	Periodic clean-up of air conditioner filers	9.64E-05
20	Utilization of methane from digesters	8.39E-05
21	Saengok LFG to energy project	7.34E-05
22	Increasing air conditioning temperature	6.70E-05
23	Light off after work hours	1.70E-05
24	Keeping optimal capacity refrigerators	1.63E-05
25	Reducing iron use time	1.34E-05
26	Small hydroelectricity power plant construction	2.23E-07

"solar light house supply" and "solar light generator installation" showed low priority. The results were similar to those of Park *et al.* (2010). Comparing investment return periods among renewable energies, they showed the longest investment return period was for solar light. Their findings of the investment return period of the renewable energies are as follows: small hydropower < solar power < wastes < thermal < bio < wind power < solar light.

There are two types of reduction action plans which have negative costs due to energy savings: they are voluntary energy saving plans, and plans where energy saving is greater than yearly cost, such as wastes recycling and urban natural gas network expansion. For the cost-negative group, the priority order of the action plans considering only GHGs reduction is as follows: green start network formation and running > daily car use control program > employing stricter low carbon design standards for building construction and renovation > switch to high efficiency LED lighting > getting energies from municipal wastes and constructing heat-only boilers. The voluntary energy saving action plans such as reducing heating time, lowering heating temperature, reducing TV watching time, cleaning up boilers regularly, and limiting indoor cooling and heating temperatures, followed the priority order. The results were different from those of the simultaneous GHGs and air pollutants reduction action plans.

For the cost-negative group, when the simultaneous GHGs and air pollutants reduction was considered, the urban natural gas network expansion showed lower priority order than utilizing extra heat from solid wastes incinerators, and thermal energy use showed relatively high priority order. The results are attributed to differences in air pollutants reduction potentials according to energy sources which could be saved by the reduction action plans.

It is important to consider the GHGs reduction potentials in addition to the priority order to be obtained through efficiency comparison when choosing reduction action plans for establishing and implementing GHGs reduction action plans. Accordingly, among negative-cost action plans, green start network formation and running, urban natural gas network expansion, daily car use control program, and employment of stricter low carbon design standards are proper measures taking into account both the GHGs reduction potentials and cost effectiveness. Contrary to that, high efficiency LED lighting usage is an action plan having relatively low reduction potential although it has high cost effectiveness. Saengok LFG to energy project, utilization of methane from digesters, and construction of small hydroelectricity power plants have low reduction potentials and relatively low cost effectiveness.

Among cost-positive action plans, ITS project and insulation improvement showed relatively high reduction potentials and high cost effectiveness. The ITS project is considered to be a proper reduction action plan since the project is considered as a good alternative to the current transportation system to solve traffic problems. Solar light house supply and solar light power generator installation had relatively low cost effectiveness.

3. CONCLUSIONS

The GHGs and air pollutants reduction potentials, and costs were estimated for the GHGs reduction action plans in the residential, commercial and public, and transport sectors of Busan Metropolitan City. The data obtained were applied to the DEA model to assess relative cost effectiveness and priority of the GHG reduction action plans.

For the cost-positive action plans, when only the GHGs reduction was considered, the priority order of the cost effectiveness of the action plans was ITS project > green home supply-insulation improvement > integrated public transportation transfer center construction > Mokdo off-shore wind power development > solar light house supply > solar light power generator installation (commercial and public sectors). However, when air pollutants reduction was considered, green home supply-insulation improvement had higher priority than ITS project. The difference in the priority order of the GHGs reduction action plans between the two scenarios is attributed to the difference in energy sources to be reduced according to the GHGs reduction action plans. This difference is likely to cause the difference in the amount of the air pollutants to be released.

For the cost-negative action plans, when only the GHGs reduction was considered, the priority order of the cost effectiveness of the action plans was green start network formation and running > daily car use control program > employing stricter low carbon design standards for building construction and renovation > switch to high efficiency LED lighting > getting energies from municipal wastes and constructing heat-only boilers. The priority order is a little changed when the GHGs reduction and air pollutants reduction are considered at the same time.

Among the cost-negative action plans, green start network formation and running, urban natural gas network expansion, daily car use control program, and employing stricter low carbon design standards for building construction and renovation are proper measures when both the GHGs reduction potentials and cost effectiveness are taken into account. High efficiency LED lighting usage is an action plan having relatively low GHG reduction potential although it has high cost effectiveness. Saengok LFG to energy project, utilization of methane from digesters, and construction of small hydroelectricity power plants have low GHG reduction potentials and relatively low cost effectiveness.

Among cost-positive measures, ITS project and green home supply-insulation improvement showed relatively high reduction potentials and high cost effectiveness. The ITS project is considered to be an important reduction action plan since the project is considered as a good alternative to the current transportation system to solve traffic problems. Solar light house supply and solar light power generator installation had relatively low cost effectiveness.

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(Received 12 May 2011, revised 17 August 2011
accepted 17 August 2011)