에너지경제연구 제 14 권 제 3 호
Korean Energy Economic Review
Volume 14, Number 3, November 2015 : pp. 83~112

What factors cause an increase of greenhouse gas emissions in Korea?*

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Abstract

This paper conducted a long-term time series econometric analysis of Korea's GHG emissions by FMOLS and VECM. GDP, heating and cooling degree days were considered as the main factors that increase the GHG emissions, and the proportion of non-fossil fuels and import price of crude oil as the factors that decrease the GHG emissions. The analysis focused on two aspects: gross GHG emissions and per capita GHG emissions. As regards total GHG emissions, GDP has the largest effect on gross GHG emissions. It is followed by heating and cooling days. Heating degree days affect GHG emissions in Korea more than cooling degree days do. The share of non-fossil fuels and the import price of crude oil have reducing effects on gross GHG emissions. As regards per capita GHG emissions, the analysis results have similar patterns. The largest effects on per capita GHG emissions are from GDP, followed by heating and cooling days.

Keywords : GHG Emissions, FMOLS, GDP, Heating and Cooling Degree Days
JEL Classifications: Q44, Q54

* This work was supported by 2013 Hongik University Research Fund. This research was developd from the part of the report "Analysis on the changing factors of the national GHG emissions" of Greenhouse Gas Inventory & Research Center of Korea.
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Ⅰ. Introduction

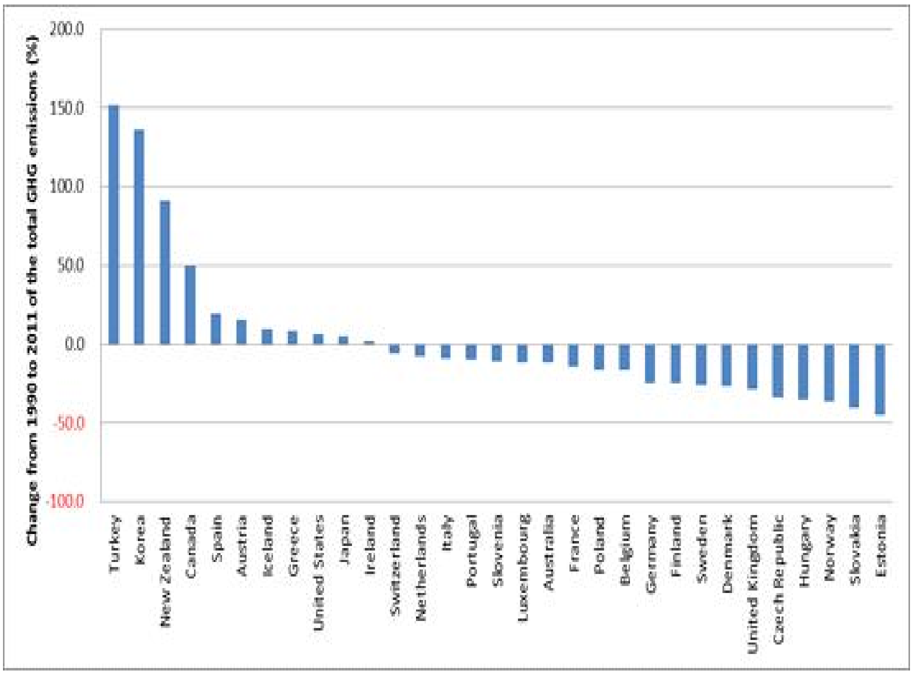
The greenhouse gas (GHG) emissions of Korea have been increased by 136% from 1990 to 2011. As shown in Fig. 1, this growth rate is the second highest among OECD countries. During the same period, the industrial production rapidly has been increased and the structure of Korea has changed over the past 20 years with an increase in the proportion of energy-intensive industries such as steel and petrochemicals. Furthermore energy consumption in the residential and commercial sectors has also increased steadily with the growth in per capita income. With the increasing need to reduce global GHG emissions, Korea voluntarily announced, at the Conference of Parties in Copenhagen, its medium-term emission reduction goal - a 30% reduction of GHG emissions by 2020 compared to the business-as-usual (BAU) to address climate change. Further, Korea has implemented the GHG target management system since 2012 and started the national emission trading system from 1, January 2015.

This paper investigates the economic forces underlying GHG emissions from fossil fuel use in Korea and aims to identify the factor that most contributes to the GHG emission growth in Korea.

Specifically, this paper will analyze the long-term characteristics of the growth in emissions through various time series econometric methods. The previous studies focused on the causal relationship between GHG emissions, GDP and energy consumption, and did not focused on the role of weather and non-fossil fuels such as nuclear energy or renewable energy in the time series econometric framework. In particular, weather is an important factor affecting on

GHG emissions, but there is no study that considers this factor on the economic model. This paper considers various factors - economic growth, temperature change, change in energy sources, price of fossil fuels, and so on - that contribute to an increase in GHG emissions in Korea.

[Fig 1] Growth rates of GHG emissions in OECD countries from 1990 to 2011.



Source: UNFCCC, the total GHG emissions including LULUCF

Note: The data of Chile, Israel and Mexico is not available and the data of Korea is from Greenhouse Gas Inventory & Research Center of Korea

Ⅱ. GHG Emissions in Korea

Korea's total gross GHG emissions were 697.7 Mt CO_2 eq. in 2011 compared to 295.7 Mt CO_2 eq. in 1990, representing a 135.9% increase (see Table 1). Total gross GHG emissions refer to the sum of emissions, excluding those from land use, land-use change, and forestry (LULUCF). Total net emissions (including LULUCF) were 654.7 Mt CO_2 eq. in 2011 compared to 269.5 Mt CO_2 eq. in 1990—a 142.9% increase. The average annual growth rate was 4.17% for gross emissions and 4.32% for net emissions. The average annual growth rate of net emissions was higher because greenhouse gas removals from LULUCF have increased steadily by afforestation.

The average annual growth rate in greenhouse gas emissions appears to be the highest in the energy industry, followed by industrial processes—8.48% and 5.59%, respectively. The rate of 4.23% in the manufacturing industry corresponds to the average annual growth rate of net greenhouse gas emissions. Indirect emissions were not included for industries such as manufacturing and construction. Greenhouse gas emissions in other sectors—the residential and commercial sectors, the public sector, etc.—show negative growth rates. This is because emission data in these sectors do not include indirect emissions from electricity use. If we add indirect emissions to the data for these sectors, the annual growth rate would show positive values. The GHG emissions from direct combustion have decreased because of the shift from combustion sources such as oil and gas to electricity. GHG emissions in agriculture show negative growth rates, which means emissions have decreased over the years. The waste sector maintained a low level of GHG emissions with an average annual growth rate of 1.82%.

As shown in Table 2, emissions from the energy sector accounted for 91.3% of the total net GHG emissions in 2011. Most of the in energy sector emissions come from fossil fuel combustion—as much as 40.3% of GHG emissions, compared to 27.9% in manufacturing industries and construction, 13.7% in transport, and 9.5% in other sectors. As shown in Figs. 1 and 2, energy-intensive industries such as iron and steel, petroleum and chemicals, and non-metallic products accounted for a large amount of emissions from the manufacturing sector. In particular, emissions from iron and steel and petroleum and chemicals have increased steadily over the past 20 years. Emissions from the non-metallic sector have decreased over the years, but those from manufacturing industries contribute a sizable share.

<Table 1> Greenhouse gas emissions in Korea

Unit: (Mt CO2eq)

	1990	1995	2000	2005	2010	2011	Average annual growth rate
Gross emissions	295.7	442.8	511.3	569.5	667.8	697.7	4.17
Net emissions	269.5	414.9	470.2	533.2	624	654.7	4.32
1. Energy	241	353.5	410.8	467.5	568.9	597.9	4.42
A. Fuel combustion	235.6	350.4	406.6	462.1	561.7	590.2	4.47
Energy industries	47.8	91.6	134.9	177.2	256.1	264.1	8.48
Manufacturing industries and constructiona	76.5	116.9	129.8	134.9	161.3	182.7	4.23
Transporta	34.8	63.4	68.7	80.4	85.4	85	4.34
Other sectorsa	76.5	78.5	73.3	69.5	59	58.4	-1.27
B. Fugitive emissions from fuels	5.4	3.1	4.1	5.4	7.2	7.7	1.73
2. Industrial processes	20.2	49.4	58.5	64.5	62.6	63.4	5.59
4. Agriculture	24.6	25.3	24.4	22	22.1	22	-0.54
5. Land-use change and forestry	-26.2	-27.9	-41.1	-36.3	-43.7	-43	2.39
6. Waste	9.9	14.6	17.6	15.4	14.0	14.4	1.82

Notes: 1. "Other sector" includes the residential and commercial sectors and the public sector.
2. Total gross greenhouse gas emissions + LULUCF = Total net greenhouse gas emissions.

Source: National Greenhouse Gas Inventory of Korea, 2013.

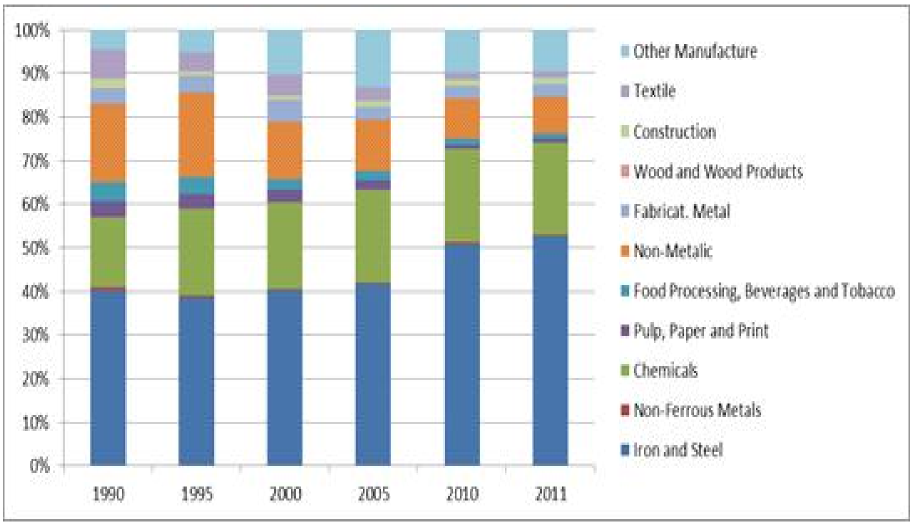
<Table 2> Percentage structure of greenhouse gas emissions in Korea (share of emissions in net GHG emissions by sector)

	1990	1995	2000	2005	2010	2011
Net emissions	100	100	100	100	100	100
1. Energy	89.4	85.2	87.4	87.7	91.2	91.3
A. Fuel combustion	87.4	84.4	86.5	86.7	90	90.1
Energy industries	17.7	22.1	28.7	33.2	41	40.3
Manufacturing industries and construction*	28.4	28.2	27.6	25.3	25.8	27.9
Transport*	12.9	15.3	14.6	15.1	13.7	13
Other sectors*	28.4	18.9	15.6	13	9.5	8.9
B. Fugitive emissions from fuels	2	0.7	0.9	1	1.2	1.2
2. Industrial processes	7.5	11.9	12.4	12.1	10	9.7
4. Agriculture	9.1	6.1	5.2	4.1	3.5	3.4
5. Land-use change and forestry	-9.7	-6.7	-8.7	-6.8	-7	-6.6
6. Waste	3.7	3.5	3.7	2.9	2.3	2.2

Source: National Greenhouse Gas Inventory of Korea, 2013.

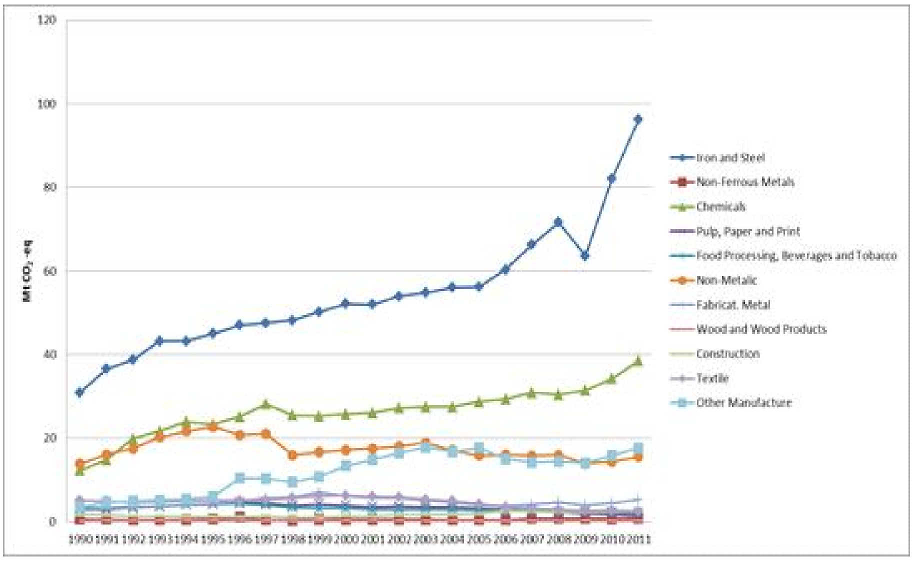
Of the total net greenhouse gas emissions in 2011, 13% were from transport and 8.9% from other sectors, including the residential and commercial sectors and the public sector. Specifically, emissions in the transport sector (rail, land, water, and air) are largely from land transport. Emissions from industrial processes contributed 9.7% of the total net greenhouse gas emissions in 2011. Emissions from industrial processes occur not from fossil fuel combustion but from chemical or physical transformation. Agriculture and waste generated emissions of 3.4% and 2.2%, respectively.

[Fig 2] The share of GHG emissions by industry



Source: National Greenhouse Gas Inventory of Korea, 2013.

[Fig 3] GHG emissions trends by industry



Source: National Greenhouse Gas Inventory of Korea, 2013.

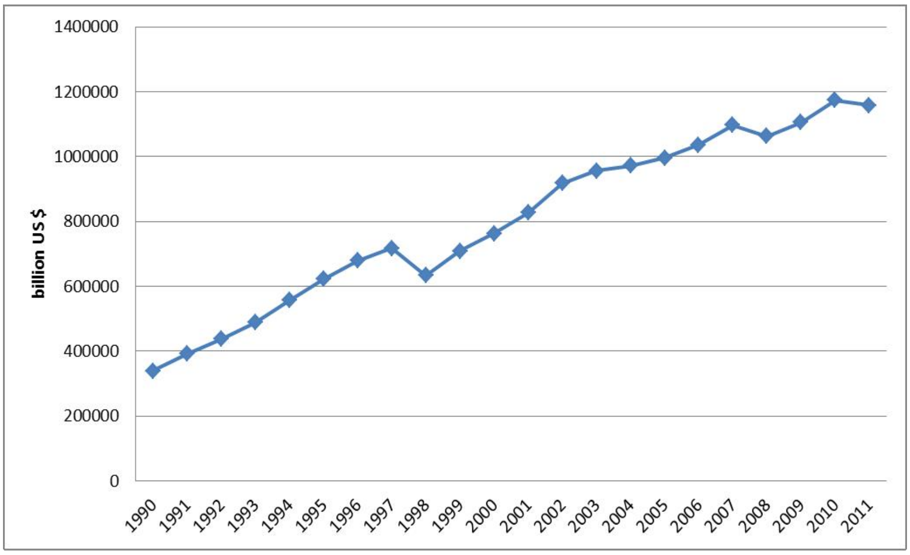
Ⅲ. Models and Data

Greenhouse gas emissions have increased for a number of reasons. However, GHG emissions are known to be proportional to economic growth. Therefore, this economic analysis of greenhouse gas emissions has focused on the relationship between emissions and economic growth. Econometric models of greenhouse gas emissions have so far focused on testing the environmental Kuznets curve (EKC) hypothesis in terms of the relationship between GHG emissions and economic growth. Previous studies on the EKC hypothesis test considered variables such as GDP and population. This was because these variables cause greenhouse gas emissions in the long term. Greenhouse gas emissions increase with energy consumption, which results from economic growth.

This perspective has been articulated in several studies such as Schmalensee, Stoker, and Judson (1998), Lantz and Feng (2006), Shafik and Bandyopadhyay (1992), Shafik (1994), Seldon and Song (1994), Holtz-Eakin and Selden (1995), Tucker (1995), Sengupta (1996), Roberts and Grimes (1997), Panayotou (1997), Shma-lenseeetal (1998), Galeotti and Lanza (1999), Agras and Chapman (1999), Auffhammer et al. (2000), Neumayer (2002), and Shi (2003).

Therefore, this paper considers other factors that affect greenhouse gas emissions, in addition to these macroeconomic variables. The first is economic growth. When the economy grows, so does the income level, too. Energy consumption increases with the income level. Higher energy consumption increases greenhouse gas emissions. In this study, real GDP was used as an indicator of economic growth. Real GDP has been regarded as an indicator of economic growth. Real GDP was derived from the nominal GDP divided by the producer price level. The producer price level of each year was derived from the benchmark level of 1 as of 2010, the reference year. The data of real GDP is from Economic Statistics System form Bank of Korea.

[Fig 4] Real GDP trends in Korea.

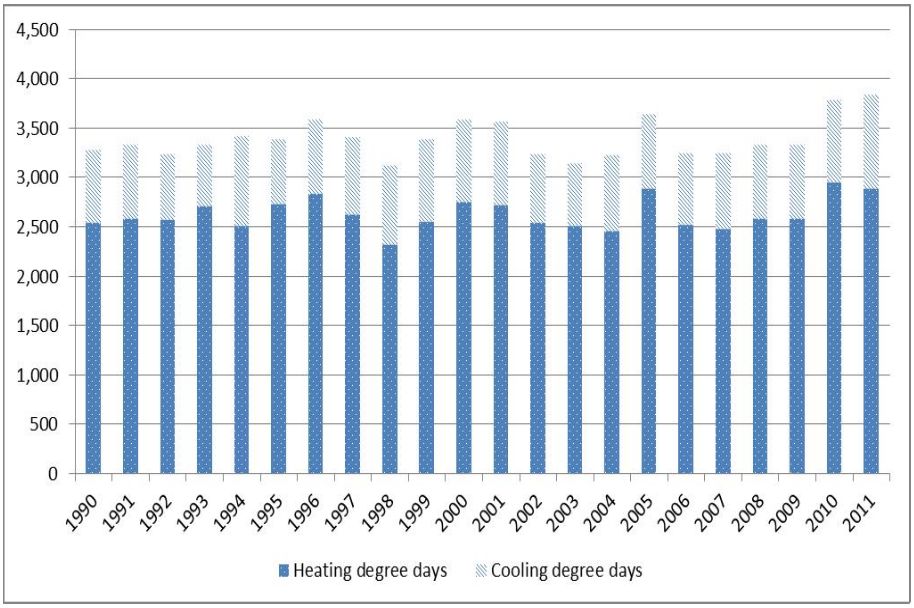


Source: Bank of Korea.

The second factor to be considered is weather. Temperature is one of important factors that determine energy consumption. Energy consumption for heating is expected to increase in cold weather. In modern society, energy consumption for air-conditioning is progressively increasing. Energy demand for air-conditioning and dehumidification is surging, especially in hot and humid weather. The short supply of electricity 2013 in Korea was due to the temporal shutdown of nuclear power plants as well as a rapid increase in electricity demand with an unexpected rise in temperature. The supply of heating and cooling equipment has increased with the improvement in living standards. This means temperature effects as a determinant of energy consumption have increased. Temperature effects are found in emissions especially from residential and commercial electricity, public electricity, and residential and commercial gas and oil used for heating and cooling.

Abnormally high temperatures caused by climate change play a vital, growing role in the increase of greenhouse gas emissions. We consider cooling degree-days (CDDs) and heating degree-days (HDDs) as temperature indexes. Although weather shows average temperature, HDD and CDD are better known as temperature indexes that explain energy consumption. [Fig. 5] shows HDD and CDD trends in Korea. The changes in HDD were greater than those in CDD. The data of CDD and HDD is obtained from Korea Energy Statistics Information System of Korea Energy Economics Institute.

[Fig 5] Heating and cooling degree day trends in Korea.

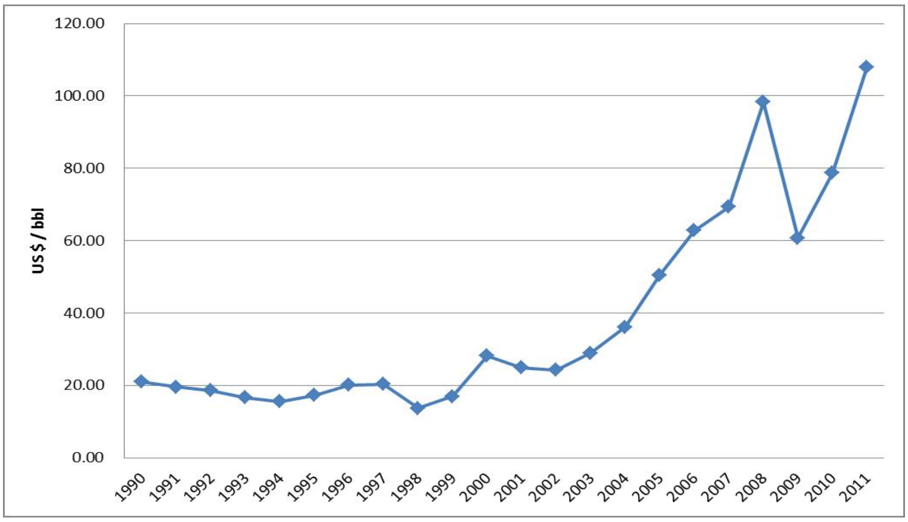


Source: Korea Energy Economics Institute.

The third factor is fossil fuel price. Depending on the price elasticity of fossil fuel, an increase in its price would reduce consumption, and in turn greenhouse gas emissions, by its substitution with other energy sources, mainly renewable energy. Although fossil fuels include oil, coal, and gas, oil price alone can represent fossil fuel price and tends to be linked to the price of other fuels. Therefore, this paper focuses on oil price, specifically the import price of crude oil (US$/barrel) obtained from the Yearbook of Energy Statistics of Korea Energy Economics Institute. As shown in Fig. 6, the import price of crude oil in Korea has increased over the years.

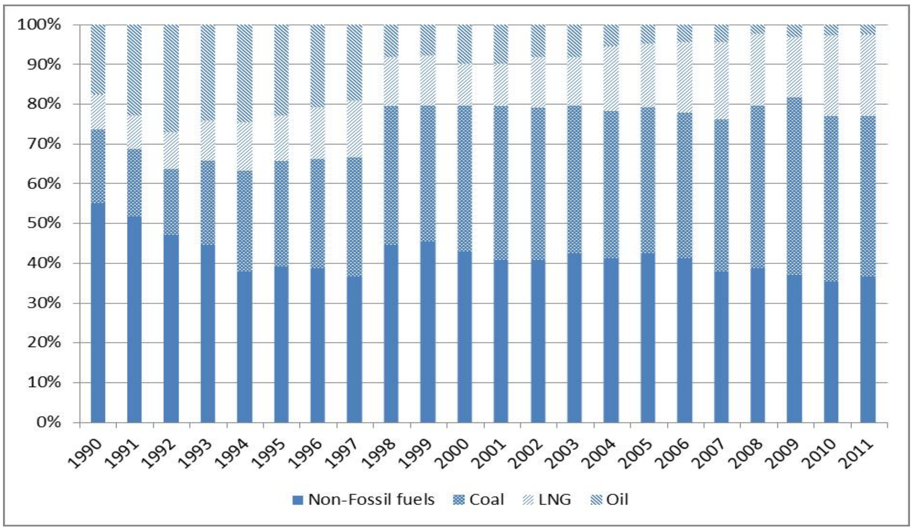
The fourth factor is the fuel mix in power generation. Greenhouse gas emissions are influenced by the fuel mix. Specifically, an increase in nuclear power generation has contributed to a mitigation of greenhouse gas emissions in Korea. Thus, the share of non-fossil fuels is linked to greenhouse gas emissions from the power sector. The share of non-fossil fuels obtained from the Yearbook of Energy Statistics of Korea Energy Economics Institute. The share of non-fossil fuels, including nuclear power, in 2011 was 36.74% of the total power generation. As shown in Fig. 6, the share of non-fossil fuels in power generation has decreased over the years. This indicates that the share of fossil fuels, especially the generation by coal has increased over the years because of cost effectiveness. The generation by LNG also has increased in recent days. Non-fossil fuel energy in power generation includes hydro, nuclear, renewable, and group and alternative energy. Greenhouse gas emissions would expectedly decrease with an increase in the share of these non-fossil fuels, and vice versa.

[Fig 6] Import price of crude oil in Korea.



Source: Yearbook of Energy Statistics, Korea Energy Economics Institute.

[Fig 7] The share of non-fossil fuel power generation in Korea.



Note: Non-fossil fuel energy sources in power generation are hydro energy, nuclear energy, renewable energy, group and alternative energy, and so on).

Source: Yearbook of Energy Statistics 2012, Korea Energy Economics Institute.

The econometric analysis used in this paper is based on the time series method. A unit root test is conducted to test whether these variables are stable. A unit root for a variable indicates that it is non-stationary (non-stationary data causes asymptotically biased coefficients in regression analysis). Through a cointegration test, we determine whether these variables have long-term equilibrium relationships. If they do, we find the causal relationships between the variables by various linear analysis techniques. This research used econometric methods such as VECM(Vector Error Correction Model), Fully Modified OLS (FMOLS) (Pedroni, 2001). Additionally, we conducted tests for heteroskedasticity, serial correlation, etc. This research focuses on short-run causal relationships as well as on long-term relationships between each variable that increase Korea's GHG emissions.

The econometric model of this research is as follows. We attempted to focus on two aspects: One, how does each variable affect gross GHG emissions? Two, how does each variable affect per capita GHG emissions. The rationale of the latter analysis is that it clearly reveals the GDP effects on GHG emissions. We exclude the population effects in the latter analysis because our focus is on the relationship between per capita GDP and per capita GHG emissions.

Equation 1 formulates the long run relationships for the gross GHG emissions and Equation 2, the per capita GHG emissions.

$$\ln E = \alpha_0 \ln G_t + \alpha_1 \ln O_t + \alpha_2 \ln M_t + \alpha_3 \ln N_t + \epsilon_t \qquad (1)$$

E is the natural log of gross GHG emissions, G is the natural log of GDP, O is the natural log of import price of crude oil, M is the natural log of heating and cooling degree days, N is the natural log of share of non-fossil fuels, ϵ_t is error term. Therefore, this is a log-log linear model. Each coefficient represents the change in the endogenous variable on a unit variation of each exogenous variable.

$$\ln e = \alpha_0 \ln g_t + \alpha_1 \ln O_t + \alpha_2 \ln M_t + \alpha_3 \ln N_t + \epsilon_t \tag{2}$$

Where e is the natural log of per capita GHG emissions, g is the natural log of per capita GDP.

If the time series are I (1) and these variables are cointegrated, we can use a panel vector error correction model (VECM) to estimate causality between these variables, suggested by Engel and Granger (1987). Finding a cointegrating relationship between of these variables is very important because an error correction mechanism exists according to which changes in the dependent variable are modeled as a function of the equilibrium in the cointegration relationship and changes in other explanatory variables. Equation (3) formulates VECM for the gross GHG emissions as in Johansen (1991). In this equation, the variables E, G and O are endogenous variables and variables M and N are strictly exogenous variables. In other words M and N variables does not affected by E, G and O because M is the weather condition variable and N is the policy variables.

$$\begin{aligned}
\Delta E_t &= c_1 + \gamma_{11}\epsilon_{1t-1} + \sum_{j=1}^{q}\gamma_{12j}\Delta E_{t-j} + \sum_{j=1}^{q}\gamma_{13j}\Delta G_{t-j} + \sum_{j=1}^{q}\gamma_{14j}\Delta O_{t-j} \\
&\quad + \gamma_{15}M_t + \gamma_{16}N_t + v_{1t} \\
\Delta G_t &= c_2 + \gamma_{21}\epsilon_{2t-1} + \sum_{j=1}^{q}\gamma_{22j}\Delta E_{t-j} + \sum_{j=1}^{q}\gamma_{23j}\Delta G_{t-j} + \sum_{j=1}^{q}\gamma_{24j}\Delta O_{t-j} \\
&\quad + \gamma_{25}M_t + \gamma_{26}N_t + v_{2t} \\
\Delta O_t &= c_3 + \gamma_{31}\epsilon_{3t-1} + \sum_{j=1}^{q}\gamma_{32j}\Delta E_{t-j} + \sum_{j=1}^{q}\gamma_{33j}\Delta G_{t-j} + \sum_{j=1}^{q}\gamma_{34j}\Delta O_{t-j} \\
&\quad + \gamma_{35}M_t + \gamma_{36}N_t + v_{3t}
\end{aligned}$$

(3)

Where Δ is the first difference operator, q is the lag length, ϵ is the error correction term, and v is the random error term. Equation (4) formulates VECM for the per capita GHG emissions.

$$\begin{aligned}
\Delta e_t &= c_1 + \gamma_{11}\epsilon_{1t-1} + \sum_{j=1}^{q}\gamma_{12j}\Delta e_{t-j} + \sum_{j=1}^{q}\gamma_{13j}\Delta g_{t-j} + \sum_{j=1}^{q}\gamma_{14j}\Delta O_{t-j} \\
&\quad + \gamma_{15}M_t + \gamma_{16}N_t + v_{1t} \\
\Delta g_t &= c_2 + \gamma_{21}\epsilon_{2t-1} + \sum_{j=1}^{q}\gamma_{22j}\Delta e_{t-j} + \sum_{j=1}^{q}\gamma_{23j}\Delta g_{t-j} + \sum_{j=1}^{q}\gamma_{24j}\Delta O_{t-j} \\
&\quad + \gamma_{25}M_t + \gamma_{26}N_t + v_{2t} \\
\Delta O_t &= c_3 + \gamma_{31}\epsilon_{3t-1} + \sum_{j=1}^{q}\gamma_{32j}\Delta e_{t-j} + \sum_{j=1}^{q}\gamma_{33j}\Delta g_{t-j} + \sum_{j=1}^{q}\gamma_{34j}\Delta O_{t-j} \\
&\quad + \gamma_{35}M_t + \gamma_{36}N_t + v_{3t}
\end{aligned}$$

(4)

Ⅲ. Result

1. Analysis of gross GHG emissions

First, model 1 was analyzed. We computed the augmented Dickey-Fuller statistic to test whether each variable is stable. For these tests, the null hypothesis is that a unit root is present while the alternative hypothesis is that it is not. The test shows that, in the case of levels, the variables E, O, and N have unit roots, but G (GDP) and M do not, at the 95% confidence interval (seeTable3). For the case of differences, as shown in Table4, the null hypothesis can not be rejected for all variables. Therefore, not all variables have unit roots in differences.

<Table 3> Test for unit root(level).

Variables	Augmented Dickey-Fuller test statistic	P-value*
GHG emissions (E)	-2.024	0.275
GDP (G)	-3.361	0.025
Import price of crude oil (O)	0.218	0.967
Heating and cooling degree days (M)	-3.457	0.021
Share of non-fossil fuels (N)	-2.758	0.082

Note: Null hypothesis: Each variable has a unit root.
 * MacKinnon(1996) one-sided p-values

<Table 4> Test for unit root(first difference)

Variables	Augmented Dickey-Fuller test statistic	P-value*
GHG emissions (E)	-4.137	0.005
GDP (G)	-3.605	0.015
Import price of crude Oil (O)	-4.022	0.007
Heating and cooling degree days (M)	-3.962	0.009
Share of non-fossil fuels (N)	-4.148	0.005

Note: Null hypothesis: Each variable has a unit root.
 * MacKinnon(1996) one-sided p-values.

Next, we performed Johansen cointegration tests check for any long-term stable relationship between the variables with unit roots (Johansen, 1988, 1991, 1992; Johansen and Juselius, 1990, 1992, 1994). Table 5 shows the results: the trace statistic, the maximum eigenvalue statistic, and P values. The trace test indicates five cointegrating equations at the 0.05 level, and the max-eigenvalue test identifies four cointegrating equations at the 0.1 level. Therefore, we can conclude that all variables have long-run stable cointegrating relationships.

<Table 5> Test for cointegration(level).

Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 Critical value	Prob.**
None *	0.833	103.689	69.819	0.000
At most 1 *	0.725	67.918	47.856	0.000
At most 2 *	0.669	42.102	29.797	0.001
At most 3 *	0.493	20.004	15.495	0.010
At most 4 *	0.275	6.432	3.841	0.011

Note: Trace test indicates five cointegrating equations at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level.
** MacKinnon-Haug-Michelis(1999) p-values.

Unrestricted cointegration rank test (maximum eigenvalue)				
Hypothesized no. of CE(s)	Eigenvalue	Max-eigen statistic	0.05 Critical value	Prob.**
None *	0.833	35.771	33.877	0.029
At most 1 *	0.725	25.816	27.584	0.083
At most 2 *	0.669	22.098	21.132	0.037
At most 3 *	0.493	13.572	14.265	0.064
At most 4 *	0.275	6.432	3.841	0.011

Note: Max-eigenvalue test indicates one cointegrating equation at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level.
** MacKinnon-Haug-Michelis(1999) p-values.

As shown above, these models can be analyzed by FMOLS on their long-term aspects since these variables are cointegrated, although some variables have unit roots. This paper considered four models to analyze gross GHG emissions. The FMOLS regression results on long-term equilibrium relationships (see Table 6) show how each variable can affect gross GHG emissions. Model 1 used (GDP), (import price of crude oil), (heating and cooling degree days), and (share of non-fossil fuels) as the exogenous variables. The exogenous variables used were in

Model 2, in Model 3, and in Model 4. We can verify, using different combinations of variables, the effects of each variable. However, this study focuses on Model 1, because the coefficients of all variables in the model are statistically significant. Specifically, the variables are significant at the 95% confidence interval. The result of Breusch-Godfrey serial correlation LM test shows no serial correlation. GDP has the largest effect on gross GHG emissions. This is followed by heating and cooling days. According to the results of this research, a 1% increase in GDP and in heating and cooling degree days raises gross GHG emissions by 0.598% and 0.463%, respectively. In contrast, the share of non-fossil fuels and the import price of crude oil have a reducing effect on gross GHG emissions in Korea. A 1% increase in the share of non-fossil fuels and in the import price of crude oil reduces gross GHG emissions by 0.162% and 0.017%, respectively. However, the GHG reduction effects of the import price of crude oil is minimal, considering that the coefficients of the import price are extremely low, although statistically significant.

<Table 6> Estimated models of gross GHG emissions(FMOLS).

Variables	Model 1 (E,G,O,M,N)		Model 2 (E,G,O,M)		Model 3 (E,G,O,N)		Model 4 (E,G,M,N)	
	Coefficient	Std. rror	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
GDP (G)	0.598***	0.021	0.658***	0.028	0.552***	0.041	0.561***	0.015
Import price of Crude Oil (O)	-0.017*	0.009	-0.034**	0.015	0.003	0.018		
Heating and cooling degree days (M)	0.463***	0.065	0.597***	0.099			0.410***	0.069
Share of non-fossil fuels (N)	-0.162***	0.050			-0.313***	0.095	-0.202***	0.054
R-squared	0.990		0.987		0.980		0.989	
Durbin-Watson d statistic	1.799		1.832		1.073		1.355	

The above analysis considers both heating degree days and cooling degree days. However, the effects of the heating degree days and cooling degree days are expectedly different. Therefore, two additional analyses were added to this research. <Table 7> shows the results on heating degree days and Tables 8 on cooling degree days. From the FMOLS analysis, the coefficient of heating degree days is 0.333, as shown in <Table 7>, and that of cooling degree days is 0.155, as shown in <Table 8>. These results show that heating degree days affect GHG emissions in Korea more than cooling degree days do. This result is consistent with the common understanding that energy consumption is greater on heating degree days than on cooling degree days.

<Table 7> Estimated models of gross GHG emissions(FMOLS).

	(E,G,O,MH,N)		(E,G,O,MH)		(E,G,MH, N)	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
GDP (G)	0.588***	0.028	0.666***	0.037	0.560***	0.019
Import price of crude oil (O)	-0.012	0.012	-0.033	0.019		
Heating degree days (MH)	0.333***	0.080	0.484***	0.120	0.298***	0.079
Share of non-fossil fuels (N)	-0.203***	0.066			-0.231***	0.068
R-squared	0.988		0.983		0.980	
Durbin-Watson d statistic	1.242		1.580		1.002	

<Table 8> Estimated models of gross GHG emissions(FMOLS).

	(E,G,O,MC,N)		(E,G,O,MC)		(E,G,MC, N)	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
GDP (G)	0.562***	0.032	0.649***	0.042	0.551***	0.021
Import price of crude oil (O)	-0.003	0.014	-0.022	0.021		
Cooling degree days (MC)	0.155***	0.050	0.201**	0.072	0.154***	0.050
Share of non-fossil fuels (N)	-0.256***	0.078			-0.264***	0.077
R-squared	0.983		0.976		0.983	
Durbin-Watson d statistic	2.004		1.639		1.954	

<Table 9> shows the results of VECM models in equation (3). shows the error correction terms and statistically significant at a 1% level. In the short run, GDP, Heating and Cooling degree days, and the share of non-fossil fuels clearly affected on GHG emissions. The coefficients of Heating and Cooling degree days and share of non-fossil fuels are 0.62 and -0.38 and statistically significant at a 1% level. GDP also increases on the GHG emissions in the short run and statistically significant at a 1% level. But the oil price did not affected on the GHG emissions in the short run because the coefficient is negative but is not statistically significant.

<Table 9> The short-run Dynamics of gross GHG emissions(VECM).

	Coefficient	Std. Error		Coefficient	Std. Error		Coefficient	Std. Error
c_1	-0.80	0.86	c_2	-0.88	1.52	c_3	-7.42**	4.09
γ_{11}	0.58***	0.17	γ_{21}	0.73***	0.30	γ_{31}	-1.10	0.79
γ_{121}	-2.31***	0.57	γ_{221}	-2.19**	1.01	γ_{321}	-4.84*	2.70
γ_{122}	-1.57***	0.48	γ_{222}	-1.37	0.84	γ_{322}	-3.18	2.26
γ_{131}	1.61***	0.41	γ_{231}	1.55**	0.72	γ_{331}	3.86*	1.94
γ_{132}	1.19***	0.38	γ_{232}	1.01	0.67	γ_{332}	2.02	1.81
γ_{141}	0.03	0.06	γ_{241}	0.04	0.10	γ_{341}	0.00	0.28
γ_{142}	0.06	0.05	γ_{242}	0.11	0.08	γ_{342}	-0.07	0.23
γ_{15}	0.62***	0.17	γ_{25}	0.47	0.30	γ_{35}	2.28*	0.80
γ_{16}	-0.38***	0.13	γ_{26}	-0.21	0.23	γ_{36}	-0.16	0.60
R-squared	0.84		R-squared	0.58		R-squared	0.80	

2. Analysis of per capita GHG emissions

First, the augmented Dickey-Fuller statistic was computed to test whether each variable is stable. As shown in Table 10, in the case of levels, this test shows that variable E (gross GHG emissions), O (import price of crude oil), and N (share of non-fossil fuels) have unit roots but G (GDP) and M (heating and cooling degree days) have no unit root at the 95% confidence interval. In the case of differences, the null hypothesis can be rejected for all variables, as shown in <Table 11>. Therefore, not all variables have unit roots in differences.

<Table 10> Test for unit root(level).

Variables	Augmented Dickey-Fuller test statistic	P-value*
GHG emissions (e)	-1.996	0.286
GDP (g)	-3.233	0.032
Import price of crude oil (O)	0.218	0.967
Heating and cooling degree days (M)	-3.457	0.021
Share of non-fossil fuels (N)	-2.758	0.082

Note: Null hypothesis: Each variable has a unit root.
* MacKinnon(1996) one-sided p-values.

<Table 11> Test for a unit root(first difference).

변수	Augmented Dickey-Fuller test statistic	P-value*
GHG emissions (E)	-4.250	0.004
GDP (G)	-3.708	0.012
Import price of crude oil (O)	-4.022	0.007
Heating and cooling degree days (M)	-3.962	0.009
Share of non-fossil fuels (N)	-4.148	0.005

Note: Null hypothesis: Each variable has a unit root.
* MacKinnon(1996) one-sided p-values.

<Table 12> Test for cointegration(level)

Unrestricte cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 Critical value	Prob.**
None *	0.849	106.135	69.819	0.000
At most 1 *	0.722	68.370	47.856	0.000
At most 2 *	0.657	42.742	29.797	0.001
At most 3 *	0.500	21.317	15.495	0.006
At most 4 *	0.312	7.466	3.841	0.006

Trace test indicates five cointegrating equation at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis(1999) p-values.

Unrestricted cointegration rank test (maximum eigenvalue)				
Hypothesized no. of CE(s)	Eigenvalue	Max-eigen statistic	0.05 Critical value	Prob.**
None *	0.849	37.765	33.877	0.016
At most 1	0.722	25.628	27.584	0.087
At most 2 *	0.657	21.426	21.132	0.046
At most 3	0.500	13.851	14.265	0.058
At most 4 *	0.312	7.466	3.841	0.006

Max-eigenvalue test indicates one cointegrating equation at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis(1999) p-values.

We performed a cointegration test to check for long-term stable relationships between these variables. The trace test result indicates five cointegrating equations at the 0.05 level. Therefore, all variables have long-run stable cointegrated relationships.

As shown in <Table 12>, the long-term aspects of these models can be analyzed by FMOLS since these variables are cointegrated, although some variables have unit roots. This paper considered four models for the analysis of per capita GHG emissions. <Table 13> shows the FMOLS regression results on long-term equilibrium relationships among variables based on per capita GHG emissions.

Model 1 used GDP, import price of crude oil, heating and cooling degree days, and share of non-fossil fuels as the exogenous variables. The exogenous variables in other models were in Model 3, in Model 4. This analysis is based on Model 1.

This is because the coefficients of each variable in Model 1 are statistically significant. Specifically, the variables are significant at the 99% confidence interval. The Breusch-Godfrey serial correlation LM test shows no serial correlation. GDP has the largest effect on per capita GHG emissions. This is followed by heating and cooling days. According to this research, a 1% increase in GDP and in heating and cooling degree days raises per capita GHG emissions by 0.539% and 0.445%, respectively. In contrast, the share of non-fossil fuels and the import price of crude oil have a reducing effect on per capita GHG emissions. A 1% increase in the share of non-fossil fuels and in the import price of crude oil decreases per capita GHG emissions by 0.019% and 0.191%, respectively. However, the GHG reduction effects of the import price of crude oil is minimal, considering that its coefficient is extremely low, although statistically significant.

<Table 13> Estimated models of per capita GHG emissions(FMOLS)

	Model 1 (e, g, O, M, N)		Model 2 (e, g, O, M)		Model 3 (e, g, O, N)		Model 4 (e, g, M, N)	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
GDP (G)	0.539***	0.021	0.610***	0.029	0.487***	0.040	0.501***	0.015
Import price of crude oil (O)	-0.019**	0.008	-0.036**	0.013	0.003	0.015		
Heating and cooling degree days (M)	0.445***	0.059	0.587***	0.090			0.377***	0.063
Share of non-fossil fuels (N)	-0.191***	0.046			-0.341***	0.083	-0.231***	0.050
R-squared	0.986		0.981		0.971		0.984	
Durbin-Watson d statistic	1.895		1.851		1.144		1.327	

<Table 14> shows the results of VECM models in equation (4). shows the error correction terms and statistically significant at a 1% level. In the short run, the coefficients of Heating and Cooling degree days and share of non-fossil fuels are 0.60 and -0.38 and statistically significant at a 1% level. GDP also increases on the GHG emissions in the short run and statistically significant at a 1% level. But the oil price did not affected on the GHG emissions in the short run because the coefficient is negative but is statistically insignificant.

<Table 14> The short-run Dynamics of per capita GHG emissions (VECM)

	Coefficient	Std. Error		Coefficient	Std. Error		Coefficient	Std. Error
c_1	-0.74	0.85	c_2	-0.80	1.51	c_3	-7.39*	4.16
γ_{11}	0.32 ***	0.09	γ_{21}	0.42***	0.17	γ_{31}	-0.66	0.46
γ_{121}	-2.08***	0.52	γ_{221}	-1.92**	0.93	γ_{321}	-5.32**	2.56
γ_{122}	-1.42***	0.46	γ_{222}	-1.17	0.82	γ_{322}	-3.53	2.26
γ_{131}	1.44***	0.38	γ_{231}	1.34*	0.68	γ_{331}	4.18**	1.87
γ_{132}	1.07***	0.37	γ_{232}	0.86	0.66	γ_{332}	2.24	1.83
γ_{141}	0.04	0.06	γ_{241}	0.04	0.10	γ_{341}	0.02	0.28
γ_{142}	0.06	0.05	γ_{242}	0.10	0.08	γ_{342}	-0.05	0.23
γ_{15}	0.60***	0.17	γ_{25}	0.44	0.29	γ_{35}	2.31***	0.81
γ_{16}	-0.38***	0.12	γ_{26}	-0.20	0.22	γ_{36}	-0.20	0.61
R-squared	0.84		R-squared	0.58		R-squared	0.80	

Ⅳ. Conclusion

This paper conducted a long-term time series econometric analysis of Korea's GHG emissions by FMOLS and VECM. The analysis focused on two aspects: gross GHG emissions and per capita GHG emissions. The two analyses yield similar results even though the specific coefficients have different values. GDP has the largest effect on gross GHG emissions. It is followed by heating and cooling days. The share of non-fossil fuels and the import price of crude oil have reducing effects on gross GHG emissions. As regards per capita GHG emissions, the analysis results have similar patterns. The largest effects on per capita GHG emissions are from GDP, followed by heating and cooling days. Again, the share of non-fossil fuels and the import price of crude oil have reducing effects on per capita GHG emissions.

Overall, GHG emissions in Korea are affected by economic growth and weather conditions. Therefore, a pattern of economic growth that mitigates GHG emissions should be preferred. What we need for this is an industrial restructuring that brings about a reduction in the share of GHG-intensive industries and an increase in the share of service industries.

The reason that the weather condition affected a lot on greenhouse gas emissions, is because of energy demand on heating and cooling. Therefore, low-carbon energy for heating and cooling is needed to mitigate the greenhouse gas emissions. That requires strengthening energy efficiency for buildings, the lower the electricity dependence in the heating and cooling energy. The recent increase of electricity use for heating and cooling has brought the increase of greenhouse gas emissions in this sector. Despite the electricity is not suitable in particular for heating because of a lot of loss in the transmission and distribution process, the electricity use for heating has been increased recently. In order to encourage voluntary energy use reduction in household sector, it is also needed to introduce market-oriented energy trading mechanism.

Korea should also switch to non-fossil fuels by promoting renewable energy and inducing energy saving through a reasonable energy price and tax structure. In addition, the renewable energy sources alone are not enough. The energy mix will evolve slowly as older investments in plant and equipment are retired, but environmental needs are urgent. Korea needs its new conventional power plants to be cleaner and more efficient. Emerging technologies make carbon-based fuels cleaner to use. Carbon capture and storage has potential to lower CO_2 emissions, and Korea should continue investing in this technology. International cooperation can be needed to hasten progress these technology.

접수일(2015년 8월 31일), 수정일(2015년 11월 17일), 게재확정일(2015년 11월 22일)

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요약

한국의 온실가스 증가요인 분석

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한국의 온실가스 배출량을 증가시키는 주요 장기요인에 대하여 FMOLS, VECM 방법론을 통해 분석하였다. 온실가스 배출량을 증가시키는 주요 요인으로는 GDP, 냉난방도일이 고려되었으며, 감소시키는 주요 요인으로는 비화석연료의 비중, 원유의 수입가격 등을 고려하였다. 본 분석은 총배출량과 일인당 배출량 두 가지 측면에서 분석되었다. 먼저 총배출량의 경우에 우리나라의 온실가스 배출량 증가는 GDP에 의해 가장 큰 영향을 받았으며, 그 다음으로는 날씨 요인인 냉난방도일(Heating and Cooling Degree Days)이 가장 큰 양향을 미쳤다. 온실가스 배출량에 미치는 영향은 냉방도일보다는 난방도일에 의해 더 큰 영향을 받는다. 비화석연료의 비중과 원유의 수입가격은 온실가스 배출을 감축하는데 중요한 요인으로 작용하였다. 일인당 배출량의 경우에도 총배출량과 비슷한 패턴을 보이고 있다. GDP가 일인당 GDP증가에 가장 큰 영향을 미쳤으며, 냉난방도일이 그 다음으로 큰 영향을 미쳤다.

주제어 : 온실가스 배출량, FMOLS, GDP, 냉난방도일

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