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An Analysis of CO_2 Emission Structures of the APEC Economies: Implications for Mitigation Policies and Regional Cooperation

Kihoon Lee and Wankeun Oh

KOREA INSTITUTE FOR
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Kihoon Lee** and Wankeun Oh***

Key Words: APEC, CO_2 Emission, Decomposition, Divisia.

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** Department of Economics, Chungnam National University
Tel: +82-42-821-5527, Fax: +82-42-823-5359, Email: khl@cnu.ac.kr
*** Department of Economics, Hannam University
Tel: +82-42-629-8052, Fax: +82-42-672-7602, Email: wanoh@mail.hannam.ac.kr

Executive Summary

We examined historical contributions of inter fuel substitution, changes in carbon efficiency and energy intensity, growth of economy and population to the APEC countries' CO_2 emissions from 1980 to 1998 using a perfect decomposition approach. We also investigated whether or not CO_2 emissions in the member countries are increasing by using new criteria suggested by Sun (2000). By adopting log mean Divisia method, we explained the causes of the differences of both the total and per capita CO_2 emissions between the income groups of APEC countries.

The study reveals that economic growth (i.e. per capita income growth) is the most significant factor for CO_2 emissions growth in most countries other than Russia, Peru, and the Philippines.Population growth is another important factor that contributes CO_2 emissions growth in all countries but Russia.

Changes in the energy intensity, fuel substitution, and carbon coefficient may be classified as negative contributors to CO_2 emissions growth. Enhanced energy intensity played an especially dominant role in halting CO_2 emissions growth in developed countries. In some less-developed countries, however, this factor played reversed role.

If the effect of per capita income growth was set aside, many countries achieved negative growth rate of CO_2 emissions. Advanced countries like the USA, Japan and Canada achieved more than 1% average annual decrease rate. This emission decrease is explained by improvement of energy efficiency. In most developing countries, however, they could not improve energy efficiency except China, which recorded considerable success in enhancing energy intensity.

In the income group comparison, per capita income effect explains the higher emission level in advanced countries than in the developing countries. Meanwhile other factors contributed to narrow the emission gaps between the groups. Above all, the higher energy efficiency in advanced economies is the most outstanding factor to decrease the gaps.

Based on the findings of this analysis, we may draw implications on policy options for CO_2 emissions mitigations and find ways to strengthen environmental cooperations among APEC member economies. Developing countries need to accelerate substitutions of fossil fuels to CO_2 free or less CO_2 intensive fuels, to enhance carbon emissions

efficiency, and to improve energy efficiency. Improving energy efficiency through various measures will yield desirable results. Controlling population growth in low income countries is also an essential factor in checking rapid CO_2 emissions growth.

In achieving emissions mitigation in developing countries, environmental cooperation among APEC member countries is essential. Developed countries need to transfer adequate technology and to finance to less-developed countries in enhancing clean and sustainable energy and economic development. To this purpose, APEC countries need to actively utilize the Kyoto Mechanism, which is Joint Implementation (JI), Clean Development Mechanism (CDM), and International Emissions Trading (IMT). The Prototype Carbon Fund to be operated by the World Bank may be a good source to expand such investment to the developing countries.

Among APEC economies, we find there exist large carbon credit suppliers and buyers. Most developing countries including China, Malaysia, Indonesia, Viet Nam, Peru, and Thailand are found to have very large potential to provide carbon credits. The USA, Japan, and Canada have to buy carbon credits to meet their commitments to the Kyoto Protocol. In that sense, their activating intra-regional trading of carbon credits in the International Emissions Trading Regime proposed by the Kyoto Protocol is recommended. It may be conceivable to form an environmental bubble like the Umbrella Group that includes the USA, Japan, Russia, Canada, Australia, New Zealand, others.

Dr. Kihoon Lee is an economics professor at Chungnam National University, who earned his Ph. D. in Economics from the Texas A&M University (1997). His specialty is environment and natural resource economics. He is especially interested in climate change issues. Contact: Department of Economics, Chungnam National University, Taejon 305-764, South Korea. Tel: +82-42-821-5527, Fax: +82-42-823-5359, Email: khl@cnu.ac.kr

Dr. Wankeun Oh is assistant professor of Economics Department, Hannam University. He earned his Ph. D. in Economics from the Texas A&M University (1996). He was associate research fellow at the First Finance Research Institute (1996-1997) and worked at the Korea Energy Economics Institute as research associate fellow (1997-1998). Contact: Department of Economics, Hannam University, Taejon 306-791, South Korea. Tel: +82-42-629-8052, Fax: +82-42-672-7602, Email: wanoh@mail.hannam.ac.kr

Contents

Tables

Figures

I. Introduction

Asia Pacific Economic Cooperation (APEC) includes 6 of the world's 10 largest carbon emitters in 1998: the USA, China, Russia, Japan, Canada, and South Korea. As a group, the APEC countries accounted for over half of world energy use by consuming 220 quadrillion Btu (quads) of energy in 1998. APEC countries emitted 3,450 million metric tons of carbon (MMTC) in 1998. CO_2 emissions in the APEC countries have increased faster than any other region due to its member countries' fast economic growth.

This trend of rapid CO_2 emission growth should be halted as UNFCCC and Kyoto Protocol explicitly or implicitly urge APEC member countries to mitigate Greenhouse Gas (GHG) emissions. Indeed, some APEC member countries such as the USA, Canada, Japan, New Zealand, Australia and Russia, committed to reduce their GHG emissions to target level by 2008-2012. Global movement to abate GHG emissions is to accelerate as the UNFCCC negotiation develops further.

The goal of this study is to examine the CO_2 emissions structure of member countries and seek appropriate mitigation policies and regional cooperation. We postulate that there will be very large potential for members to cooperate since APEC has a broad spectrum of energy-environment-economy situations: the stages and patterns of economic development, population growth, energy consumption, emission technology, etc. The views and positions towards climate change and directions of the UNFCCC among APEC member economies vary substancially. As an example, the USA and five other countries belong to the Annex I countries while China is leader of the Group 77/China, who use to stand opposite the position of Annex I at the UNFCCC negotiation table. Singapore and Papua New Guinea are members of the Alliance of Small Island States (AOSIS), countries which are the most vulnerable to climate change.

We first analyze historical contributions of inter fuel substitution, changes in carbon efficiency and energy intensity, economic growth and population to the APEC countries' CO_2 emissions from 1980 to 1998. Next, we judge whether or not CO_2 emissions in the member countries are decreasing. We adopt new criteria for this judgment. Finally, we find the causes of the differences of CO_2 emissions between the groups of APEC countries. Based on this analysis, we draw implications for mitigation policies and measures for member countries. we also find directions for cooperation among members in mitigating CO_2 emissions.

II. Economic Growth, Energy Consumption, and CO_2 Emissions

1. The APEC Economies and the UNFCCC

As a group, Asia-Pacific Economic Cooperation (APEC) economies account for over half of world energy production and consumption. In 1998, APEC consumed 220 quadrillion Btu of energy and produced 203 quads, making it a net energy importer of 17 quads.

There were six of the world's ten largest carbon emitters among the APEC members in 1998: the United States at 1,495 million metric tons; China at 740 million metric tons; Russia at 405 million metric tons; Japan at 288 million metric tons; Canada at 139 million metric tons; South Korea at 108 million metric tons.

Under the Kyoto Protocol, the United States, Canada and Japan committed to reduce its carbon emissions 7%, 6%, 6% below 1990 levels by 2008-2012 respectively. Even though its emissions dropped sharply since 1992 due to its deteriorating economic situation, Russia is allowed to emit up to the 1990 level by 2008-2012. As developing countries in APEC belong to the non-Annex I group, they have no obligation to reduce emissions so far. Singapore and Papua New Guinea (PNG) belong to the Alliance of Small Island States (AOSIS), representing countries at risk of losing territories to rising sea levels due to climate change.

Carbon emissions in most APEC countries have been increased continuously. The United States carbon emissions have continued to rise steadily since 1990 and expected to rise. Owing to heavy use of carbon-intensive coal and rapid GDP coupled with population growth, China is expected to surpass the USA to become the world's largest carbon emitter by 2020 even though its carbon consumption per GDP have been decreasing dramatically. South Korea became the top ten world carbon emitters owing to the dramatic economic growth throughout the 1980s and 1990s.

16 of Among the 21 APEC economies were selected for our analysis. Hong Kong, Singapore, PNG, and Brunei are excluded because they are small countries. Chinese Taipei is not included because it is small and not an UNFCCC member country. <Table 2> contains the data for energy consumption and CO_2 emissions in 16 countries. All country data run from 1980 to 1998 except Viet Nam (1983-1998) and Russia (1992-1998). The source of the data is the National Energy Information Center, Department of Energy, USA, Internet sit

http://www.eia.doe.gov/emeu/international/energy.html.

<Table 1> Key Indicators of APEC Members Economies (1998)

Member Economy	Area (Sq km)	Population (Million)	GDP (Billion US$)	GDP Per head (US$)	Visible Exports (Bil $, fob)	Visible Imports (Bil $, fob)
Australia	7,682	18.3	394	20,650	64.9	63.0
Brunei Darussalam	5.8	0.31	5	17,246	2	4
Canada	9,971	30.3	608	19,640	217.4	199.9
Chile	757	14.62	77	4,820	16.9	18.2
China	9,561	1,244.2	902	860	182.7	136.4
Hong Kong, China	1	6.5	163.8	25,200	188.1	209.2
Indonesia	1,919	203.4	221.5	1,110	56.3	46.3
Japan	378	126	4,812.1	38,160	409.2	307.6
Korea	99	45.7	485.2	10,550	138.6	141.8
Malaysia	333	21.0	98.2	4,530	77.9	40
Mexico	1,973	94.3	348.6	3,700	110.4	109.8
New Zealand	271	3.8	59.5	15,830	13.9	13.9
Papua New Guinea	453	4.21	5	946	3	2
Peru	1,285	24.4	63.7	2,610	6.8	8.6
Philippines	300	71.4	88.4	1,200	25.2	36.4
Russia	17,075	147.7	349.9	2,680	88.9	71.4
Singapore	1	3.4	101.8	32,810	125.8	124.6
Chinese Taipei	36	21.7	283.4	13,060	121.7	107.8
Thailand	513	59.7	165.8	2,740	56.7	55.1
USA	9,373	271.8	7,783	29,080	681.3	877.3
Viet Nam	325	76.55	26	335	9	14

Source: http://www.apecsec.org.sg

<Table 2> Energy Consumption and CO_2 Emissions from Energy Consumption (APEC: 1998)

Country	CO_2 Emissions (MMTC)	ENERGY Consumption (QBtu)	Energy Intensity (MBtu/$)	Per GDP CO_2 Emissions (TC/000$)	Fossil Fuel Share in total Energy Consumption	CO_2 Emissions Coefficient (TC/Mbtu)	Per capita Energy consumption (MBtu)	Per Capita CO_2 consumptions (TC)
USA	1494.6	94.79	13.41	211.4	0.85	18.54	0.35	5.53
Japan	288.48	21.28	6.55	88.8	0.79	17.15	0.17	2.28
Canada	138.46	11.85	17.54	205	0.67	17.53	0.39	4.57
Australia	83.40	4.30	11.46	222.1	0.95	20.30	0.23	4.45
China	740.38	33.93	39.10	853.3	0.94	23.31	0.03	0.59
Russia	405.04	25.99	74.19	1156.4	0.90	17.24	0.18	2.76
Chile	14.29	0.91	16.63	261.5	0.83	19.05	0.06	0.96
Indonesia	67.82	3.62	22.96	430.6	0.97	19.38	0.02	0.33
Malaysia	28.11	1.74	24.74	400.7	0.98	16.50	0.08	1.31
Korea	107.51	6.93	17.91	277.8	0.87	17.79	0.15	2.32
Mexico	95.02	5.92	17.72	284.3	0.92	17.41	0.06	0.95
New Zealand	8.68	0.79	15.09	166.7	0.34	32.68	0.21	2.29
Thai	42.67	2.34	19.29	351.4	0.97	18.85	0.04	0.7
Philippines	17.72	1.08	19.74	324.7	0.81	20.28	0.01	0.24
Peru	7.29	0.53	10.81	149.4	0.73	19.00	0.02	0.29
Viet Nam	12.25	0.74	61.03	1015.7	0.75	22.30	0.01	0.16

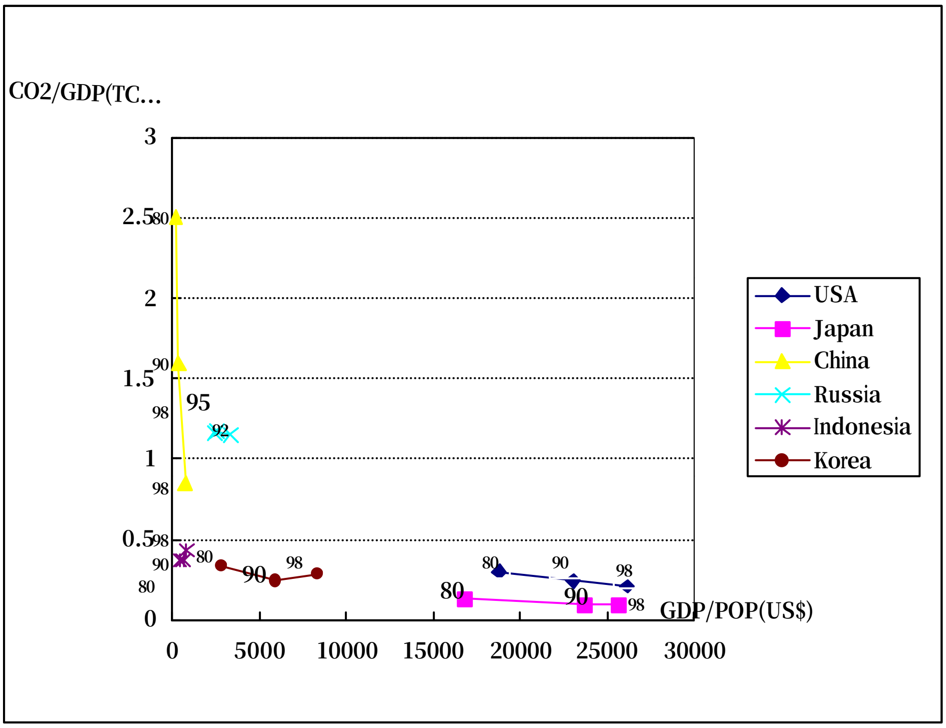
2. The Relationship between the Environment and Economic growth

This section investigates the relationship between economic development and emission performance using both a cross section and a time series approach. <Figure 1> compares (i) CO_2 emissions efficiency (CO_2 emission per dollar of GDP), and (ii) GDP per capita for three distinct country groups: (USA and Japan as developed, high income, countries, Korea and Russia as middle income, China and Indonesia as low income developing countries for the year 1980, 1990, and 1998)

The distribution pattern in the figure shows developed countries tend to exhibit relatively high per capita incomes and a low level of CO_2 emissions per unit of GDP (high efficiency) while developing countries display the opposite pattern : low per capita incomes and high level of CO_2 emissions per unit of GDP (low efficiency).

A time series analysis from 1980 to 1998 shows CO_2 emission efficiencies improved in USA and Japan being accompanied by big income growth. China made remarkable progress in CO_2 emissions efficiency during the same period. Both Indonesia and Russia have shown deteriorated performance.

<Figure 1> Economic Growth and CO_2 Emissions

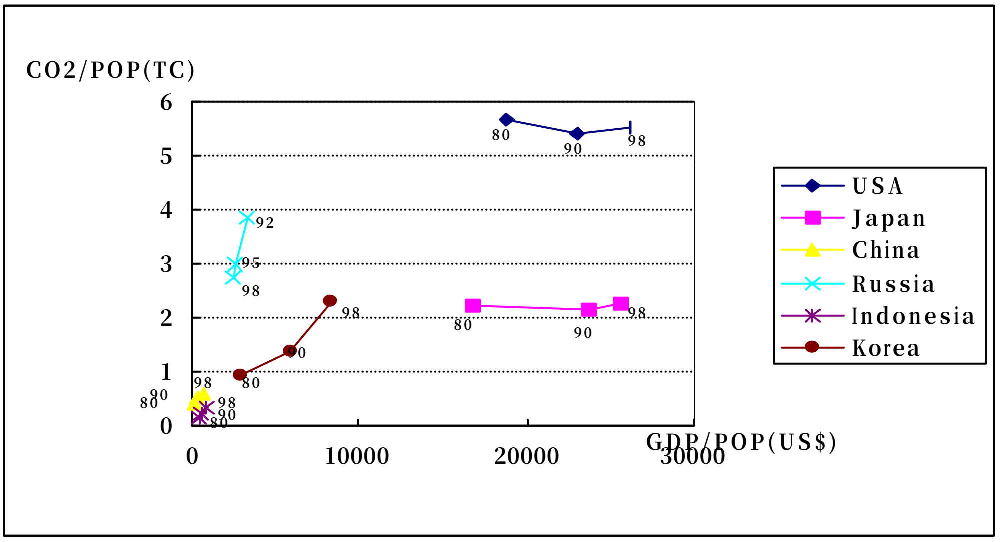


<Figure 2> compares (i) per capita CO_2 emissions, and (ii) GDP per capita for the same three distinct country groups (USA and Japan as developed, high income countries; Korea and Russia as middle income; China and Indonesia as low income, developing countries) for the years 1980, 1990, and 1998.

We note that capita GDP and per capita CO_2 emissions are positively related. Advanced economies like the USA and Japan are in the upper right, while low income countries are located in the lower left part of the figure. People in rich country consume more energy, and thus pollute more than poor people.

Almost all the dots are upward sloping from 1980 to 1998 except in developed countries. As income rises, so do energy consumption and CO_2 emissions. CO_2 emissions per capita, however, did not rise in Japan and the USA. It may be that energy consumption and CO_2 emissions per person have reached the saturation level.

<Figure 2> GDP and CO_2 Emissions per Capita



III. An Analysis of CO_2 Emissions in APEC economies

1. Breakdown of the CO_2 Emissions Changes

The Model

Among the many factors affecting CO_2 emissions, we select five : carbon coefficient, share of fossil fuel consumption in total energy consumption, energy intensity, per capita GDP and population. First, we analyze the historical contributions of changes in these factors (improved carbon emissions efficiency, inter-fuel substitution, changes in energy intensity, economic growth, and population growth) to the APEC countries' CO_2 emissions between 1980 and 1998.

As in Zhang (2000), a perfect decomposition method is applied. CO_2 emissions in a country can be decomposed as follows:

$$E = (\frac{E}{FEC}) \cdot (\frac{FEC}{TEC}) \cdot (\frac{TEC}{GDP}) \cdot (\frac{GDP}{POP}) \cdot POP \qquad (1)$$

where, E is the amount of CO_2 Emissions, FEC is the Fossil fuel Energy Consumption (coal, natural gas, petroleum), TEC is the Total primary Energy Consumption, GDP is the Gross Domestic Product, and POP is the Population.

By taking logs and differences over time, we have

$$\begin{aligned} \Delta \log E = \Delta \log(E/FEC) + \Delta \log(FEC/TEC) + \Delta \log(TEC/GDP) \\ + \Delta \log(GDP/POP) + \Delta \log(POP). \end{aligned} \qquad (2)$$

Thus, the changes in the total CO_2 emissions are sum of (i) the changes in Carbon coefficient, $\Delta \log(E/FEC)$, the Coefficient Effect C_{eff}, (ii) the changes in the share of fossil fuel, $\Delta \log(FEC/TEC)$, the Substitution Effect S_{eff} , (iii) the changes in the energy intensity, $\Delta \log(TEC/GDP)$, the Intensity Effect I_{eff} , (iv) the growth in the per capita GDP, $\Delta \log(GDP/POP)$, the Per capita GDP Effect G_{eff} , (v) the expansion of population, $\Delta \log(POP)$, the Population Effect P_{eff} . This perfect decomposition method is perfect because it yields no residuals.

The calculation method of each effect for the APEC as a group is explained in the appendix.

The Results

<Table 3> shows the results of the decomposition of the CO_2 emissions in the 16 APEC countries for the period 1980-1998. This clearly identifies the relative importance of each factor for CO_2 emissions changes.

During the same period, most countries experienced an increase of CO_2 emissions. China showed the biggest increase with 347.35 MTC. The USA ranked second with 203.79 MTC. Korea, Malaysia, and Indonesia followed them. Russia is the only country whose CO_2 emissions decreased (by 164.88 MTC) due to economic decline. As a group, CO_2 emissions in 15 APEC economies increased by 846.3 MTC from 1980 to 1998. The amount falls to 681.4 MTC if Russia is included.

Among the five factors, increase of per capita GDP and population are the two dominant contributors to the larger CO_2 emission for all countries except for Peru and Russia. The former factor alone contributed 1414.4 MTC while the latter contributed 517.3 MTC. These two factors contributed as much as 1,931.7 MTC to CO_2 emission growth. This pattern was profound in China and the USA.

By contrast, other factors like fuel substitutions, improved CO_2 emission efficiencies, and lower energy intensities reduced CO_2 emissions by 1250.4 MTC during the corresponding period. Some advanced countries such as the USA, Japan, and Canada have been successful in the reduction of CO_2 emission through the improvement of aggregate energy intensity and fuel switching. Among developing countries, China made a significant improvement in energy efficiency and resulting emissions reduction. The contribution of improvement of energy intensity for the reduction of CO_2 emission accounts for -192.2% in the high income group. Meanwhile, worsening energy intensities in developing countries other than China contributed to considerable CO_2 emissions growth in this region.

Based on these results, we find it is essential for developing countries to halt population growth, to improve energy efficiency, and to improve fuel switching in order to control CO_2 emissions growth. There exists strong potential for cooperation between advanced and developing countries for the reduction of CO_2 emission through technology transfer and direct investment to improve energy efficiency.

<Table 3> Breakdown of the Contributions to CO_2 Emissions Growth: APEC, 1980-1998 (MTC)

Country	Change in CO_2	Causes of CO_2 Emissions Changes				
		E/FEC	FEC/TEC	TEC/GDP	GDP/POP	POP
U.S.	203.79 (100)	7.13 (3.5)	-66.61 (-32.7)	-435.69 (-213.8)	460.70 (226.1)	238.26 (116.9)
Japan	28.08 (100)	-32.81 (-116.9)	-30.50 (-108.6)	-47.13 (-167.9)	116.87 (416.3)	21.66 (77.1)
Canada	13.31 (100)	-7.40 (-55.7)	-8.12 (-61.0)	-30.33 (-228.0)	28.69 (215.6)	30.48 (229.1)
Australia	29.13 (100)	-1.27 (-4.4)	0.28 (1.0)	-8.44 (-29.0)	22.07 (75.8)	16.50 (56.6)
New Zealand	3.15 (100)	0.72 (22.9)	-0.67 (-21.4)	0.40 (12.8)	1.32 (41.9)	1.38 (43.7)
Sub-total	***277.46 (100)***	***-34.32 (-12.4)***	***-107.77 (-38.8)***	***-533.31 (-192.2)***	***639.40 (230.4)***	***-313.46 (113.0)***
Korea	72.46 (100)	-12.34 (-17.0)	-6.97 (-9.6)	7.46 (10.3)	71.56 (98.8)	12.75 (17.6)
Mexico	26.93 (100)	-8.05 (-29.9)	-2.21 (-8.2)	2.75 (10.2)	5.04 (18.7_	29.41 (109.2)
Malaysia	20.81 (100)	-1.46 (-6.9)	0.30 (1.4)	5.37 (25.8)	9.69 (46.6)	6.88 (33.1)
Thailand	32.87 (100)	-1.22 (-3.7)	0.16 (0.5)	9.15 (27.8)	18.75 (57.0)	6.03 (18.4)
Peru	0.97 (100)	-0.05 (-5.7)	-0.78 (-80.7)	-0.10 (-10.1)	-0.54 (-55.6)	2.45 (252.1)
Chile	7.45 (100)	0.05 (0.7)	0.07 (0.9)	-1.60 (-21.4)	6.04 (81.1)	2.89 (38.8)
Sub-total	***161.50 (100)***	***-24.94 (-15.4)***	***-10.27 (-6.4)***	***24.08 (14.9)***	***110.59 (68.5)***	***62.04 (38.4)***
China	347.35 (100)	-5.65 (-1.6)	-16.72 (-4.8)	-566.56 (-163.1)	804.24 (231.5)	132.04 (38.0)
Indonesia	44.58 (100)	-4.21 (-9.5)	-0.19 (-0.4)	10.29 (23.1)	25.10 (56.3)	13.59 (30.5)
Philippine	7.77 (100)	0.16 (2.0)	-0.84 (-10.8)	3.47 (44.7)	-0.97 (-12.5)	5.95 (76.6)
Vietnam	7.65 (100)	-1.05 (-13.7)	-1.77 (-23.1)	1.73 (22.6)	5.87 (76.7)	2.87 (37.5)
Sub-total	***407.34 (100)***	***-12.80 (-3.1)***	***-24.83 (-6.1)***	***-750.56 (-184.3)***	***1002.23 (246.0)***	***193.31 (47.5)***
Grand Total (- Russia)	***846.30 (100)***	***-72.50 (-8.5)***	***-142.88 (-16.9)***	***-1259.79 (-148.9)***	***1752.22 (207.0)***	***568.81 (67.2)***
Russia	-164.88 (100)	-15.5 (9.4)	-7.39 (4.5)	23.86 (-14.5)	-159.99 (97.0)	-5.80 (3.5)

Note 1): A negative sign means a decline. Numbers in parenthesis are % shares to the total CO_2 emissions change.

2): Sample period for Russia is 1992-1998.

2. The Trends in CO_2 Emissions: Increasing or Decreasing?

The Model

We examine the trends of CO_2 emissions in each member country and determine whether CO_2 emissions have been increased or decreased. To decide this, following Sun (1999), a perfect decomposition method is used again. Equation (1) can be reduced to equation (3) as follows:

$$E = \frac{E}{FEC} \times \frac{FEC}{TEC} \times \frac{TEC}{GDP} \times GDP \equiv C \times S \times I \times GDP \qquad (3)$$

Meanwhile, the total emissions in the APEC may be decomposed as

$$E = \sum_{i=1}^{n} \frac{E_i}{FEC_i} \times \frac{FEC_i}{TEC_i} \times \frac{TEC_i}{GDP_i} \times GDP \equiv \sum_{i=1}^{n} C_i \times S_i \times I_i \times GDP \qquad (3)'$$

where subscript *i* denotes a particular country.

The change in CO_2 emissions (ΔE) in a country or a group between 1980-1998 is decomposed as the Coefficient Effect (C_{eff}), the Substitution Effect (S_{eff}), the energy Intensity Effect (I_{eff}), and the GDP Effect(GDP_{eff}). Note that the GDP Effect (GDP_{eff}) here is different from the per capita GDP Effect (G_{eff}) in the previous chapter. The following equation shows this relationship.

$$\Delta E = C_{eff} + S_{eff} + I_{eff} + GDP_{eff} \qquad (4)$$

Each effect for an individual country is obtained in accordance with Zhang (2000) as computed in the previous analysis.

In accordance with Sun (1999), even though the actual CO_2 emissions increase includes all these effect, we regard GDP_{eff} as main and theoretical CO_2 emission growth. The difference between actual and hypothetical emission growth is $C_{eff} + S_{eff} + I_{eff}$. We define the hypothetical growth as a reference growth. If the actual CO_2 emission is greater than the reference CO_2 emission, we define CO_2 emission as increased. If the actual CO_2 emission is less than the reference, we define CO_2 emission as decreased. In other words, if $C_{eff} + S_{eff} + I_{eff} \geq 0$, CO_2 emission has increased. If $C_{eff} + S_{eff} + I_{eff} < 0$, CO2 emission as decreased. This is because if $C_{eff} + S_{eff} + I_{eff} < 0$, then ΔE < $GDP_{eff,}$ and then the real change is smaller the CO_2 change caused by economic growth.

Therefore, if a growth of CO_2 emissions occurred:

$$\text{The Growth of } CO_2 \text{ emissions } = C_{eff} + S_{eff} + I_{eff} \qquad (5)$$

The rate of growth of CO_2 emissions for year t is

$$\frac{\text{Growth of } CO_2 \text{ emission in year t}}{E^{t-1} + GDP^{t}_{eff}} \times 100\% \qquad (6)$$

The rate of growth of CO_2 emissions for the whole period (from 0 to T) is

$$\frac{\sum_{t=1}^{T} \text{Growth of } CO_2 \text{ emission in year t}}{E^{0} + \sum_{t=1}^{T} GDP^{t}_{eff} \text{ in year t}} \times 100\%, \quad t=1, 2, ..., T \qquad (7)$$

where E^0 is the base year.

The Results

The results, shown in <Table 4>, reveal that CO_2 emissions in most APEC member economies were decreased hypothetically. Actual CO_2 emissions are less than the reference emissions level by 495 MTC in 1998. To put it differently, if we exclude the effect of GDP growth on CO_2 emissions increase, CO_2 emissions in most APEC nations have decreased. The biggest part of the total decrease can be attributed to the energy intensity effect.

Most nations achieved a negative growth rate in CO_2 emissions between 1980-1998. For 15 APEC countries as a whole, the average annual rate of decrease of CO_2 emissions was 1.36% for the period 1980-1998.

China showed the biggest negative growth rate, -2.07% per year. The USA, Japan and Canada achieved more than a 1% average annual decrease rate. These four countries' contributions accounted for almost all of the total decrease in CO_2 emissions in APEC.

Meanwhile Malaysia, Thailand, Philippines, Indonesia, and Viet Nam recorded positive average annual growth rates. Even though total emissions in Korea was decreased, its positive energy intensity effect contributed CO_2 emissions growth.

<Table 4> Decomposition of the Changes in CO_2 Emissions and the Rate of Growth (MTC): APEC, 1980-1998

	Decomposition of Changes (1980-98)				Reference Emission (1998)	Actual Emission (1998)	Increase	Rate of Increase (AAGR,%)
	E/FEC	FEC/TEC	TEC/GDP	GDP				
United States	7.13	-66.61	-435.69	698.96	1989.76	1494.60	-495.17	-1.0
Japan	-32.81	-30.50	-47.13	138.52	398.93	288.48	-110.45	-1.1
Canada	-7.40	-8.12	-30.33	59.16	184.32	138.46	-45.86	-1.0
Australia	-1.27	0.28	-8.44	38.56	92.83	83.40	-9.43	-0.3
China	-5.65	-16.71	-566.56	936.28	1329.31	740.38	-588.93	-2.0
Russia	-15.56	-7.39	23.86	-165.8	404.14	405.05	0.91	0.0
Chile	0.05	0.07	-1.60	8.92	15.76	14.29	-1.48	-0.3
Indonesia	-4.21	-0.19	10.29	38.69	61.93	67.82	5.89	0.3
Malaysia	-1.43	0.30	5.37	15.07	23.88	28.11	4.23	0.5
Korea	-12.34	-6.97	7.46	84.31	119.36	107.51	-11.85	-0.3
Mexico	-8.05	-2.21	2.75	34.45	102.53	95.02	-7.51	-0.2
New Zealand	0.72	-0.67	0.41	2.70	8.22	8.68	0.45	0.1
Thailand	-1.22	0.16	9.15	24.78	34.58	42.67	8.09	0.7
Philippines	0.16	-0.84	3.47	4.98	14.93	17.72	2.79	0.6
Peru	-0.05	-0.78	-0.10	1.91	8.23	7.29	-0.94	-0.4
Viet Nam	-1.05	-1.77	1.73	7.74	13.60	12.51	-1.08	-0.3
APEC*	-72.50	-142.88	-1259.79	2321.03	4621.71	3146.54	-1475.1	-1.3

Note 1): Negative signs indicate a decrease on CO_2 emissions.
2): Sample period for Russia is 1992-1998.
* Russia is not included.

3. Group Comparisons

We compare energy-related CO_2 emission levels between groups of 16 APEC countries using a decomposition method. The difference in both total CO_2 emission levels and per capita CO_2 levels between regions are explained by the differences in fuel mix, energy intensity, per capita GDP, and population. In this comparison, the logarithmic mean Divisia decomposition technique is applied as proposed by Sun (1999).

The Groups

16 APEC countries may be classified as the three groups according to income level: the High Income Group (High), the Middle Income Group (Middle), and the Low Income group (Low). The High group includes developed APEC countries, which are the USA, Japan, Canada, Australia, and New Zealand, with per capita income ranging US$ 15,830-38,160. The Middle group comprises middle-income developing countries, Korea, Mexico, Chile, Peru, Malaysia, and Thailand. Per capita GDP ranges US$ 2,610 - 10,550 for this group. The Low group comprises less-developed countries with per capita GDP below US$ 1,200. China, Indonesia, Philippines, and Viet Nam belong to this group.

An overview of CO_2 emission, energy consumption, and GDP data for three groups of APEC in 1996 are shown in <Table 5>. The year of 1996 is chosen in order for these comparisons to be unaffected by the Asian financial crisis which began in 1997. From <Table 5>, we notice the total CO_2 emission level, the energy consumption level and per capita emission level in the High group were significantly greater than other groups. Per capita CO_2 emission and per capita energy consumption of the High group is about 8 and 10 times greater than those of the Low group, respectively. From the fact that the per capita GDP of the High group is about 40 times greater than that of the Low group, we may presume high energy efficiency in the High group narrowed the difference in the per capita CO_2 emissions between the groups.

<Table 5> CO_2 Emissions, Energy Consumption, and GDP (APEC, 1996)

	High	**Middle**	**Low**
CO_2 Emission (MTC)	2001.85	294.75	884.50
Energy Consumption (QBtu)	132.75	18.01	40.64
GDP (Mil 90 US$)	10,889.7	988.7	976.8
Population (Mil)	442.6	261.0	1578.1
Per Capita CO_2 (TC)	4.52	1.13	0.56
Per Capita Energy Consumption (BBtu)	299.9	69.0	25.8
Per Capita GDP (1990 US$)	24,601.8	3787.4	619.0

However, we need to be cautious in getting meaningful information from direct comparisons of the total GDP, CO_2 emissions, energy consumption of each group because numbers and size of countries included in each group are not the same. For example, total CO_2 emissions in the Middle group are less than those in the Low group simply because a big economy, China is included in the latter.

We investigate and explain the differences of CO_2 emission levels between the groups with the contributing factors being quantified. Inter-regional comparison is done in two parts: (1) the comparison of the total CO_2 emissions and (2) the comparison of per capita CO_2 emissions.

The Model for the Comparisons of Total CO_2 Emissions

As proposed by Ang and Zhang(1999), we use a logarithmic mean Divisia decomposition method for inter-group comparisons. The CO_2 emissions from a region can be written as

$$E = \sum_i \frac{E_i}{FEC_i} \times \frac{FEC_i}{TEC} \times \frac{TEC}{GDP} \times \frac{GDP}{POP} \equiv \sum_i C_i \times S_i \times I \times G \times P \quad (8)$$

where the subscripts i denotes a particular fossil fuel (coal, gas, and oil).

Now, the difference in the CO_2 emissions between the two groups can be expressed as

$$\Delta E = E_1 - E_2 = \sum_i E_{i1} - \sum_i E_{i2} = \sum_i C_{i1} S_{i1} I_1 G_1 P_1 - \sum_i C_{i2} S_{i2} I_2 G_2 P_2 \quad (9)$$

where the subscripts 1 and 2 denote variables for group 1 and 2, respectively.

Following Ang and Zhang (1999) and applying a log mean Divisia decomposition approach, this difference can be decomposed as follows:

$$\Delta E = \Delta E_C + \Delta E_S + \Delta E_I + \Delta E_G + \Delta E_P \quad (10)$$

where the right hand side terms are the CO_2 emissions differences (ΔE) caused by (i) differences in Carbon coefficients (Carbon coefficient Effect, ΔE_C), (ii) differences in energy mix (Substitution Effect, ΔE_S), (iii) differences in energy intensity (Intensity Effect, ΔE_I), (iv) differences in Per capita GDP (GDP Effect, ΔE_G) (v) differences in Population (Population Effect, ΔE_P), respectively.

These right hand side effects are given as follows:

$$\Delta E_C = \sum_i \left[L(E_{i1}, E_{i2}) \ln(C_{i1}/C_{i2}) \right]$$

$$\Delta E_S = \sum_i \left[L(E_{i1}, E_{i2}) \ln(S_{i1}/S_{i2}) \right] \qquad (11)$$

$$\Delta E_I = \sum_i \left[L(E_{i1}, E_{i2}) \ln(I_1/I_2) \right]$$

$$\Delta E_G = \sum_i \left[L(E_{i1}, E_{i2}) \ln(G_1/G_2) \right]$$

$$\Delta E_P = \sum_i \left[L(E_{i1}, E_{i2}) \ln(P_1/P_2) \right]$$

where $L(E_{i1}, E_{i2}) = \dfrac{E_{i1} - E_{i2}}{\log E_{i1} - \log E_{i2}}$, E_{ij} is CO_2 emissions from fuel i in the group j .

The Results (1)

<Figure 3> and <Table 6> show the results of decomposition of the difference in total CO_2 emissions between the groups. The 1996 total CO_2 emission level in the High group is 1,707.10 MTC higher than in the Middle group (i.e. High-Middle) and 1,117.34 MTC higher than in the Low group (i.e. High-Low). Whereas the level in the Middle group is 589.75 MTC lower than in the Low group (i.e. Middle-Low) due to the presence of China in the Low group.

The gaps in per capita GDP and population (in the order of their magnitudes) in the High-Mid contributed to a higher level of total CO_2 emission in the High group than in the Middle group. The growth effect and the population effect are estimated to account for 96% and 27% of the difference in CO_2 emission levels, respectively. On the other hand, improvements in aggregate energy intensity (-21%) and fuel switching (-22%) helped the High group in reducing CO_2 emissions relative to the Middle group.

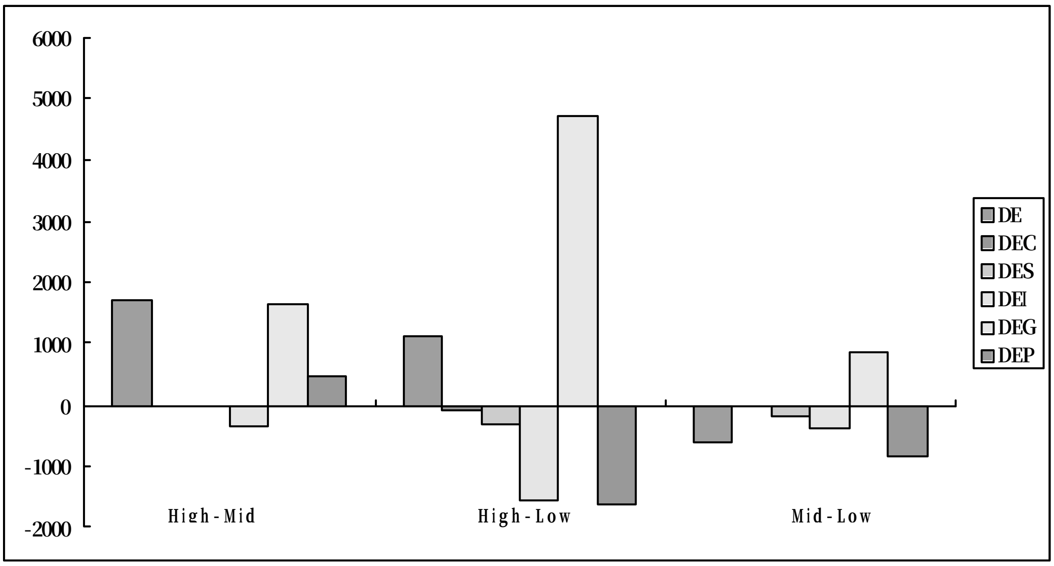
A comparison between the High group and the Low group tells us a different story. Only the growth effect contributed to a higher level of total CO_2 emission in the High group than in the Low group. All other factors except the growth effect lead to a lower emission level in the High group than the Low group. The growth effect is, however, dominant compared to other factors so that the total CO_2 emission in the High group is still larger than the Low group.

The growth effect in the Mid-Low case is about the same as in the High-Low case. Opposite to the High-Low, other factors dominate the growth effect so that the amount of difference in total CO_2 emission between the two groups is negative. This means that Low group emits more CO_2 than the Mid group.

<Table 6> Difference in Total CO_2 emissions between the Groups in 1996 (MTC)

	ΔE	ΔE_C	ΔE_S	ΔE_I	ΔE_G	ΔE_P
High-Mid	1707.10 (100)	-21.90 (-1.28)	-22.26 (-1.30)	-351.89 (-20.61)	1,640.23 (96.08)	462.91 (27.12)
High-Low	1,117.34 (100)	-78.05 (-6.99)	-318.27 (-28.48)	-1,570.08 (-140.52)	4,709.45 (421.49)	-1,625.71 (-145.50)
Mid-Low	-589.75 (100)	-21.20 (3.60)	-182.26 (30.90)	-392.01 (66.47)	859.36 (-145.71)	-853.63 (144.74)

<Figure 3> Difference in Total CO_2 Emissions between APEC Countries in 1996



The Model for the Comparisons of per capita CO_2 Emissions

By dividing equation (8) by population, we get equation (12) for decomposing the differences in per capita emissions. All the procedures are the same as before.

$$E' = \sum_i E_i / POP = \sum_i \frac{E_i}{FEC_i} \times \frac{FEC_i}{TEC} \times \frac{TEC}{GDP} \times \frac{GDP}{POP} \equiv \sum_i C_i \times S_i \times I \times G \qquad (12)$$

The difference in per capita CO_2 emissions between two groups is decomposed as :

$$\Delta E' = \Delta E'_C + \Delta E'_S + \Delta E'_I + \Delta E'_G \qquad (13)$$

where the right hand side terms are the CO_2 emissions differences ($\Delta E'$) caused by (i) differences in Carbon coefficients (Carbon coefficient Effect, $\Delta E'_C$), (ii) differences in energy mix (Substitution Effect, $\Delta E'_S$), (iii) differences in energy intensity (Intensity Effect, $\Delta E'_I$), and (iv) differences in Per capita GDP (GDP Effect, $\Delta E'_G$), respectively. These effects can be obtained as follows:

$$\Delta E'_C = \sum_i \left[L(E'_{i1}, E'_{i2}) \ln(C_{i1} / C_{i2}) \right] \qquad (14)$$

$$\Delta E'_S = \sum_i \left[L(E'_{i1}, E'_{i2}) \ln(S_{i1} / S_{i2}) \right]$$

$$\Delta E'_I = \sum_i \left[L(E'_{i1}, E'_{i2}) \ln(I_1 / I_2) \right]$$

$$\Delta E'_G = \sum_i \left[L(E'_{i1}, E'_{i2}) \ln(G_1 / G_2) \right].$$

Note that $E'_{ij} = E_{ij} / POP_j$, where j denotes a particular group.

The Results (2)

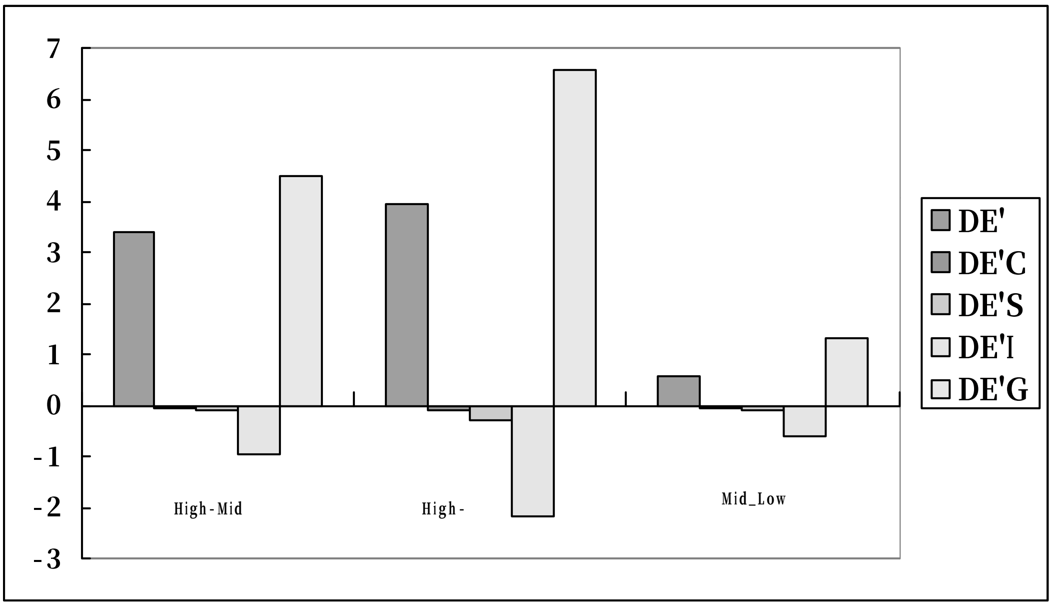
<Table 7> shows the results of the decomposition of the difference in per capita CO_2 emissions. The Per capita CO_2 emission level in the High group is 3.39 MTC higher than that in the Middle group (i.e. High-Mid) and 3.96 MTC higher than that in the Low group (i.e. High-Low). Unlike the difference in total CO_2 emission, the per capita level in the Middle group is 0.57 MTC higher than in the Low group.

Unlike the previous comparison of the total emissions, this comparison of per capita emissions between the groups shows one clear pattern: The growth effect is the sole factor that positively and most significantly contributed to the differences in per capita emissions between the groups while all the other factors (the substitution effect, the carbon coefficient effect, and the energy intensity effect) did negatively. Among the negative contributing factors, the energy intensity effect is most significant in all cases.

<Table 7> Difference in per Capita CO_2 Emission between the Groups in 1996 (TC)

	$\Delta E'$	$\Delta E'_C$	$\Delta E'_S$	$\Delta E'_I$	$\Delta E'_G$
High-Mid	3.39 (100)	-0.06 (-1.77)	-0.08 (-2.38)	-0.97 (-28.45)	4.50 (132.59)
High-Low	3.96 (100)	-0.11 (-2.89)	-0.29 (-7.37)	-2.18 (-55.14)	6.55 (165.40)
Mid-Low	0.57 (100)	-0.04 (-6.50)	-0.10 (-17.76)	-0.59 (-104.23)	1.30 (228.49)

<Figure 4> Difference in per Capita CO_2 Emissions between APEC Countries in 1996



A comparison of per capita emissions between the High group and the Middle group displayed a similar pattern to the previous case of the total CO_2 emission comparison. In other words, per capita GDP is the main contributor to the difference between the High group and the Middle group. In the case of the High and Low groups, the growth effect plays a major role and dominates other factors such as fuel switching and energy intensity, keeping the High group's larger per capita CO_2 emission than the Low group. In the Mid-Low comparison case, per capita CO_2 emission in the Middle group is larger than for the Low group. Note that for total CO_2 emission, the opposite hold.

IV. Summary and Implications for Mitigation Policies and Regional Cooperation

We examined historical contributions of inter fuel substitution, changes in carbon efficiency and energy intensity, growth of economy and population to the APEC countries' CO_2 emissions from 1980 to 1998 using a perfect decomposition approach. We also investigated whether or not CO_2 emissions in the member countries are decreasing by using new criteria by Sun (2000). By adopting a log mean Divisia method, we explained the causes of the differences in both the total and per capita CO_2 emissions between the groups of APEC countries.

The study reveals that economic growth (i.e. per capita income growth) is the most significant factor for CO_2 emissions growth in most countries other than Russia, Peru, and the Philippines.Population growth is another important factor that contributes CO_2 emissions growth in all countries but Russia.

Changes in energy intensity, fuel substitution, and carbon coefficient may be classified as negative contributors to CO_2 emissions growth. In other words, improvement in these factors offset the increase of CO_2 emissions due to economic and population growth considerably during 1980-1998 in the APEC. Enhanced energy intensity played an especially dominant role in halting CO_2 emissions growth in developed countries. In some less-developed countries, however, this factor played reversed role. As far as carbon coefficient is concerned, Japan showed the most significant improvement, -116.9% contribution to the change in CO_2 emissions during the same period.

If the effect of per capita income growth were set aside, many achieved a negative growth rate of CO_2 emissions. Advanced countries like the USA, Japan and Canada achieved more than a 1% average annual decrease rate. This emission decrease is explained by improvements in energy efficiency. In most developing countries, however, they did not improve energy efficiency much, except for China, which recorded considerable success in enhancing energy intensity.

In the group comparison, the per capita income effect explains the higher emission level for advanced countries relative to the developing countries. Meanwhile other factors contributed to narrow the emission gaps between the groups. Above all, the higher energy efficiency in advanced economies is the most important factor for decreasing the gaps.

Based on the findings of this analysis, we may draw implications on policy options for

CO_2 emissions mitigation and find ways to strengthen environmental cooperation among APEC member economies. It should be developed countries who use every possible policy and measure to achieve their commitments to the Kyoto Protocol and to realize substantial and effective mitigation of CO_2 emissions.

Needless to say, participation of developing countries is also important and desirable. However, CO_2 emission increase from economic development should be regarded as inevitable. Mitigation policies and measures in developing countries should not hinder local sustainable development. They need to accelerate substitution form fossil fuels to CO_2 free or less CO_2 -intensive fuels, to enhance carbon emissions efficiency, and to improve energy efficiency. As we have seen that developed countries reduced emissions through improving energy efficiency, and that there are large gaps in energy efficiency between developed countries and developing countries, we think improving energy efficiency through various measures will yield desirable results. Controlling population growth in low income countries is also an essential factor in checking rapid CO_2 emissions growth.

In achieving emissions mitigation in developing countries, environmental cooperation among APEC member countries is essential. Developed countries need to transfer adequate technology and to finance to less-developed countries for enhancing energy efficiency. For this purpose, APEC countries need to actively utilize the Kyoto Mechanism, which is Joint Implementation (JI), Clean Development Mechanism (CDM), and International Emissions Trading (IMT). The Prototype Carbon Fund to be operated by the World Bank may be a good source to expand such investment to the developing countries.

Among APEC economies, we find there exist large carbon credit suppliers and buyers. Most developing countries including China, Malaysia, Indonesia, Viet Nam, Peru, and Thailand are found to have very large potential to provide carbon credits. The USA, Japan, and Canada have to buy carbon credits to meet their commitments to the Kyoto Protocol. In that sense, their activating intra-regional trading of carbon credits in the International Emissions Trading Regime proposed by the Kyoto Protocol is recommended. Another option is to form an environmental bubble like the Umbrella Group that includes the USA, Japan, Russia, Canada, Australia, New Zealand, others.

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http://www.eia.doe.gov/emeu/international/energy.html

http://www.oecdwash.org

Appendix

Total emissions in the APEC economies and its effects can be obtained as follows:

$$E = \sum_{i}^{16} \frac{E_i}{FEC_i} \times \frac{FEC_i}{TEC_i} \times \frac{TEC_i}{GDP_i} \times \frac{GDP_i}{POP_i} \times POP_i \equiv \sum_{i}^{16} (C_i \times S_i \times I_i \times G_i \times P_i)$$

The Total Effect: $\Delta E = C_{eff} + S_{eff} + I_{eff} + G_{eff} + P_{eff}$

The coefficient effect of CO_2:

$$\begin{aligned}
C_{eff} &= \sum_{i}^{16} \Delta C_i \times S_i^0 \times I_i^0 \times G_i^0 \times P_i^0 \\
&+ \frac{1}{2}\sum_{i}^{16} \Delta C_i \times [\Delta S_i \times I_i^0 \times G_i^0 \times P_i^0 + S_i^0 \times \Delta I_i \times G_i^0 \times P_i^0 + S_i^0 \times I_i^0 \times \Delta G_i \times P_i^0 + S_i^0 \times I_i^0 \times G_i^0 \times \Delta P_i \\
&+ \frac{1}{3}\sum_{i}^{16} \Delta C_i \times [\Delta S_i \times \Delta I_i \times G_i^0 \times P_i^0 + \Delta S_i \times I_i^0 \times \Delta G_i \times P_i^0 + \Delta S_i \times I_i^0 \times G_i^0 \times \Delta P_i \\
&+ S_i^0 \times \Delta I_i \times \Delta G_i \times P_i^0 + S_i^0 \times \Delta I_i \times G_i^0 \times \Delta P_i + S_i^0 \times I_i^0 \times \Delta G_i \times \Delta P_i \quad] \\
&+ \frac{1}{4}\sum_{i}^{16} \Delta C_i \times [\Delta S_i \times \Delta I_i \times \Delta G_i \times P_i^0 + \Delta S_i \times \Delta I_i \times G_i^0 \times \Delta P_i + \Delta S_i \times I_i^0 \times \Delta G_i \times \Delta P_i \\
&+ S_i^0 \times \Delta I_i \times \Delta G_i \times \Delta P_i \quad] + \frac{1}{5}\sum_{i}^{16} \Delta C_i \times \Delta S_i \times \Delta I_i \times \Delta G_i \times \Delta P_i
\end{aligned}$$

where superscript 0 denotes the base year, 1980.

The substitution effect:

$$S_{eff}=\sum_{i}^{16}\Delta S_i\times C_i^0\times I_i^0\times G_i^0\times P_i^0$$

$$+\frac{1}{2}\sum_{i}^{16}\Delta S_i\times[\Delta C_i\times I_i^0\times G_i^0\times P_i^0+C_i^0\times\Delta I_i\times G_i^0\times P_i^0+C_i^0\times I_i^0\times\Delta G_i\times P_i^0+C_i^0\times I_i^0\times G_i^0\times\Delta P_i]$$

$$+\frac{1}{3}\sum_{i}^{16}\Delta S_i\times[\Delta C_i\times\Delta I_i\times G_i^0\times P_i^0+\Delta C_i\times I_i^0\times\Delta G_i\times P_i^0+\Delta C_i\times I_i^0\times G_i^0\times\Delta P_i$$

$$+C_i^0\times\Delta I_i\times\Delta G_i\times P_i^0+C_i^0\times\Delta I_i\times G_i^0\times\Delta P_i+C_i^0\times I_i^0\times\Delta G_i\times\Delta P_i]$$

$$+\frac{1}{4}\sum_{i}^{16}\Delta S_i\times[\Delta C_i\times\Delta I_i\times\Delta G_i\times P_i^0+\Delta C_i\times\Delta I_i\times G_i^0\times\Delta P_i+\Delta C_i\times I_i^0\times\Delta G_i\times\Delta P_i$$

$$+C_i^0\times\Delta I_i\times\Delta G_i\times\Delta P_i]+\frac{1}{5}\sum_{i}^{16}\Delta C_i\times\Delta S_i\times\Delta I_i\times\Delta G_i\times\Delta P_i$$

The energy intensity effect:

$$I_{eff}=\sum_{i}^{16}\Delta I_i\times C_i^0\times S_i^0\times G_i^0\times P_i^0$$

$$+\frac{1}{2}\sum_{i}^{16}\Delta I_i\times[\Delta C_i\times S_i^0\times G_i^0\times P_i^0+C_i^0\times\Delta S_i\times G_i^0\times P_i^0$$

$$+C_i^0\times S_i^0\times\Delta G_i\times P_i^0+C_i^0\times S_i^0\times G_i^0\times\Delta P_i]$$

$$+\frac{1}{3}\sum_{i}^{16}\Delta I_i\times[\Delta C_i\times\Delta S_i\times G_i^0\times P_i^0+\Delta C_i\times S_i^0\times\Delta G_i\times P_i^0+\Delta C_i\times S_i^0\times G_i^0\times\Delta P_i$$

$$+C_i^0\times\Delta S_i\times\Delta G_i\times P_i^0+C_i^0\times\Delta S_i\times G_i^0\times\Delta P_i+C_i^0\times S_i^0\times\Delta G_i\times\Delta P_i]$$

$$+\frac{1}{4}\sum_{i}^{16}\Delta I_i\times[\Delta C_i\times\Delta S_i\times\Delta G_i\times P_i^0+\Delta C_i\times\Delta S_i\times G_i^0\times\Delta P_i+\Delta C_i\times S_i^0\times\Delta G_i\times\Delta P_i$$

$$+C_i^0\times\Delta S_i\times\Delta G_i\times\Delta P_i]+\frac{1}{5}\sum_{i}^{16}\Delta C_i\times\Delta S_i\times\Delta I_i\times\Delta G_i\times\Delta P_i$$

Growth effect:

$$G_{eff} = \sum_{i}^{16} \Delta G_i \times C_i^0 \times S_i^0 \times I_i^0 \times P_i^0$$
$$+\frac{1}{2}\sum_{i}^{16} \Delta G_i \times [\Delta C_i \times S_i^0 \times I_i^0 \times P_i^0 + C_i^0 \times \Delta S_i \times I_i^0 \times P_i^0$$
$$+ C_i^0 \times S_i^0 \times \Delta I_i \times P_i^0 + C_i^0 \times S_i^0 \times I_i^0 \times \Delta P_i]$$
$$+\frac{1}{3}\sum_{i}^{16} \Delta G_i \times [\Delta C_i \times \Delta S_i \times I_i^0 \times P_i^0 + \Delta C_i \times S_i^0 \times \Delta I_i \times P_i^0 + \Delta C_i \times S_i^0 \times I_i^0 \times \Delta P_i$$
$$+ C_i^0 \times \Delta S_i \times \Delta I_i \times P_i^0 + C_i^0 \times \Delta S_i \times I_i^0 \times \Delta P_i + C_i^0 \times S_i^0 \times \Delta I_i \times \Delta P_i]$$
$$+\frac{1}{4}\sum_{i}^{16} \Delta G_i \times [\Delta C_i \times \Delta S_i \times \Delta I_i \times P_i^0 + \Delta C_i \times \Delta S_i \times I_i^0 \times \Delta P_i + \Delta C_i \times S_i^0 \times \Delta I_i \times \Delta P_i$$
$$+ C_i^0 \times \Delta S_i \times \Delta I_i \times \Delta P_i] + \frac{1}{5}\sum_{i}^{16} \Delta C_i \times \Delta S_i \times \Delta I_i \times \Delta G_i \times \Delta P_i$$

the population effect:

$$P_{eff} = \sum_{i}^{16} \Delta P_i \times C_i^0 \times S_i^0 \times I_i^0 \times G_i^0$$
$$+\frac{1}{2}\sum_{i}^{16} \Delta P_i \times [\Delta C_i \times S_i^0 \times I_i^0 \times G_i^0 + C_i^0 \times \Delta S_i \times I_i^0 \times G_i^0 + C_i^0 \times S_i^0 \times \Delta I_i \times G_i^0 + C_i^0 \times S_i^0 \times I_i^0 \times \Delta G_i]$$
$$+\frac{1}{3}\sum_{i}^{16} \Delta P_i \times [\Delta C_i \times \Delta S_i \times I_i^0 \times G_i^0 + \Delta C_i \times S_i \times \Delta I_i \times G_i^0 + \Delta C_i \times S_i^0 \times I_i^0 \times \Delta G_i$$
$$+ C_i^0 \times \Delta S_i \times \Delta I_i \times G_i^0 + C_i^0 \times \Delta S_i \times I_i^0 \times \Delta G_i + C_i^0 \times S_i^0 \times \Delta I_i \times \Delta G_i]$$
$$+\frac{1}{4}\sum_{i}^{16} \Delta P_i \times [\Delta C_i \times \Delta S_i \times \Delta I_i \times G_i^0 + \Delta C_i \times \Delta S_i \times I_i^0 \times \Delta G_i + \Delta C_i \times S_i^0 \times \Delta I_i \times \Delta G_i$$
$$+ C_i^0 \times \Delta S_i \times \Delta I_i \times \Delta G_i] + \frac{1}{5}\sum_{i}^{16} \Delta C_i \times \Delta S_i \times \Delta I_i \times \Delta G_i \times \Delta P_i$$

국문 요약

이 논문에서 APEC 국가들의 탄소 배출구조를 분석하고, 탄소 배출 저감을 위한 국가내 정책 시사점을 도출하며, 나아가 회원국간의 배출 저감 협력방안을 분석하였다. 먼저 16개 회원국들을 대상으로 1980-1998년 기간 중 에너지 소비로부터의 이산화탄소 배출을 단순분해 기법(perfect decomposition approach)을 이용하여 연료간 대체, 탄소배출 효율의 변화, 에너지 집약도의 변화, 경제성장, 인구변화 등 기여 요인과 기여도를 분석하였다.

또한, Sun(2000이 제시한 이른바 Refined Laspeyres 방식과 기준을 적용하여 회원국들의 이산화탄소 배출량이 증가 혹은 감소추세인지 판별하고 그 변화율을 계산하였다. 아울러 회원국들을 소득 수준별로 세 그룹으로 구분한 뒤 대수평균 디비지아 방법(log mean Divisia method)으로 그룹간 전체 및 일인당 이산화탄소 배출량의 차이를 요인별로 설명하였다.

분석 결과 대부분의 국가에 있어서 이산화탄소 배출량 증가의 최대 요인은 경제성장인 것으로 확인되었다. 일인당 GDP 증가와 인구증가가 러시아 등 일부 회원국을 제외한 대부분 국가의 이산화탄소 배출 증가에 가장 크게 기여하였다. 에너지 집약도와 탄소배출효율의 향상은 경제성장으로 인한 배출 증가를 상당폭 상쇄하는 데 기여한 것으로 분석되었다. 특히 이런 경향은 선진국에서 두드러졌다. 따라서, 경제성장에 의한 배출 증가분을 제외한다면 많은 국가에서 이산화탄소 배출량은 감소한 것으로 평가된다. 소득 그룹별 이산화탄소 배출량의 차이의 가장 큰 부분은 소득 격차에 의해 설명되었고, 에너지 사용 효율의 차이는 격차를 줄이는 요인으로 작용하였다.

이러한 분석을 바탕으로 볼 때 탄소배출을 줄이려는 정책은 무엇보다도 에너지 집약도 개선과 탄소배출 효율 제고에 중점이 주어져야 할 것으로 판단된다. 이러한 정책의 효과는 선진국보다 개도국에서 더 큰 것으로 분석되는 만큼 역내 선진국과 개도국간의 에너지 효율 증대를 위한 기술 이전, 자금지원, 직접 투자 확대가 요구된다. 쿄토메커니즘인 공동이행, CDM의 적극적인 참여와 활용은 선진 회원국들의 기후협약상 탄소배출 저감 의무 달성과 개도권 회원국들의 지속적인 개발과 에너지 효율 제고에 크게 이바지할 것으로 기대된다. 역내에는 탄소배출권 공급국가와 수요국가가 공존하고 있어 역내 회원국간의 배출권 거래 활성화나 버블을 형성하는 것도 상호 이득이 될 것으로 보인다.

著者 略歷

李紀勳

연세대학교 경제학과 졸업(1983)
미국 Texas A&M University 경제학 박사(1997)
산업연구원 연구원/책임연구원(1983-1988)
중앙일보사 기자(1988-1992)
에너지경제연구원 선임연구원(1997 - 98)
충남대학교 경상대학 경제학과 조교수(현재, Email: khl@cnu.ac.kr)

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吳完根

한국외국어대학교 경제학과 졸업(1986)
한국외국어대학교 경제학 석사(1988)
미국 Texas A&M University 경제학 박사(1996)
제일금융연구원 부연구위원(1997)
에너지경제연구원(1998)
한남대학교 경상대학 경제학과 조교수(현재, Email: wanoh@mail.hannam.ac.kr)

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KOREA INSTITUTE FOR INTERNATIONAL ECONOMIC POLICY

300-4 Yomgok-Dong, Seocho-Gu, Seoul 137-747, Korea
Tel: (822) 3460-1114
Fax: (822) 3460-1122
URL: http://www.kiep.go.kr

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