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Atmospheric Stabilization of CO_2 Emissions:

Near-term Reductions and Intensity-based Targets

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Abstract

This study analyzes CO_2 emissions reduction targets for various countries and geopolitical regions by the year 2030 in order to stabilize atmospheric concentrations of CO_2 at the level of 450 ppm (550 ppm including non CO_2 greenhouse gases). It also determines CO_2 intensity cuts that would be needed in those countries and regions if the emission reductions were achieved through intensity-based targets while assuming no effect on forecasted economic growth. Considering that the stabilization of CO_2 concentrations at 450 ppm requires the global trend of CO_2 emissions to reverse before 2030, this study develops two scenarios: reversing the global CO_2 trend in (i) 2020 and (ii) 2025. The study shows that global CO_2 emissions would be 42 percent above the 1990 level in 2030 if the increasing trend of global CO_2 emissions is reversed by 2020. If reversing the trend is delayed by 5 years, the 2030 global CO_2 emissions would be 52 percent higher than the 1990 level. The study also finds that to achieve these targets while maintaining assumed economic growth, the global average CO_2 intensity would require a 68 percent drop from the 1990 level or a 60 percent drop from the 2004 level by 2030.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to study climate change and clean energy issues. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at gtimilsina@worldbank.org.

Atmospheric Stabilization of CO_2 Emissions: Near-term Reductions and Intensity-based Targets[†]

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1. Introduction

Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) defines the ultimate objective of the Convention as 'stabilization of atmospheric concentrations of greenhouse gases (GHGs) at a level that would prevent dangerous anthropogenic interference with the climate system' (UN, 1992). The level of stabilization has not been unambiguously determined yet because of scientific uncertainties involved in the climatic system, the dynamics and capacity of the adaptation systems (Kopp, 2004; Metz and van Vuuren 2006). However, existing studies, such as Stern's Review suggest that the risks of the worst impacts of climate change can be substantially reduced if GHG concentrations can be stabilized between 450 and 550 ppm[1] CO_2 equivalent (CO2e) (Stern 2006)[2]. Moreover, a large number of studies analyzing long-term climate change mitigation policies have also considered a range of 450 to 550 ppm of CO_2 concentrations by the year 2100 (Grubb et al 2006; Weyant et al. 2006; Weyant, 2004; Schellnhuber et al. 2006).

Stern (2006) concludes that if the current rate of emissions continues, the GHG concentrations could double its pre-industrial level by 2035; and stabilizing at or below

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1 PPM stands for Parts Per Million; it refers to the number of CO_2 molecules for every one million molecules of dry air.

2 The current (as of year 2005) level of atmospheric concentrations of CO_2 is about 380 ppm, 35.4 percent higher than the pre-industrial level of 280 ppm (IPCC, 2007). If other GHGs are also included, the current level of GHG concentrations reaches 430 ppm CO2e (Stern et al 2006).

this level would require global emissions to peak in the next 10 - 20 years and then start falling at a rate of 1 - 3 percent per year to reach 25 percent below the current level by 2050. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) suggests that global GHG emissions in 2050 should be limited to -30 percent to +5 percent of 2000 level to stabilize CO_2 concentrations between 440 ppm and 485 ppm or 535 ppm and 590 ppm if non-CO_2 GHGs are also included (IPCC 2007). To stabilize CO_2 concentrations at 450 ppm, global CO_2 emissions require to start declining before 2030, the earlier is the better (Grubb et al. 2006; Weyant et al. 2006; Stern, 2006).

The Kyoto Protocol is merely a starting point. The emission reduction targets set forth by the Protocol for the 2008 - 2012 period originally aimed to reduce GHG emissions of Annex I countries[3] (i.e., developed countries and economies in transition) by 5.2 percent, in average, from their 1990 level. The U.S. and Australia have not ratified the Protocol. Russia and other economics in transition are not prevented from selling their surplus emission allowances[4]. Considering these situations, the Kyoto Protocol may not be able to lead reductions in Annex I countries' total GHG emissions as compared to

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[3] Countries listed in the Annex I of the UNFCCC text (UN, 1992) are referred to as 'Annex I' countries whereas the rest of the countries are referred to as 'Non-Annex I' countries. Annex I countries have mandatory obligations to reduce their GHG emissions under the Kyoto Protocol, whereas Non-Annex I countries do not.

[4] Russia and Ukraine are allowed to emit during the first Kyoto Commitment period at the level of their 1990 emissions; however it is not expected that these countries will achieve their economic recovery by 2010. Their actual emissions during that period would therefore be smaller than that they are allowed for. This difference is defined as "surplus allowance". It is popularly known as "hot air".

their 1990 level during its first commitment period. Moreover, developing countries' GHG emissions are rapidly increasing thereby resulting in global GHG emissions in 2012 much higher than that in 1990.

The reversing of the global trend of CO_2 emissions before 2030 to stabilize atmospheric concentrations at 450 ppm depends on a number of factors: (i) willingness of Annex I countries, including U.S. and Australia to accept targets more stringent than those for the first commitment period, (ii) willingness of developing countries to stabilize their emissions before 2030 and then reduce gradually. At what level should the global emissions be reduced by the Annex I countries and limited by non-Annex I countries to reverse the global trend of CO_2 emissions? Alternatively, what targets for emission reduction do Annex I and non-Annex I countries require for this purpose? If these targets were to meet without sacrificing economic outputs, by how much would emission intensities be reduced in both Annex I and non-Annex I countries? No answers to these specific questions can be found in the existing literature.

To address the research gaps mentioned above, this study first develops two plausible scenarios to reverse the trend of global CO_2 emissions before 2030. The first scenario considers reversing the global trend by 2025 through increased mitigation targets for Annex I countries and stabilization of non-Annex I countries' emission at their 2025 level. The second scenario examines the possibility of reversing global emission trend 5 years earlier in 2020 through stabilization of non-Annex I countries' emission from that year and with Annex I emission targets as specified in the previous scenario.

Secondly, the study translates the absolute emission reduction targets to emission intensity based targets using projected data form the 2007 International Energy Outlook of the U.S. Department of Energy (USDEE) (EIA, 2007b)[5]. Intensity based targets appear politically palatable because these are interpreted as not reducing economic outputs. In 2002, the U.S. administration announced an intensity based target to reduce GHG intensity by 18 percent over the next 10 years (The White House, 2002). In 2007 April, the Canadian Government announced mandatory cuts in industrial sector GHG intensities by 18 percent from 2006 level by 2010 and 2 percent reduction per year thereafter (Environment Canada, 2007). Argentina was the first non-Annex I country to commit an intensity based emission reduction target (Argentine Republic 1999). Theoretically, both absolute emission based targets and emission intensity based targets result in the same level of mitigation as long as these target are set appropriately (see e.g., Ellerman and Wing, 2003). Our study shows that targets based on emission intensity would be higher than that based on absolute emissions because economic outputs are expected to increase in future.

The paper is organized as follows. Section 2 develops the methodology and describes data sources followed by a brief discussion of historical as well as projected CO_2 emissions through 2030 in Section 3. Also discussed in Section 3 is the historical and projected trend of CO_2 intensities. Section 4 links the global GHG mitigation implied by the Kyoto Protocol during its first commitment period with the atmospheric stabilization of CO_2 concentrations; this section also presents the two scenarios developed for the purpose of this study. This is followed by an analysis of emission

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[5] The reasons behind the use of data from USDOE will be discussed in Section 2.

reductions by various countries and regions to reverse the global trend of CO_2 emissions before 2030. Section 6 translates the absolute emission based targets into emission intensity based targets. Finally, key conclusions are drawn in Section 7.

2. Methodology and Data

Future emissions are calculated using information on the base year (e.g., 1990 for most Annex I countries) emissions and absolute emission targets:

$$em_{j,y} = em_{j,0} . \tau_{j,y}^{EMISSION} \quad (1)$$

where $em_{j,y}$ and $em_{j,0}$ refers to CO_2 emissions of a country or region j in a year y and the base year, respectively; $\iota^{EMISSION}_{j,y}$ refers to an emission target of the country or region in the year y expressed as a fraction of the base year emissions. The values of $\iota^{EMISSION}_{j,y}$ applied in this study are discussed in Section 4.2. The emission intensity of a country or region j in year y ($int_{j,y}$) is estimated using its CO_2 emissions ($em_{j,y}$) and GDP ($gdp_{j,y}$):

$$\text{int}_{j,y} = \frac{em_{j,y}}{gdp_{j,y}} \quad (2)$$

One of the objectives of the study is to calculate the emission intensity based targets equivalent to absolute emission based targets. The equivalent intensity based targets, $\iota^{INTENSITY}_{j,y}$, are calculated as:

$$\tau_{j,y}^{INTENSITY} = \frac{\text{int}_{j,y}}{\text{int}_{j,0}} \quad (3)$$

where, $int_{j,0}$ is the emission intensity of a country or region j in the base year. Applying the definition of energy intensity (i.e., Equation 2) in Equation (3), we get:

$$\tau_{j,y}^{INTENSITY} = \frac{em_{j,y}}{gdp_{j,y}} \Big/ \frac{em_{j,0}}{gdp_{j,0}} = \frac{em_{j,y}}{em_{j,0}} \Big/ \frac{gdp_{j,y}}{gdp_{j,0}} \tag{4}$$

From Equation (1) and Equation (4), we obtain:

$$\tau_{j,y}^{INTENSITY} = \frac{\tau_{j,y}^{EMISSION}}{\tau_{j,y}^{GDP}} \tag{5}$$

where $\iota^{GDP}_{j,y}$ is a target for GDP or expected economic growth, i.e.:

$$\tau_{j,y}^{GDP} = \frac{gdp_{j,y}}{gdp_{j,0}} \tag{6}$$

where $gdp_{j,0}$ is GDP of a country or region j in the base year. As an economy of a country grows, $\iota^{GDP}_{j,y}$ becomes greater than one.

The understanding of the relationship between the absolute emission target and the intensity based target is very important. Equation (5) demonstrates that the relationship between these two targets depends on future expectations on economic (i.e., GDP) growths. For example, if a country expects higher economic growth, its emission intensity is required to be cut at a rate greater than that of its absolute emissions to achieve the same level of emission reductions. The reverse would be true if the country expects an economic downturn in the future.

The study uses data, particularly CO_2 emissions and GDP from the Energy Information Administration (EIA) of the United States Department of Energy (EIA 2007a and EIA 2007b). Besides, EIA, CO_2 emission inventories are also produced by various organizations such as the International Energy Agency (IEA); World Resources Institute (WRI), a Washington DC based environmental policy research organization; national institutions particularly those preparing National Communications to the UNFCCC, etc. The selection of EIA for data source is based mainly on two reasons. First, the focus of this study is on future emissions instead of the historical emissions, sources like WRI and UNFCCC do not forecast future emissions[6]. IEA projects future emissions, but with a lower details as compared to EIA[7]. Second, the IEA does not provide the projection of emission intensities which is the primary element of this study. Note, however, that emissions projections between IEA and EIA are not significantly different; IEA's reference case projections of energy related global CO_2 emissions are 2 percent and 6 percent smaller than those of EIA's in 2015 and 2030, respectively.

3. Global CO_2 Emissions and Intensities

[6] While UNFCCC provides historical emissions for all Annex I countries, it does not cover those Non-Annex I countries which have not submitted necessary information, such as, National Communications.

[7] IEA (2006) does not provide CO_2 emission forecasts for years 2010, 2020 and 2025, whereas EIA (2007) provides the forecasts at 5 years interval for the 2004-2030 period.

This section briefly discusses on historical and future CO_2 emissions as well as CO_2 emission intensities of various countries and geopolitical regions[8].

3.1 CO_2 Emissions

Table 1 and Figure 1 present historical and future CO_2 emissions from energy related activities[9], country/regional mix in global CO_2 emissions and average annual growth rates of emissions experienced over the last 25 years and expected over the next 25 years. There is a slight difference between the historical emissions and the projected emissions; while the historical emissions account for emissions from oil and natural gas flaring, the projected emissions do not. The difference, however, is negligible and hence ignored.

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[8] Ideally, study like this should have discussed GHG emissions and GHG intensities instead of only CO_2 emissions and intensities, however, data limitations, particularly the lack of detailed data for non-CO_2 GHGs constrained in so doing. Although IPCC (2000) provides forecasts of all types of GHG under 40 scenarios, these forecasts are presented in globally aggregated level and not available at the national or regional levels. Moreover, the focus of IPCC scenarios is for long-term forecasts (i.e., for 100 years) instead of short-term ones this study is dealing with.

[9] Other activities such as land use, land use change and forestry (LULUCF) also release CO_2 emissions. At the same time, these activities also act as sink of CO_2; net release of CO_2 differs country to country. For example, LULUCF has been acting as a net sink of CO_2 historically in the United States (USEPA, 2006). The Initial National Communication of China to the UNFCCC reports that the LULUCF has acted as a net sink of CO_2 in China (PRC, 2004).

Table 1: CO_2 Emissions, National/Regional Shares and Average Annual Growth Rates

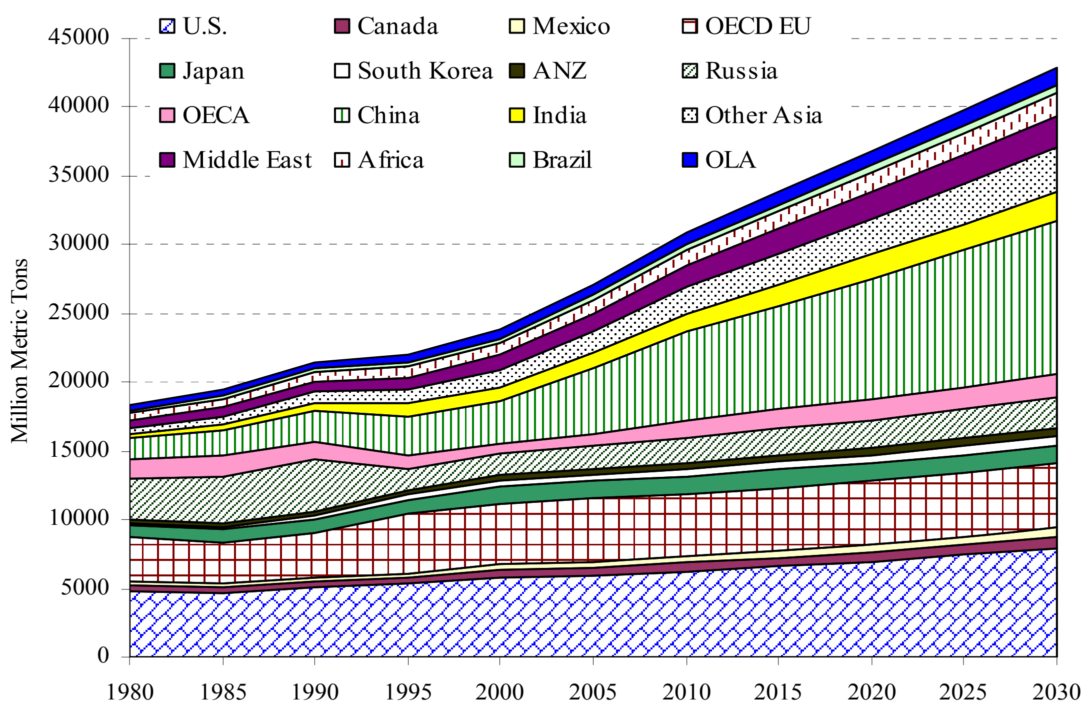
Country or Region	CO_2 Emissions (Million Metric Tons CO_2)			Country/regional Share (percent)			Average Annual Growth Rate (percent)	
	1980	2004	2030	1980	2004	2030	(1980-04)	(2004-30)
United States	4,755	5,912	7,950	25.9	21.9	18.5	0.9	1.2
Canada	453	588	750	2.5	2.2	1.7	1.1	1.0
Mexico	231	385	699	1.3	1.4	1.6	2.1	2.4
OECD EU	3,263	4,653	4,684	17.8	17.2	10.9	1.4	0.0
Japan	938	1,262	1,306	5.1	4.7	3.0	1.2	0.1
South Korea	126	497	691	0.7	1.8	1.6	5.6	1.3
ANZ	218	424	573	1.2	1.6	1.3	2.7	1.2
Russia	3,028	1,685	2,185	16.5	6.2	5.1	-2.3	1.0
OECA	1,395	866	1,693	7.6	3.2	3.9	-1.9	2.7
China	1,475	4,786	11,239	8.0	17.7	26.2	4.8	3.5
India	300	1,113	2,156	1.6	4.1	5.0	5.4	2.7
Other Asia	499	1,523	3,141	2.7	5.6	7.3	4.6	2.9
Middle East	495	1,320	2,306	2.7	4.9	5.4	4.0	2.3
Africa	534	987	1,655	2.9	3.6	3.9	2.5	2.1
Brazil	187	337	597	1.0	1.2	1.4	2.4	2.3
OLA	437	705	1,254	2.4	2.6	2.9	1.9	2.3
Global	18,333	27,042	42,879	100	100	100	1.6	1.9

OECD EU refers to OECD Europe; ANZ stands for Australia and New Zealand; OECA for Non-EU countries and Central Asian Republics, and OLA for South America excluding Brazil.

Source: EIA (2007a) for historical emissions and IEA (2007b) for projected emissions.

As illustrated in the figure and table, the global CO_2 emissions reached about 27 billion tons of CO_2 (tCO_2) in 2004 from about 18 billion tCO_2 in 1980, registering a 50 percent increase. Asia and Middle East countries have experienced the fastest growth in their CO_2 emissions during the 1980-2004 period. For example, the CO_2 emissions in China in 2004 are more than double its 1980 level. India and South Korea's emissions in 2004 are about three times as high as their 1980 emissions. Other developing Asian countries as a whole have also experienced the doubling of their CO_2 emissions in 2004 as compared to their 1980 emissions. Intuitively, two factors are responsible for developing Asia and Middle East's relatively higher growth of CO_2 emissions: first, high economic growths and secondly, heavy reliance on fossil fuels. Some OECD countries have also registered large increases in their CO_2 emissions during the 1980-2004 period. Australia and New Zealand's combined emission has increased by 94 percent, Mexico has exhibited a 67 percent increase.

Figure 1: CO_2 Emissions by Countries and Regions for years 1980 and 2004 (Million Metric Tons of CO_2)



Source: EIA (2007a) for historical emissions and IEA (2007b) for projected emissions.

Russia and Other Europe & Central Asia[10] experienced significant drops in their CO_2 emissions. While Russia's total CO_2 emissions in 2004 was 44 percent smaller from its 1980 level, Other Europe & Central Asia's total CO_2 emissions was 38 percent smaller from the region's 1980 emissions. Two reasons can be attributed for these drops in emissions, first economic down-turn during their transition from centrally planned economy to market economy and secondly, particularly in the case of Russia, change in country's geography – it was Former Soviet Union (FSU) in 1980 but only Russia in 2004.

According to the reference case projection of EIA (2007b), the global CO_2 emissions would reach about 43 billion tCO_2 by 2030 (see Figure 1 and Table 1). It is 2.3 times as high as that of 1980 level, twice as high as that of 1990 level, 80 percent higher than 2000 level and about 60 percent higher than 2004 level. Unlike the historical trends where Russia and Other Europe & Central Asia experienced significant drops in their emissions, all countries or regions are expected to increase their emissions along with their economic growths. Although annual emission growth rates over the next 25 years are expected to be smaller than those over the last 25 years in many countries or regions, the reverse is expected in the United States, Mexico, Russia, Other Europe & Central Asia and South America excluding Brazil. It is interesting to note that while most

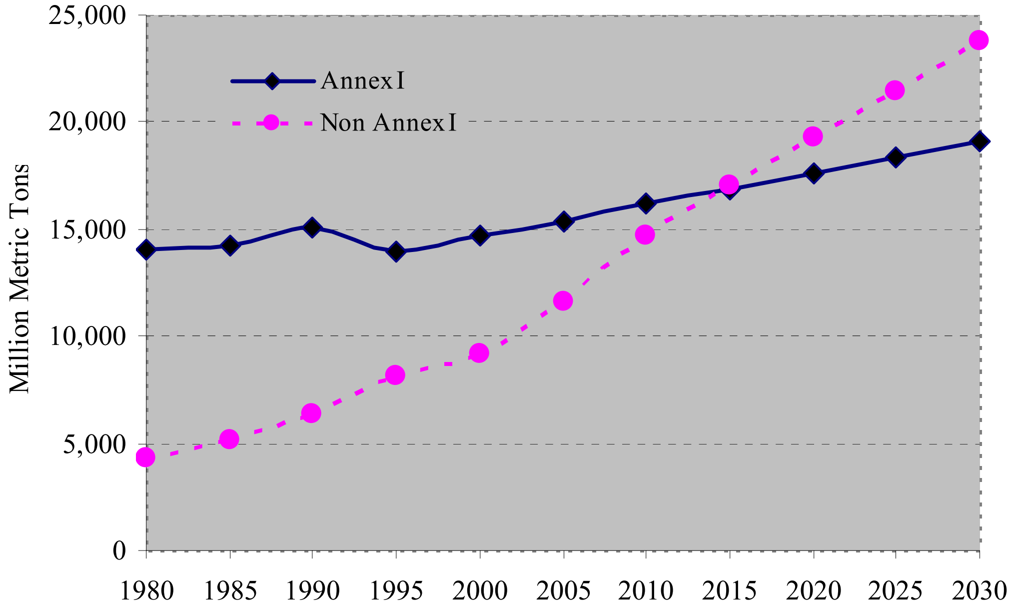
[10] Russia refers to Former Soviet Union (FSU) in 1980 but only Russia in 2004. 'Other Europe & Central Asia' includes Albania, Bulgaria, Former Czechoslovakia, Former Yugoslavia, Former East Germany, Hungary, Malta, Poland and Romania in 1980. In 2004, this group includes all countries which were part of FSU excluding Russia, all newly independent European countries and other NON-OECD European countries.

developing countries future emissions would grow at smaller rates than their past emissions, United States is expecting to grow its future CO_2 emissions at a higher rate than its past emissions. The global CO_2 emission increased by an average rate of about 1.6 percent per year over the last 25 years, this rate could reach 1.9 percent over the next 25 years.

United States, European Union and Former Soviet Union accounted for respectively, 26, 18 and 17 percent of the global CO_2 emissions in 1980. This mix has significantly changed by 2004 as China emerged in a second place after the United States. By 2030, it is expected that China would top with 26 percent of global CO_2 emissions followed by the United States with 19 percent.

It would be more relevant to present the global CO_2 emissions dividing between Annex I and non-Annex I group of countries. Although non-Annex I countries' historical growth rates of CO_2 emissions are much higher than that of Annex I countries, the former' total CO_2 emissions is still smaller than that of latter's. In 1980, non-Annex I countries' share in the global CO_2 emissions was 23 percent. However, it has almost doubled by 2004. Moreover, non-Annex I countries' total emissions is expected to surpass Annex I countries' by 2015 (see Figure 2). Their share in global CO_2 emissions would increase to 50 percent in 2015 from 43 percent in 2004. The share would further increase to 55 percent by 2030. This implies that although developed countries were primarily responsible for past emissions, developing countries would be equally responsible for future emissions.

Figure 2: Projection of Annex I and Non-Annex I Countries Total CO_2 Emissions (Million Metric Tons of CO_2)



Source: EIA (2007a) for historical emissions and IEA (2007b) for projected emissions.

3.2 CO_2 Intensity

Figure 3 and Table 2 illustrate comparisons of historical as well as future trends of CO_2 intensities across different countries and regions[11]. Historically CO_2 intensities decreased in most of the countries or regions, thereby resulting in decline of global average CO_2 intensity[12]. The highest level of decline is observed in China, where it

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[11] Baumert et al. (2004) reports that global average CO_2 intensity is about 15 percent smaller than global average GHG intensity in 2000.

[12] Decomposition analyses could be helpful to explain the factors responsible for emission intensity trends (Lee and Oh, 2006; Wang et al. 2005).

decreased to 0.72 Metric tons per thousand dollar GDP in 2004 from 1.96 Metric tons per thousand dollar GDP in 1980, a 63 percent drop due mainly to decrease in energy intensity[13]. Other countries or regions exhibiting large drops in their CO_2 intensities during 1980-2004 period include OECD Europe (41 percent), United States (40 percent), Other Europe & Central Asia (36 percent), Canada (33 percent), Japan (24 percent) and South Korea (20 percent). While the reduction in energy intensity is mainly responsible for the decrease in emission intensity in North America and OECD Europe, fuel substitution, particularly from coal and oil to gas is responsible for the decrease in Other Europe & Central Asia, Japan and South Korea.

Some regions have experienced increase in CO_2 intensities during the period; the most notable is the Middle East region, where the CO_2 intensity increased by 95 percent during the 1980-2004 period because of increases in their energy intensities. The CO_2 intensities of Brazil and Africa also increased during the period.

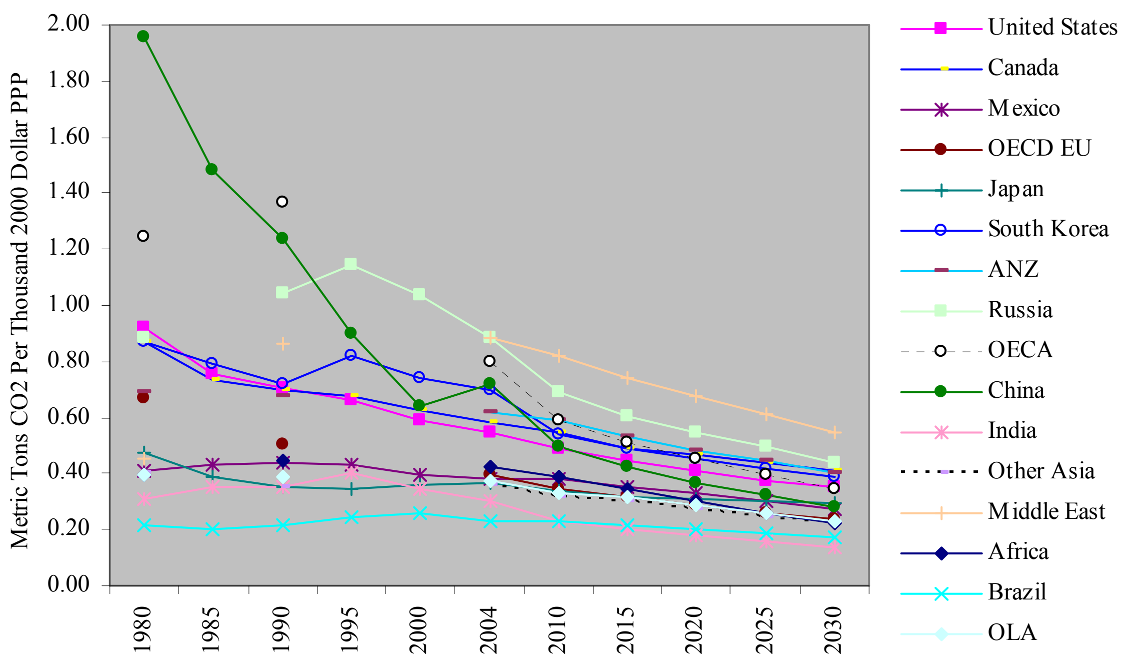
Unlike in the historical case, CO_2 intensities are expected to decrease in future in all countries or regions by, at least, 20 percent in 2030 from their 2004 levels. This would result in a drop of global average CO_2 intensity in 2030 by 44 percent from that in 2004. Like in the past, China is expected to lead in cutting its CO_2 intensity, again through a

[13] Energy intensities decrease due mainly to two reasons: structural change and energy efficiency improvement. The structural change here refers to switching over to less energy intensive industries (e.g., service sectors, textile, computer and electronics etc.) from more energy intensive industries (e.g., iron & steel, cement, pulp & paper etc.). The energy efficiency improvement refers to improvements in efficiency of energy consuming devices and processes.

reduction in its energy intensity. By 2030, China's CO_2 intensity could be 60 percent below its 2004 level. This is followed by Other Europe & Central Asia with a 56 percent drop. India, which exhibited just a 3 percent drop over the last 25 years, is expecting to drop its future intensity by 54 percent over the next 25 years through the reduction in energy intensity[14]. Other countries expecting CO_2 intensity drops by more than 40 percent are Russia (50 percent), Africa (47 percent), South Korea (44 percent) and OECD Europe slightly above 40 percent.

Figure 3: CO_2 Emission Intensity

(Metric Tons of CO_2 per Thousand Dollar of GDP Measured in 2000 Purchasing Power Parity)



Source: EIA (2007a) for historical intensities and IEA (2007b) for projected intensities.

[14] EIA (2007b) assumptions on the reduction of energy intensities in China and India for the next 25 years might look too optimistic.

There are two very interesting and important findings from this emission intensity analysis. First, developing countries like China, India and even Africa are expecting higher percentage drops in their CO_2 intensities than developed countries in future. Secondly, developing countries' future CO_2 intensities would remain, as in the past, much smaller than that of most developed countries by 2030 (Please see Table 2). These findings could provide an important insight during the negotiations for post-Kyoto commitments.

Table 2: CO_2 Intensities and their Average Annual Growth Rates

Country/Region	CO_2 Intensities (Metric tons per thousand dollar)			AAGR of CO_2 Intensities (percent)	
	1980	2004	2030	1980-2004	2004-2030
United States	0.92	0.55	0.35	-2.1	-1.7
Canada	0.87	0.58	0.41	-1.7	-1.4
Mexico	0.41	0.38	0.27	-0.3	-1.2
OECD EU	0.67	0.39	0.24	-2.2	-2.0
Japan	0.48	0.36	0.29	-1.1	-0.8
South Korea	0.87	0.69	0.39	-0.9	-2.2
ANZ	0.69	0.62	0.40	-0.5	-1.7
Russia	0.88	0.88	0.44	0.0	-2.6
OECA	1.24	0.80	0.34	-1.8	-3.2
China	1.96	0.72	0.28	-4.1	-3.5
India	0.31	0.30	0.14	-0.1	-3.0
Other Asia	0.40	0.36	0.22	-0.4	-1.9
Middle East	0.45	0.89	0.55	2.8	-1.9
Africa	0.40	0.43	0.22	0.3	-2.4
Brazil	0.21	0.23	0.17	0.4	-1.1
OLA	0.39	0.37	0.23	-0.2	-1.8
Global	0.71	0.49	0.28	-1.5	-2.2

Source: EIA (2007a) for historical intensities and IEA (2007b) for projected intensities.

4 The Kyoto Protocol and Stabilization Scenarios

4.1 The Kyoto Protocol

The Kyoto Protocol to the UNFCCC mandated Annex I countries to limit their GHG emissions over the 2008-2012 period 5.2 percent, in average, below their 1990 level; the Protocol does not set any targets for the rest of the countries. Australia and United States have not ratified the Protocol. Table 3 translates global CO_2 emissions in year 2010 under three different conditions: (a) No- Kyoto obligations (i.e., BAU); (b) full Kyoto obligation including the United States and Australia's participation and (c) Kyoto obligation without the United States and Australia. The table also presents percentage changes in CO_2 emissions in 2010 from 1990.

Table 3: CO_2 Emissions Change as Specified in Kyoto Protocol

	No Kyoto Obligation (BAU)	Full Kyoto Obligation	Kyoto Obligation without US and Australia
1990 CO_2 Emissions (Million Metric Tons of CO_2)			
Annex I	15,091		
Non-Annex I	6,335		
Global	21,425		
2010 CO_2 Emissions (Million Metric Tons of CO_2)			
Annex I	16,168	14,366 (12,359)	16,323 (14,117)
Non-Annex I	14,690	14,690	14,690
Global	30,858	29,056 (27,049)	31,013 (28,807)
Percentage Change in CO_2 Emissions between 1990 and 2010 (percent)			
Annex I	7	-5 (-18)	7 (-6)
Non-Annex I	132	132	132
Global	44	36 (26)	44 (34)

The numbers in parenthesis refer to the case where Russia and Ukraine do not sell their surplus allowances

The level of CO_2 reduction due to the Kyoto Protocol depends on number of factors. First the participation level of Annex I countries; second treatment of Russia and Ukraine's potential surplus allowances and third Annex I countries' ability to meet their commitments. If the Kyoto Protocol were to implement as it was designed initially and Russia and Ukraine do not use their surplus allowances, Annex I countries total emissions would decrease by 18 percent. Since Non-Annex I countries do not have any binding targets, their emissions would increase at the same rate as in the BAU case, 132 percent. Globally, CO_2 emissions in 2010 would be 26 percent higher than that of 1990. However, this is not a reality now because the U.S. and Australia have decided to stay outside the Kyoto Protocol. Moreover, there is no legal provision under the Kyoto Protocol to prevent Russia and Ukraine from selling their surplus allowances. In the absence of US and Australia's participation, there would be no reduction in Annex I countries' total CO_2 emissions if Russia and Ukraine's surplus allowances were utilized. In fact, Annex I and global emissions would be slightly higher than their BAU emissions if Russia and Ukraine utilize their surplus allowances. On the other hand, if Russia and Ukraine do not find markets for their surplus emissions, Annex I countries' total emissions would be 6 percent below from 1990 level even in the absence of the U.S. and Australia's participation to Kyoto. In this case, global emissions in 2010 would be 34 percent higher than that in 1990. Summarizing this discussion, global CO_2 emissions in 2010 would be 26 percent to 44 percent higher than their 1990 level depending on factors mentioned above.

4.2 Stabilization Scenarios

The ultimate objective of the UNFCCC is to stabilize GHG concentrations in the atmosphere to avoid climate change (UNFCCC, 1992). Due to scientific uncertainties in the climatic system the concentrations level to be stabilized has not been unambiguously determined yet (Metz and van Vuuren 2006). However, there is a general understanding among the scientific community that atmospheric concentrations of CO_2 may need to be contained below 450 ppm to avoid the "dangerous interference" mentioned in the UNFCCC text (Kopp 2004). If non-CO_2 GHGs are also included, the concentrationss level would be 550 ppm CO_{2eq}. Non-CO_2 GHGs would have significant impacts on global warming because of their much higher rediative forcing (or global warming potential) compared to CO_2 (IPCC 2007). Moreover, their inclusion provides flexibility to reduce the costs of stabilizing the GHG concentrations (e.g., Weyant et al. 2006). However, non-CO_2 GHGs are often excluded from most existing studies because of lack of data (Sarofim et al 2004). This study too does not include non-CO_2 GHGs because neither historical nor forecasts of these gases are available to the details needed here.

To stabilize atmospheric CO_2 concentrations at 450 ppm level, global CO_2 emissions must decline before 2030 (Grubb et al 2006; Stern 2006). The Fourth Assessment Report of IPCC concludes that to stabilize CO_2 concentrations between 400 – 440 ppm level, global CO_2 emissions should start declining by 2020; to stabilize CO_2 concentrations between 440 – 485 ppm level, global CO_2 emissions should start declining by 2030 (IPCC 2007). To achieve this level of stabilization, stringent mitigation targets and wider participation, including non-Annex I countries, might be required.

In this study, we have developed two scenarios for the near-term (i.e., until 2030) targets for CO_2 emissions reductions in line with long term stabilization of CO_2 concentrations at 450 ppm level. While developing these scenarios we followed two principles. First, Annex I countries' historical emissions are primarily responsible for the hitherto build up of GHG concentrations in the atmosphere. Secondly, non-Annex I countries share in the total CO_2 emissions is continuously increasing and will surpass to that of Annex I countries within a few years. By 2030, non-Annex countries would contribute 55 percent of the global CO_2 emissions (EIA, 2007b). It is unlikely to get global emissions declining before 2030 unless non-Annex I countries' total emissions start declining. We therefore consider two scenarios for non-Annex I countries' total emissions[15] : stabilization of their total CO_2 emissions at the (i) 2020 level and (ii) 2030 level[16]. In the case of Annex I countries, their emissions paths are assumed to follow the targets as specified below in both scenarios:

- For OECD Annex I countries, GHG reduction targets in 2010 doubles in 2020 and triples in 2030 no matter whether or not the Annex I countries participate in the

[15] This does not mean that every Non-Annex I country has to stabilize their CO_2 emissions. Our focus here is the stabilization of Non-Annex I countries' total emissions, which could be achieved if major Non-Annex I emitters reduces their emissions leaving least developed countries to emit in their BAUs.

[16] The study also estimates CO_2 reductions required from the Annex I countries to reverse the global CO_2 trend before 2030 even in the absence of Non-Annex I countries' efforts in so doing.

first commitment period (2008-2012) or comply with their commitments during that period;

- Russia and Economies in transition stabilize their emissions at their 2015 emission levels until 2030, and they do not sell their surplus allowances during the first commitment period;

- Australia's 2020 and 2030 emissions would be 10 percent and 20 percent below from its 1990 emission level.

It is possible to develop a large number of scenarios. However, we have limited to two plausible scenarios for the sake of clarity. One additional scenario which assumes developing countries to stabilize their CO_2 emissions before 2020, say 2015, could be developed. Moreover, non-Annex I countries could be assumed not only stabilizing their emissions at the level of their 2020 or 2025 emissions but also reduce gradually thereafter. However, following the current post-Kyoto negotiations, such scenarios might be unlikely. Still, the study could be extended further to include these scenarios.

The scenarios considered in this study have been developed in line with the long-term stabilization paths considered in the most existing studies. For example, IPCC (2007) projects that a scenario to stabilize CO_2 concentrations between 440 ppm and 485 ppm requires global CO_2 emissions in 2050 to be limited to -30 percent to +5 percent of 2000 level. Stern (2006) suggests that stabilizing CO_2 concentrations around 440 to 500 ppm would require global emissions to be around 25 percent below the current (i.e., 2005) levels. All the models presented in Grubb et al (2006) find that the stabilization of atmospheric CO_2 concentrations at 450 ppm level require global CO_2 trend to be reversed by 2025 at the latest and CO_2 emissions in 2050 would be 8 to 32 percent below from the 2000 level.

5. Reductions in CO_2 Emissions under the Stabilization Scenarios

The percentage reduction of CO_2 emissions in different countries/regions from their 1990 levels under both scenarios are presented in Table 4. Under Scenario 1, global CO_2 emissions in 2020 and 2030 would be 46 percent and 52 percent higher than thier1990 levels. While Annex I countries' total emissions in 2020 and 2030 would be respectively, 21 percent and 26 percent lower from their 1990 levels, non-Annex countries' total emissions would be two times higher from their 1990 levels in 2020 and 2.4 times higher in 2030. Under Scenario 2, global CO_2 emissions in 2030 would be 10 percent lower than that under Scenario 1 (i.e., 42 percent above the 1990 levels); non-Annex I countries' total emissions in 2030 would still be twice as high as that of 1990 levels.

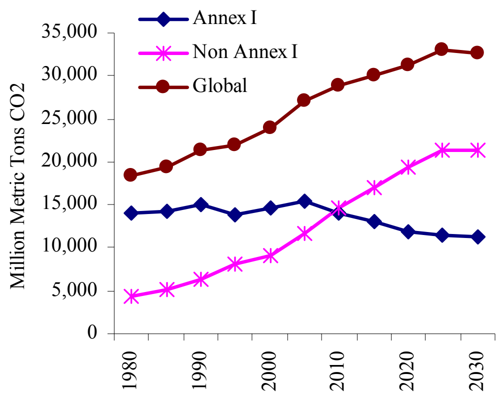
Table 4: Percentage Reduction of GHG Emissions from their 1990 Level

Country/Region	Percentage Change in CO_2 Emissions					
	Scenario 1			Scenario 2		
	2010	2020	2030	2010	2020	2030

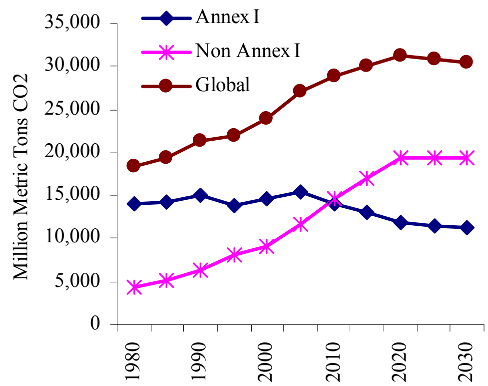
U.S.	24	-14	-21	24	-14	-21
Canada	-6	-12	-18	35	-12	-18
Mexico	60	97	115	60	97	97
OECD EU	-8	-16	-24	-8	-16	-24
Japan	-6	-12	-18	-6	-12	-18
South Korea	120	158	173	120	158	158
ANZ	62	0	-10	62	0	-10
Russia and OECA	-40	-35	-35	-40	-35	-35
China	185	286	336	185	286	286
India	118	192	230	118	192	192
Other Asia	146	232	266	146	232	232
Middle East	119	170	193	119	170	170
Africa	59	98	115	59	98	98
Brazil	81	125	144	81	125	125
OLA	76	125	146	76	125	125
Annex I Group	-5	-21	-26	-5	-21	-26
Non-Annex I Group	132	204	239	132	204	204
Global	35	46	52	35	46	42

Figure 4 illustrates emission paths of total CO_2 emissions at Annex I, non-Annex I and Global levels. As can be seen from the figure, Annex I countries' total CO_2 emissions are gradually declining from 15.4 billion tCO_2 in 2004 to 11.2 billion tCO2 in 2030 in both scenarios. non-Annex I and global CO_2 emissions peak in 2025 with 21.4 billion tCO_2 and 33 billion tCO_2, respectively under Scenario 1. The global CO_2 emissions then drop to 32.6 billion tCO_2 by 2030. Under Scenario 2, non-Annex I and global CO_2 emissions peak in 2020 with 19.3 billion tCO_2 and 31.2 billion tCO_2, respectively. The global CO_2 emissions drop to 30.8 billion tCO_2 in 2025 and 30.4 in 2030.

Figure 4: Global, Annex I and Non-Annex I CO_2 Emissions under Different Scenarios



(a) Scenario 1



(b) Scenario 2

We also examined a question: how much CO_2 reductions would be required from Annex I countries if they were alone to take responsibilities of reversing the global trend of CO_2 before 2030. If Non-Annex I countries do not reduce their CO_2 emissions and if global CO_2 emissions path has to be maintained as specified under Scenario 1, Annex I countries, as a whole, require to limit their CO_2 emissions 18 percent and 37 percent below from 1990 levels in 2025 and 2030, respectively. Similarly, to attain the global CO_2 emissions path as specified under Scenario 2 in the absence of non-Annex I countries mitigation efforts, Annex I countries, as a whole, need to cut their CO_2 emissions 15 percent, 33 percent and 52 percent below from 1990 levels in 2020, 2025 and 2030 respectively.

Table 5 presents the levels of CO_2 reductions in various countries/regions from respective BAU cases to achieve the scenarios considered. To cause the global CO_2 emissions declining stating from 2025 (i.e., Scenario 1), Annex I and non-Annex countries' total emissions are required to be lowered by 42 percent and 10 percent respectively in 2030 from the respective BAU emissions. If the peaking of global emissions is advanced by 5 years to 2020 (i.e., global emissions start declining from 2020, Scenario 2), Annex I and non-Annex I countries require to lower their total CO_2 emissions in 2030 by 42 percent and 19 percent, respectively from their BAU levels. Global CO_2 emissions in 2030 would be 24 percent and 29 percent smaller from their BAU levels under Scenario 1 and Scenario 2, respectively.

Table 5: Percentage Reduction of GHG Emissions from their BAU Level

Country/Region	Percentage Change in CO_2 Emissions					
	Scenario 1			Scenario 2		
	2010	2020	2030	2010	2020	2030
United States	0	-38	-50	0	-38	-50
Canada	-31	-39	-48	0	-39	-48
Mexico	0	0	-8	0	0	-15
OECD EU	-34	-41	-48	-34	-41	-48
Japan	-25	-31	-36	-25	-31	-36
South Korea	0	0	-6	0	0	-11
Australia/New Zealand	0	-44	-54	0	-44	-54
Russia, Other Europe & Central Asia	0	-7	-15	0	-7	-15
China	0	0	-11	0	0	-22
India	0	0	-10	0	0	-20
Other Asia	0	0	-9	0	0	-17
Middle East	0	0	-7	0	0	-14
Africa	0	0	-7	0	0	-14
Brazil	0	0	-9	0	0	-16
Other Latin America	0	0	-7	0	0	-15
Annex I Group	-11	-32	-42	-11	-32	-42
Non-Annex I Group	0	0	-10	0	0	-19
Global	-6	-15	-24	-6	-15	-29

6. The Intensity based Targets for Atmospheric Stabilization

It would be interesting to investigate how much cuts in emission intensities would be required if the Scenario 1 and 2 were to achieve through intensity targets meaning that de-carbonization of economies without sacrificing economic outputs (i.e., GDP)[17]. Figure 5 presents percentage reductions of CO_2 intensities required in 2020 and 2030 from current levels to cause global CO_2 emissions decline by 2025 (Scenario 1) and by 2020 (Scenario 2).

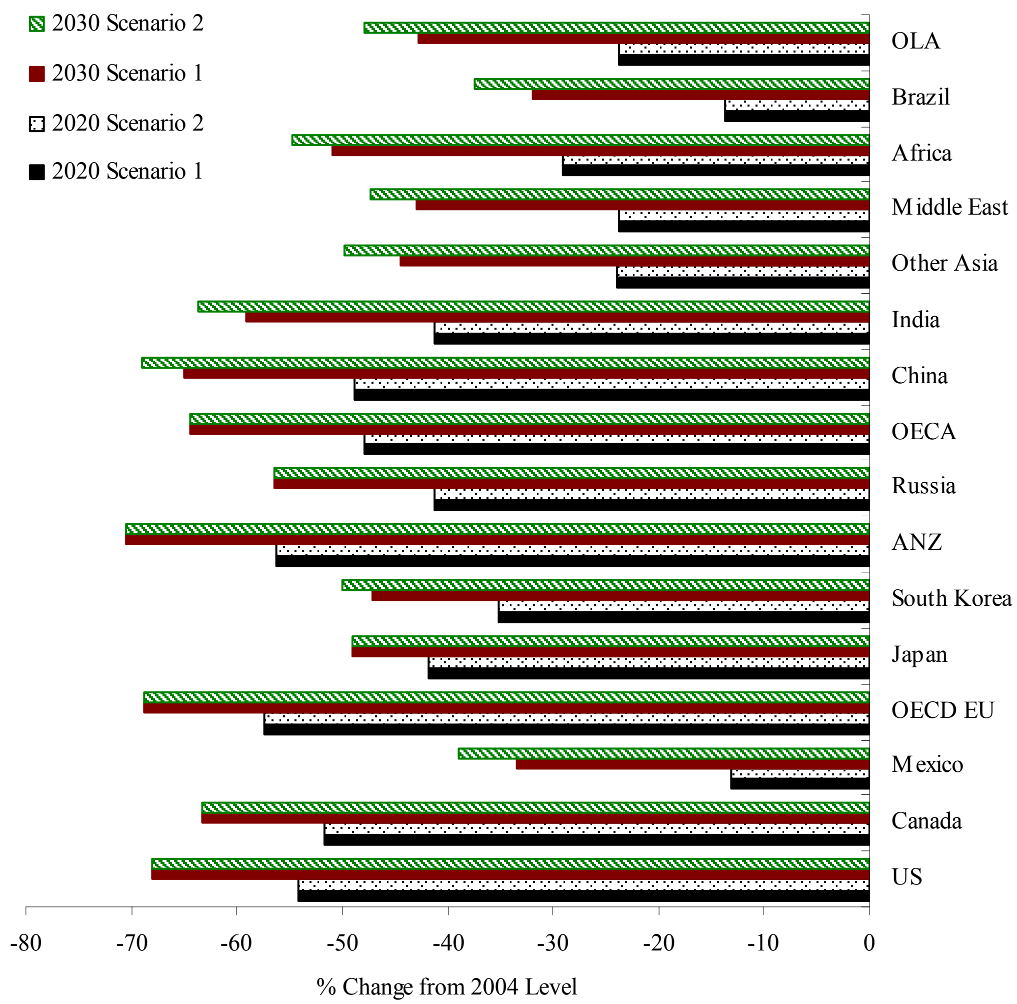
In order to cause global CO_2 to decline by 2025 (Scenario 1) without negatively affecting the expected economic growths, CO_2 emission intensities of most Annex I countries and China need to be reduced by 50 percent or more from their 2004 levels by 2025. The CO_2 intensities of these countries plus India are required to be cut by more than 60 by 2030 to maintain that declining trend of global CO_2 emissions through 2030. If the global CO_2 emissions were to decline by 2020 (Scenario 2) without sacrificing economic outputs, the CO_2 intensities of most Annex I countries plus China and India would be required to be cut by more than 40 percent in 2020, more than 50 percent in 2025 and more than 65 percent in 2030.

Since CO_2 intensities are also expected to decline in BAU case, the additional cuts in CO_2 intensities above their BAU varies significantly across countries/regions. For example, under Scenario 2, most OECD Annex I countries would require to further cut their CO_2 intensities 50 percent above their BAU reductions in 2030. On the other hand,

[17] More precisely, without impacting negatively the expected (or BAU) economic (i.e., GDP) growth.

larger non-Annex countries, such as India and China, would require cutting more than 20 percent above their BAU reductions in 2030.

Figure 5: Required Emission Intensity Reductions in Various Countries or Regions to Cause a Decline in Global CO_2 Emissions before 2030 (Percent)



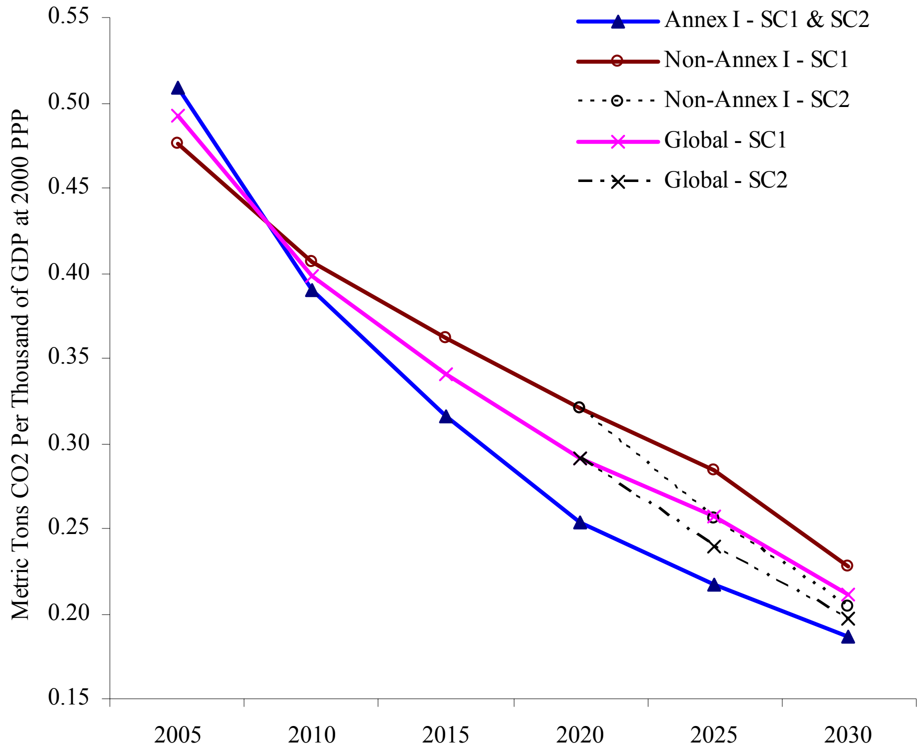
Note: The percentage reductions in 2020 are the same for both Scenario 1 and Scenario 2 because the scenarios start from this year (i.e., the same for that year)

In order to trigger the global CO_2 emissions declining by 2025 (i.e., Scenario 1) without negatively affecting expected economic growths, the Annex I countries' average

CO_2 intensity would be required to drop by 50 percent in 2020, 57 percent in 2025 and 63 percent in 2030 from the 2004 level of 0.51 Metric tons per thousand dollars (see Figure 6). Similarly, the non-Annex I countries' average CO_2 intensity would be required to drop by 33 percent in 2020, 40 percent in 2025 and 52 percent in 2030 from the 2004 level of 0.48 Metric tons per thousand dollar. At the Global level, the average CO_2 intensity would be required to drop by 41 percent in 2020, 48 percent in 2025 and 57 percent in 2030 from the 2004 level. In order to cause the global CO_2 emissions declining by 2020 (i.e., Scenario 1) without negatively affecting expected economic growths, the non-Annex I countries' average CO_2 intensity would be required to drop further, by 5 percent at the top of the reductions under Scenario 1 in 2025 and 2030. Similarly, the global average CO_2 intensity would be required to drop further, by 3 percent.

Our study shows that Annex I countries are required reducing their absolute emissions by 21 percent, in average, from their 1990 levels in 2020 to cause global CO_2 emissions to decline from that year. If the intensity targets were set to achieve the same level of absolute emission reductions, their average CO_2 intensity should be cut by 62 percent from the 1990 level in 2020 and 72 percent in 2030. Note that the percentage reductions in CO_2 intensity required are almost three times as high as that of absolute emissions. This is because their total GDP in 2020 and 2030 are expected to be, respectively, 2.1 times and 2.6 times as high as that of 1990 level. If Non-Annex I countries' total CO_2 emissions were to stabilize at 2020 level without negatively affecting their economic growths, their average emission intensity would drop by 42 percent and 63 percent from their 1990 level in 2020 and 2030, respectively.

Figure 6: Reductions in Average Global, Annex I and Non-Annex I Emission Intensities Required to Cause a Decline in Global CO_2 Emissions before 2030



Would it be feasible to achieve the required emission reductions through intensity based targets meaning that without affecting the expected economic growths? To answer this question is beyond the scope of this study. Climate change policy models, particularly based on dynamic general equilibrium settings, might be able to answer this query. Further studies are hence needed to investigate whether or not intensity based targets could lead to the atmospheric stabilization of CO_2 concentrations at the level implied by the Article 2 of the UNFCCC.

7. Conclusions and Final Remarks

This study analyzes CO_2 emissions reduction targets for various countries and geopolitical regions by the year 2030 in order to stabilize atmospheric concentrations of CO_2 at the level of 450 ppm (550 ppm including non-CO_2 GHGs). Moreover the study determines the level CO_2 intensity cuts (or intensity based targets) needed in those countries and regions to achieve the emission reductions without negatively affecting their expected economic growth. We developed two scenarios to reverse the trend of global average CO_2 emissions, which is otherwise expected to increase by approximately 2 percent annually between 2004 and 2030. The first scenario aims to decrease the global CO_2 emissions starting from 2025, whereas the second scenario aims at the same goal five years earlier in 2020.

The study finds that reversing the global CO_2 emissions trend by 2020 requires Annex I countries total CO_2 emissions to be reduced 21 percent and 26 percent below the their 1990 levels in years 2020 and 2030, respectively. The non-Annex I countries' total CO_2 emissions, on the other hand, are kept at the 2020 level, which would be twice as high as their 1990 level. The global CO_2 emissions would remain 46 percent and 42 percent above the 1990 level in 2020 and 2030, respectively. The global, non-Annex I and Annex I emissions would be 29, 19 and 42 percent smaller than respective business as usual or BAU emissions in 2030. If the reversing of global CO_2 emissions is delayed by five years, allowing the non-Annex I to emit in their business as usual path until 2025, the global CO_2 emissions would be 52 percent higher from the 1990 level and 24 percent lower from the BAU level in 2030.

If intensity based targets instead of absolute emission targets were to use to achieve the same levels of emission reduction, our study finds that the former would be significantly higher than the latter. In order to reverse the global trend of CO_2 emissions by 2020 and maintaining it 42 percent above the 1990 level in 2030, average CO_2 intensities at global, non-Annex I and Annex I levels would be cut by respectively, 68, 63 and 72 percent from the respective values in 1990. In 2030, the percentage cut in average emission intensity of Annex I countries is 2.6 times as high as the percentage cut in their total emissions. This study does not investigate whether or not such cuts in CO_2 intensities are feasible. Further studies are therefore needed to examine the viability of intensity based targets to stabilize atmospheric stabilization of GHG concentrations at the level implied by the United Nations Framework Convention on Climate Change.

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