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Greenhouse Gas Emission Drivers: Population, Economic Development and Growth, and Energy Use

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Summary

In the context of climate change and possible responses to the risk associated with it, three variables strongly influence the levels and growth of greenhouse gas (GHG) emissions: population, income (measured as per capita gross domestic product [GDP]), and intensity of emissions (measured as tons of greenhouse gas emissions per million dollars of GDP).

$$(Population) \times (per\ capita\ GDP) \times (Intensity_{ghg}) = Emissions_{ghg}$$

This is the relationship for a given point in time; over time, any effort to change emissions alters the exponential rates of change of these variables. This means that the rates of change of the three left-hand variables, measured in percentage of annual change, sum to the rate of change of the right-hand variable, emissions.

For most countries, and for the world as a whole, population and per capita GDP are rising faster than intensity is declining, so emissions are rising. Globally, for the variables above over the period 1990-2005, *the rates of change* (Δ) in annual percent sum as follows (numbers do not add precisely because of rounding):

$$Population\ \Delta + per\ capita\ GDP\ \Delta + Intensity_{ghg}\ \Delta = Emissions_{ghg}\ \Delta$$
$$(+1.4) + (+1.7) + (\ -1.6) = (+1.6)$$

As can be seen, global emissions have been rising at a rate of about 1.6% per year, driven by the growth of population and of economic activity.

Within this generalization, countries vary widely. (Unless otherwise noted, comments about countries refer to the top-20 emitters as of 2005, who accounted for about 75% of world emissions that year.) Between 1990 and 2005, in some countries, including Brazil, Mexico, Indonesia, and South Africa, population growth alone exceeded the decline in intensity. For most countries, and for the world as a whole, per capita GDP growth exceeded the intensity improvement each achieved. Countries for whom intensity improvements were greater than their per capita GDP increases included Germany, the United Kingdom, the United States, France, and South Africa. And both the Russian Federation and the Ukraine, following their economic contractions in the 1990s, posted negative numbers for population, per capita income, intensity, and GHG emissions between 1990 and 2005. Besides the Russian Federation and the Ukraine, only the United Kingdom and Germany reduced their GHG emissions for the period (Germany being helped by reductions in the former East Germany).

Stabilizing greenhouse gas emissions would mean the rate of change equals zero. Globally, with a population growth rate of 1.4% per year and an income growth rate of 1.7% per year, intensity would have to decline at a rate of -3.1% per year to hold emissions at the level of the year that rate of decline went into effect. Within the United States, at the 1990-2005 population growth rate of 1.1% per year and income growth rate of 1.8% per year, intensity would have had to decline at a rate of -2.9% per year to hold emissions level; however, U.S. intensity declined at a rate of -1.9%, leaving emissions to grow at 1.0% per year.

Looking to the future, under auspices of the Copenhagen Accord, the United States has submitted a target of reducing emissions from the 2005 level by 17% in 2020. This would require the United States to reduce the intensity of its emissions by some -4.6% per year during the 2010-2020 decade. This implies that the rate of intensity decline needs to better than double.

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Introduction

The interactions of three variables underlie debates on the issue of climate change[1] and what responses might be justified: the magnitude and rates of change of (1) population, (2) incomes, and (3) intensity of greenhouse gas emissions relative to economic activities. This report examines the interrelationships of the variables to explore their implications for policies that address climate change.

Both internationally and domestically, initiatives are underway both to better understand climate change and to take steps to slow, stop, and reverse the overall growth in greenhouse gas emissions,[2] the most important of which is carbon dioxide (CO_2), emitted by the combustion of fossil fuels.

These initiatives include the following bulleted items.

- The United Nations Framework Convention on Climate Change (UNFCCC), to which the United States and almost all other nations are Parties. Its stated objective is to stabilize greenhouse gas concentrations in the atmosphere at levels that "would prevent dangerous interference with the climate system."[3] It established the principle that all nations should take action, and that developed nations should take the lead in reducing emissions. It required Parties to prepare national action plans to achieve reductions, with developed countries aiming to reduce year 2000 emissions to 1990 levels. It required preparation of inventories of emissions and annual reports. And it set up a process for the Parties to continue meeting.
- The Kyoto Protocol, an agreement negotiated under the auspices of the UNFCCC; 169 nations—but *not* the United States—are Parties to the Protocol. Even as the Framework Convention was going into force, it was recognized that most nations would not meet their 2000 aims of holding emissions at 1990 levels. Ensuing negotiations, in which the United States participated, led to the Kyoto Protocol, which called for mandatory reductions in greenhouse gases for the period 2008-2012 by developed nations—but not by developing ones. With the United States not participating, and with developing nations not required to make GHG reductions (and China became the world's largest emitter in about 2005), the reductions mandated by Kyoto will not significantly slow the accumulation of GHG in the atmosphere, although much is being learned of the institutional structures, such as the European Union's "cap and trade" mechanism, for handling reductions. Even as the Kyoto process began, negotiations on next steps resumed.
- The Asia-Pacific Partnership on Clean Development and Climate (APP), composed of the United States, China, India, Japan, Australia, and South Korea.

[1] CRS Report RL33849, *Climate Change: Science and Policy Implications*, by (name redacted), for more information.

[2] For a review of international activities, see CRS Report RL33826, *Climate Change: The Kyoto Protocol, Bali "Action Plan," and International Actions*, by (name redacted). For a review of U.S. activities, see CRS Report R40556, *Market-Based Greenhouse Gas Control: Selected Proposals in the 111th Congress*, by (name redacted), (name redacted), and (name redacted). .

[3] UNFCCC, Article 2, "Objectives."

The purposes of the Partnership are to create a voluntary, non-legally binding framework for international cooperation to facilitate the development, diffusion, deployment, and transfer of existing, emerging, and longer-term cost-effective, cleaner, more efficient technologies and practices among the Partners through concrete and substantial cooperation, so as to achieve practical results. It has the goal of meeting "national pollution reduction, energy security and climate change concerns, consistent with the principles of the U.N. Framework Convention on Climate Change (UNFCCC)."[4]

- The Copenhagen Accord is an agreement of the Parties to the UNFCCC to begin establishing actions to follow on the Kyoto Protocol. The Copenhagen Accord[5] does not mandate specific reductions, but sets a goal of reducing global emissions "so as to hold the increase in global temperature below 2 degrees C, and take action to meet this objective consistent with science and on the basis of equity." Annex I nations commit to implement "quantified economy-wide emissions targets for 2020" and non-Annex I nations commit to implement "mitigation actions." Both sets of nations commit to reporting and verification procedures "in accordance with guidelines adopted by the Conference of the Parties." (Monitoring, reporting, and verification were a key demand of the United States of developing nations.) Also, the accord contained the promise that developed countries would make available $100 billion a year by 2020 "to address the needs of developing countries."

However, these several, related efforts have had to struggle with substantive economic, technical, and political differences among regional, national, and local circumstances. Foremost among these differences is the divide between developed and less-developed nations.[6] Conflict arises because any pressure to reduce emissions comes up against increases in emissions likely to result from energy use fueling economic development and raising standards of living in developing economies, which contain a large share of the world's population. Even in many developed nations, efforts to constrain emissions by, for example, conservation, increased energy efficiency, and use of energy sources that emit less or no CO_2, have been outstripped by increases in total energy use associated with population and economic growth. For example, between 1990 and 2005, in the United States, the greenhouse gas intensity of the economy declined at a rate of -1.9% per year, but total emissions increased at the rate of 1.0% per year.[7] Although some countries have experienced declines in emissions—either through economic contraction[8] or deliberate policies—the overall trend, both globally and for most individual nations, reflects increasing emissions.

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[4] Charter for the Asia-Pacific Partnership on Clean Development and Climate (January 12, 2006), "Purposes," 2.1.1. For additional information, see http://www.asiapacificpartnership.org/.

[5] http://en.cop15.dk/files/pdf/copenhagen_accord.pdf

[6] See, for example, CRS Report RL32721, *Greenhouse Gas Emissions: Perspectives on the Top 20 Emitters and Developed Versus Developing Nations*, by (name redacted) and (name redacted); CRS Report RL32762, *Greenhouse Gases and Economic Development: An Empirical Approach to Defining Goals*, by (name redacted) and (name redacted); *Climate Data: Insights and Observations* (World Resources Institute; prepared for the Pew Center on Global Climate Change, December 2004), http://cait.wri.org/.

[7] World Resources Institute, Climate Analysis Indicators Tool (CAIT), as described below.

[8] In particular, following the breakup of the former Soviet Union, the economies of various Eastern European and former Soviet republics contracted in the 1990s, such that their emissions declined substantially between 1990 and 2000.

This upward trend in greenhouse gas emissions runs counter to the long-term objectives of these climate change initiatives. This report identifies drivers of the increase in emissions and explores their implications for efforts to reduce emissions. During this exploration, it is useful to bear in mind that although short-term efforts may not achieve emissions reductions that immediately meet goals to prevent dangerous interference with the climate system, such endeavors may nevertheless establish a basis for longer-term efforts.

Greenhouse Gas Emission Variables

The analysis below, which uses data from the World Resources Institute's Climate Analysis Indicators Tool (CAIT),[9] is based on the following relationships:

Equation 1. $(Population) \times (per\ capita\ GDP) \times (Intensity_{ghg}) = Emissions_{ghg}$

The CAIT database includes 185 nations (plus a separate entry for the European Union) with a 2005 population of 6.462 billion, compared with 191 members of the United Nations and with a 2005 world population count of 6.470 billion by the U.S. Census Bureau.[10] Average income is measured as per capita Gross Domestic Product (GDP), in international dollars of purchasing power parity ($PPP).[11] (Note that population times per capita GDP equals GDP.) Greenhouse gas intensity is measured as tons of emissions in carbon equivalents[12] per million dollars of GDP.

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[9] This database uses a variety of data sources to provide information on greenhouse gas emissions and other relevant indicators. Full documentation, along with caveats, is provided on the WRI website at http://cait.wri.org/.

[10] See http://www.census.gov/ipc/www/idb/worldpop.html.

[11] GDP-PPP is gross domestic product converted into international dollars using purchasing power parity (PPP) rates. An international dollar has the same purchasing power in the domestic currency as a U.S. dollar has in the United States. The World Bank is the source of CAIT's PPP data. (World Resources Institute, *CAIT: Indicator Framework Paper*, December 2008, p. 23.)

[12] Emissions comprise six greenhouse gases: carbon dioxide, nitrous oxide, methane, perfluorocarbons, hydrofluorocarbons, and sulfur hexafluoride. To aggregate emissions data, figures are typically given in millions of metric tons of carbon equivalents (MMTCE). Thus, global aggregate greenhouse gas emissions (excluding land use changes) for 2005 were 10,569 MMTCE, or 10.6 billion tons. In the text, unless otherwise explicitly stated, "tons" of emissions means "metric tons of carbon equivalents." To convert carbon equivalents to CO_2 equivalents, multiply by 44/12.

Characteristics of Intensity

Intensity can be expressed in many different ways; for example, as CO_2 emitted per million $PPP, as all six greenhouse gases emitted per million $PPP, and as CO_2 or greenhouse gases emitted per unit of some activity, such as electricity generated or vehicle miles traveled. Also, measures of intensity can include or exclude emissions or sequestration associated with land use changes.

In this analysis, intensity is identified as greenhouse gas (GHG) intensity (all six greenhouse gases of the UNFCCC) or as CO_2 intensity (referring only to CO_2 emissions from energy use and cement manufacture). In both cases, tonnage of emissions is expressed in carbon equivalents. CAIT has data on all six greenhouse gases only for 1990, 1995, 2000, and 2005; analyses referring to other years necessarily include only CO_2.

Unless otherwise specified, land use changes are not included in emissions or intensity data cited in this report.

Using international, purchasing power parity dollars can yield figures different from analyses using other economic measures, such as market exchange rate dollars. Intensity figures in this report, derived using $PPP, may differ from comparable intensity figures in other studies using other GDP measures.

For the United States, using international $PPP (or market exchange rate dollars) for GDP, CAIT yields a decline in intensity for U.S. emissions of all greenhouse gases between 1990 and 2005 of -1.9% per year.

To ensure consistency, CAIT emissions data and international $PPP are used throughout this report, unless stated otherwise.

Table 1 provides a snapshot of the **equation 1** variables for the top 20 greenhouse gas emitters in the year 2005,[13] plus for the European Union 27, and for the world. The data reflect the wide range of circumstances faced by any initiative to address GHGs. However, it is the way those variables are changing that illuminates both the seemingly inexorable rise in GHG emissions and the challenge of reducing them. A variable changing at an annual rate of 6.9% doubles in 10 years; at an annual rate of 3%, it doubles in 23 years.

Table 1. Drivers of Greenhouse Gas Emissions: Top 20 Emitting Countries, 2005

(Excludes land use changes)

Country	Population (in 1,000s)	Per Capita GDP (2005 Int'l $PPP/ person)	Intensity (Tons Cequiv/ million 2005 Int'l $PPP)	Total GHG Emissions (MMTCE)
China	1,304,500	4,088	369.4	1,970.3
United States	296,507	41,813	153.3	1,900.6
EU-27	490,032	26,592	105.7	1,377.7
Russian Fed	143,150	11,861	315.1	534.9
India	1,094,583	2,230	207.2	505.7
Japan	127,773	30,290	94.7	366.5
Brazil	186,831	8,474	174.8	276.8
Germany	82,469	30,445	106.2	266.8
Canada	32,312	34,972	176.7	199.7

[13] The year 2005 is the most recent year for which CAIT has data for all six greenhouse gases. Note that analyses based on 1990-2005 data are affected by the collapse of the former USSR and do not take into account the most recent rapid increases in energy use and emissions for India and China.

Country	Population (in 1,000s)	Per Capita GDP (2005 Int'l $PPP/ person)	Intensity (Tons Cequiv/ million 2005 Int'l $PPP)	Total GHG Emissions (MMTCE)
U.K.	60,226	31,371	92.4	174.6
Mexico	103,089	11,387	146.4	171.9
Indonesia	220,558	3,209	229.2	162.2
Iran	69,087	9,314	240.2	154.6
Italy	58,607	27,750	94.9	154.4
France	60,873	30,591	80.7	150.2
S. Korea	48,294	21,273	145.8	149.8
Australia	20,400	31,656	231.9	149.7
Ukraine	47,105	5,583	503.0	132.3
Spain	43,398	27,180	101.5	119.7
S. Africa	46,892	8,478	290.3	115.4
Turkey	72,065	10,370	143.6	107.3
WORLD	6,461,584	8,708	188.1	10,569.3

Source: Climate Analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

Growth Relationship of Greenhouse Gas Drivers

Incorporating growth, **equation 1** becomes

Equation 2. $(Population)e^{k_p t} \times (percapitaGDP)e^{k_g t} \times (Intensity)e^{k_i t} = (Emissions)e^{k_e t}$

in which k_p = population growth rate, k_g = per capita GDP growth rate, k_i = intensity growth rate, and k_e = emissions growth rate; t = time; and e = a constant 2.71828 (the base of natural logarithms).

The exponents of multiplicands are added, so

Equation 3. $(k_p + k_g + k_i) = k_e$

The growth rate of each of the variables of equation 1 can be expressed as an exponent, the annual percentage rate of change over some time period (see **Growth Relationship of Greenhouse Gas Drivers**). As exponents of multiplicands are added, relationship among the variables can be simply expressed: the growth rates of the three variable on the left side of the equation sum to the growth rate of the variable (emissions) on the right side. Thus, if the sum of the three growth rate variables on the left is positive, emissions are rising; if the sum is negative, emissions are declining; and if the sum is zero, emissions are constant.

This growth relationship among the variables makes explicit why there is upward pressure on GHG emissions. For nearly all nations, population is increasing, with developing nations typically having the highest rate. Thus population growth rate is positive globally and for most nations; it is zero or negative for only a few nations.[14] The economic development of less-developed nations is a global objective acknowledged by the UNFCCC; developed nations also promote economic growth to raise living standards. Thus economies are growing globally and for most nations. With the population and economic activity variables positive, emissions will be rising unless the decline in intensity exceeds the growth in population and economic activity, which has seldom been the case. If the goal is to reduce GHG emissions, the larger the *negative* change in intensity, the better.

Table 2 shows the changes in these variables for 1990 - 2005. (The figures in the right-most column are taken from the CAIT database.[15]) As the table shows, global growth rates for population and per capita income outpaced the rate of decline in intensity—so GHG emissions rose; this is also true of the majority of nations, including the United States. Circumstances in several individual countries highlight some important points about GHG emissions and their potential control.

- First, for many nations, population growth is an important contributor to the increase in GHG emissions. For Brazil, Mexico, Indonesia, Iran, Australia, Spain, South Africa, and Turkey, any improvements in intensity were annulled by increases in population alone.[16]
- Second, developing countries, focused on developing their economies, have increasing GHG emissions even when they manage to improve intensity (e.g., China, India, Mexico, Indonesia, South Korea, and South Africa). For these countries, population growth combined with per capita GDP growth overwhelmed whatever intensity improvements they achieved.[17]
- Third, lower emissions can be associated with decreasing economic activity. For the Russian Federation and Ukraine, economic contraction following the dissolution of the Soviet Union contributed to decreases in their emissions. During 2008-2009,GHG emission reductions occurred in many if not most nations as a result of the global recession, and almost certainly declined globally.
- Fourth, several developed countries improved per capita GDP while holding their GHG emissions to a 1% increase or less: the United States, Japan, Germany, the United Kingdom, Italy, and France. Germany and the United Kingdom (and also the European Union 27) actually decreased their emissions.
- Fifth, in some developed countries, income growth alone exceeded the decline in intensity (e.g., Japan, Italy, Canada, Australia, and Spain).

[14] The rate of population growth has declined in many countries in recent decades, partly as a result of deliberate policies (e.g., birth control programs and, in a few countries, such as China, limits on family size); and partly as a result of education, higher standards of living, and cultural changes. Global population growth is expected to continue at least to mid-century, with projections suggesting a global population of around 9 billion in 2050.

[15] In principle, these figures could be calculated by adding the three left-hand data columns; in fact, a number of rows do not add; this may be due to rounding or, where discrepancies are large, from shortcomings in the underlying reported data. Nevertheless, the figures are consistent with the generalizations about trends.

[16] For Iran and Spain, population and intensity both increased.

[17] For Iran, GHG emissions rose because population and GDP growth had no offset at all from intensity, which worsened.

Stabilizing emissions would require an accelerated decline in intensity.[18] For global emissions to have met the UNFCCC voluntary goal of being at 1990 levels in 2000, intensity would have had to decline at the rate of -2.9% per year, rather than at the actual -2.0%.[19] For the United States, the situation was similar: for emissions in 2000 to have remained at 1990 levels, intensity would have had to decline at the rate of -3.2% per year, rather than the actual -1.9%.[20] Looking to the future, this relationship holds—absent a declining population or a contracting economy, GHG emissions can be expected to decline only if intensity declines at a rate faster than it has been.

Table 2. Annual Percentage Rate of Change in Factors Affecting Greenhouse Gas Emissions: Top 20 Emitting Countries, 1990-2005

(Excludes land use changes)

Country	Population (average annual %)	Per Capita GDP (average annual %)	Intensity (average annual %)	Total GHG Emissions (average annual %)
China	0.9	9.1	-4.9	4.8[a]
United States	1.1	1.8	-1.9	1.0
EU-27	0.3	1.8	-2.4	-0.4
Russian Fed	-0.2	-0.4	-2.1	-2.7
India	1.7	4.2	-2.3	3.5
Japan	0.2	1.0	-0.4	0.9
Brazil	1.5	1.1	0.0	2.6
Germany	0.3	1.3	-2.9	-1.3
Canada	1.0	1.8	-1.2	1.6
U.K.	0.3	2.1	-3.0	-0.6
Mexico	1.4	1.5	-0.6	2.3
Indonesia	1.4	2.9	-0.5	3.8
Iran	1.6	2.7	1.2	5.6
Italy	0.2	1.1	-0.6	0.8
France	0.5	1.4	-1.7	0.1
S. Korea	0.8	4.7	-1.3	4.2
Australia	1.2	2.0	-1.0	2.2
Ukraine	-0.6	-2.4	-1.2	-4.2

[18] Emissions could also be stabilized by declines in population or GDP. However, because U.S. policymakers are unlikely to promote population reduction or GDP contraction, analysis of these options seems unwarranted. In some countries (e.g., China), deliberate efforts to constrain population do occur.

[19] That is, annual population growth (1.5%) + per capita GDP growth (1.4%) + intensity change (-2.9% [rather than the actual -2.0%]) = 0 emissions growth.

[20] That is, annual population growth (1.2%) + per capita GDP growth (2.0%) + intensity change (-3.2% [rather than the actual -1.9%]) = 0 emissions growth.

Country	Population (average annual %)	Per Capita GDP (average annual %)	Intensity (average annual %)	Total GHG Emissions (average annual %)
Spain	0.7	2.2	0.0	3.0
S. Africa	1.9	0.6	-0.9	1.6
Turkey	1.6	2.3	-1.1	2.7
WORLD	1.4	1.7	-1.6	1.5

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

a. These figures are taken from the CAIT data base. In principle, they could be calculated by adding the three left-hand data columns; in fact, a number of rows do not add; this may be due to rounding or, where discrepancies are large, from inconsistencies in the underlying reported data.

How fast and how far might intensity be driven down? There are two ways to approach this question: one is to examine the sources of emissions and consider how much and how fast they could be curtailed; a second is to assess what level of greenhouse gases can be emitted to the atmosphere without causing "dangerous interference with the climate system" (in the words of the UNFCCC) and to calculate from those emissions what the intensity would have to be over time, taking into account population and income growth.

Sectoral Breakdown of GHG Emissions

Greenhouse gas emissions result from diverse human activities, including agriculture and the combustion of fossil fuels – the latter providing the energy that has driven the industrial revolution and accounting for much of the rise in CO_2 levels in recent centuries. This section of the report examines several of those major sources of emissions.

Table 3 presents emissions data by economic sector for the top 20 emitting nations (plus the EU-27 and the world), including Land-Use Change and Forestry, and International Bunkers (so the total is different than in **Table 1**). As **Table 3** shows, the energy sector is by far the largest contributor of greenhouse gases, accounting for 64% of total world emissions in 2005; the agricultural sector is second, accounting for about 14%. These two sectors dominate for almost all countries (industrial process emissions rank second for Japan and South Korea) – except for the dominance of Land-Use Change and Forestry for Brazil and Indonesia.

Table 4 presents a breakdown of the energy sector emissions. Electricity and heat contributes the largest share, accounting for about 43% of total energy sector emissions in 2005, followed by transportation at about 19%, manufacturing at about 18%, other fuel combustion at about 13%, and fugitive emissions at about 6%.

Table 3. GHG Emissions by Sector: Top 20 Emitting Countries, 2005

(Includes International Bunkers and Land-Use Change and Forestry)

Country	Energy (CO_2, N_2O, and CH_4) MMTCE	Industrial Processes (All 6 GHG) MMTCE	Agriculture (N_2O and CH_4) MMTCE	Waste (e.g. landfills) (N_2O and CH_4) MMTCE	Land-Use Change & Forestry (CO_2) MMTCE	International Bunkers (CO_2) MMTCE	Total (All 6 GHG) MMTCE
China	1,441	183[a]	304	48	-13	8	1,970
United States	1,652	68	121	51	-32	36	1,896
EU-27	1,134	71	137	36	—[b]	77	1,456
Russian Fed	474	12	32	13	16	4	552
India	342	24	110	34	—	3	512[c]
Japan	337	21	10	3	—	11	381[c]
Brazil	94	9	161	12	500	4	780
Germany	229	10	23	4	—	8	274[c]
Canada	168	6[a]	20	7	18	1	221
U.K.	154	6	13	3	—	11	187[c]
Mexico	134	8	21	13	11	3	189
Indonesia	108	5	36	9	398	1	558
Iran	132	5	10	4	—	1	153[c]
Italy	129	10	11	3	—	5	159[c]
France	109	9	28	3	—	7	156[c]
S. Korea	130	16	5	4	—	11	166[c]
Australia	116	3	30	3	—	3	156[c]
Ukraine	116	3	12	4	—	0	135[c]
Spain	94	9	12	3	—	9	128[c]
S. Africa	94	4	11	6	—	3	118[c]
Turkey	74	6[a]	21	5	9	2	118
WORLD	7,761	514	1,658	387	1,467	257	12,044

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

a. CH_4 data not available.

b. Not available

c. Data from Land-Use Change & Forestry not available.

Table 4. Energy Sector GHG Emissions: Top 20 Emitting Countries, 2005

(Excludes land use changes)

Country	Electricity and Heat (CO_2) MMTCE	Manufacture and Construction (CO_2) MMTCE	Transportation (CO_2) MMTCE	Other Fuel Combustion (CO_2, N_2O & CH_4) MMTCE	Fugitive Emissions (CO_2 & CH_4) MMTCE
China	728	435	91	148	39
United States	746	171	493	185	57
EU-27	445	180	256	228	25
Russian Fed	255	61	60	45	54
India	189	69	27	44	13
Japan	139	78	68	52	0
Brazil	16	26	37	12	3
Germany	100	31	42	51	4
Canada	52	28	44	34	12
U.K.	65	18	35	32	5
Mexico	49	16	36	11	23
Indonesia	34	25	20	13	16
Iran	29	19	28	34	23
Italy	45	22	32	28	2
France	20	20	36	32	1
S. Korea	60	26	24	19	1
Australia	66	13	22	8	8
Ukraine	37	25	8	14	32
Spain	35	18	30	11	1
S. Africa	58	14	12	8	2
Turkey	22	16	10	13	14
WORLD	3,367	1,427	1,465	1,024	477

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

The most revealing aspect of sectoral emissions emerges from **Table 5,** which shows their rates of change, and **Table 6,** which shows the rates of change of the energy subsectors.[21]

[21] Rates of change were not calculated if both the 1990 and 2005 emission levels were below 5 million tons. At low levels, even small changes can yield notable rates of change—for example, if emissions went from 2 to 4 million tons between 1990 and 2005, the rate of change would be 3.8% per year, but the actual emissions are too small to meaningfully affect overall totals.

Global emissions are growing fastest in the Industrial Processes sector[22] (4.0%/year); next is the International Bunkers sector, growing at 2.9%/year: but as these two sectors are much smaller shares of total emissions than energy (see **Table 3**), the increases are relatively small in absolute terms; however, the rate of increase is substantial for nations that are industrializing, especially China, India, and South Korea.

The largest absolute increase in emissions is driven by the rate of increase for the energy sector, growing at 1.6%/year. Within that sector (see **Table 6**), the most rapidly growing subsector is electricity and heat energy, at 2.5% per year, led by developing nations, especially China, India, Brazil, South Korea, Iran, and Indonesia, and also by Spain and Turkey. In contrast, for the EU-27, the rate and absolute emissions for the subsector declined slightly; but for the Russian Federation and Ukraine, the rate and absolute emissions declined substantially as their economies contracted. The next fastest growing subsector is transportation, at 2.0% a year, with every nation showing a positive rate of growth except the Russian Federation and Ukraine, with their contracting economies during the 1990s, and Germany, with a minimal decrease. The fastest rates of transportation emissions growth occurred in China, Iran, Indonesia, and South Korea.

Energy Use as a CO_2 Intensity Driver

The previous section looked at emissions and the rate of change, 1990-2005, for all six greenhouse gases and all sectors of the economy (insofar as data are available). Of the six greenhouse gases, CO_2 dominates, accounting for 76.8% of the carbon equivalents of global GHG emissions in 2005 and 84.6% of U.S. GHG emissions (these figures include Land-Use Change and Forestry, and International Bunkers). Overwhelmingly, the source of that CO_2 is energy use: for world CO_2 emissions, energy use accounts for 77.9%; for the United States, energy use accounts for 98.8%.

Two factors largely determine the intensity of CO_2 emissions of a nation's economy: energy intensity (energy per unit of GDP) and the fuel mix (emissions per unit of energy):[23]

Equation 4.

$$\frac{\textit{Energy Use}}{\textit{GDP}} \times \frac{\textit{Emissions}_{co2}}{\textit{Energy Use}} = \frac{\textit{Emissions}_{co2}}{\textit{GDP}}$$

[22] Including CO_2 from cement manufacture, N_2O from Adipic and Nitric Acid production, N_2O and CH_4 from other industrial processes, plus HFCs, PFCs, and SF_6.

[23] See Timothy Herzog et al., *Target: Intensity, An Analysis of Greenhouse Gas Intensity Targets* (Washington, DC: World Resources Institute, November 2006), pp. 3-9; and Frank Princiotta, "Global Climate Change and the Mitigation Challenge, *Journal of the Air & Waste Management Association* (October 2009), Vol. 59, pp.1194-1211.

Table 5. Annual Percentage Rate of Change of GHG Emissions by Sector: Top 20 Emitting Countries, 1990-2005

(Includes International Bunkers and Land-Use Change and Forestry)

Country	Energy (CO_2, N_2O, and CH_4) %	Industrial Processes (All 6 GHG) %	Agriculture (N_2O and CH_4) %	Waste (e.g. landfills) (N_2O and CH_4) %	Land-Use Change & Forestry (CO_2) %	International Bunkers (CO_2) %	Total (All 6 GHG) %
China	5.4	11.4[a]	1.4	0.9	[b]	12.7	4.3
United States	1.0	3.0	0.2	-0.9		0.2	1.0
EU-27	-0.2	-0.8	-1.2	-2.5		3.2	-0.3[d]
Russian Fed	-2.6	-2.6	-4.1	-0.6		-4.9	-2.6
India	4.4	7.5	1.3	1.8		[c]	3.6[d]
Japan	0.9	1.1	-0.7	1.0		1.9	0.9[d]
Brazil	3.5	2.4	2.2	1.4			0.8
Germany	-1.1	-1.6	-1.8	-6.7		2.0	-1.3[d]
Canada	1.7	-1.5[a]	1.6	2.0			1.2
U.K.	-0.3	-4.4	-0.7	-5.8		3.7	-0.5[d]
Mexico	2.5	4.6	0.9	1.6			2.1
Indonesia	5.0	6.4	1.5	1.4			0.9
Iran	6.0	6.0	3.2	1.6			5.6[d]
Italy	0.9	1.0	-0.2	-1.1		2.9	0.8[d]
France	0.5	-1.9	-0.4	-1.0		2.5	0.2[d]
S. Korea	4.8	5.6	-0.0	-3.6		13.4	4.5[d]
Australia	2.7	1.4	0.9	1.0			2.2[d]
Ukraine	-4.4	-4.0	-3.8	-0.7			-4.2[d]
Spain	3.3	2.4	1.1	3.5		5.7	3.2[d]
S. Africa	1.7	5.6	-0.3	1.2			1.6[d]
Turkey	3.9	4.0[d]	-0.3	1.6			2.6
WORLD	1.6	4.0	1.0	0.6	-0.8	2.9	1.2

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

a. CH_4 data not available.

b. Individual country data unavailable or insufficient for useful analysis of trends.

c. No entry indicates not calculated for countries for which both 1990 and 2005 emissions were <5 MMTCE.

d. Data from Land-Use and Forestry not available.

Table 6. Annual Percentage Rate of Change of Energy Sector GHG Emissions: Top 20 Emitting Countries, 1990-2005

Country	Electricity and Heat (CO_2) %	Manufacture and Construction (CO_2) %	Transportation (CO_2) %	Other Fuel Combustion (CO_2, N_2O & CH_4) %	Fugitive Emissions (CO_2 & CH_4) %
China	9.2	3.9	7.2	0.0	0.7
United States	1.6	-0.7	1.6	0.0	-1.3
EU-27	-0.2	-1.5	1.5	-0.3	-2.9
Russian Fed	-1.8	-1.8	-2.0	-5.5	-4.6
India	6.7	2.8	1.2	2.5	3.3
Japan	1.5	-0.2	1.1	1.0	[a]
Brazil	5.2	3.6	3.6	1.4	
Germany	-0.6	-2.9	-0.1	-1.2	—[b]
Canada	2.0	1.1	3.6	1.9	1.9
U.K.	-0.2	-1.7	0.6	0.0	-3.2
Mexico	3.7	-1.5	2.8	1.3	4.5
Indonesia	6.0	7.2	5.8	2.9	2.1
Iran	6.7	3.2	6.6	5.5	8.7
Italy	1.0	-0.3	1.5	1.2	
France	0.9	-0.7	1.1	0.8	
S. Korea	8.7	3.9	4.7	0.0	
Australia	3.7	0.1	1.7	3.5	1.7
Ukraine	-6.2	-5.2	-3.8	-3.5	-0.9
Spain	3.5	2.4	3.7	3.9	
S. Africa	2.6	-1.9	2.6	3.6	
Turkey	5.0	3.5	2.0	2.8	5.9
WORLD	2.5	1.0	2.0	-0.0	0.2

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

a. No entry indicates not calculated for countries for which both 1990 and 2005 emissions were <5 MMTCE.

b. Not available.

Table 7 presents data on energy sector CO_2 emissions for 2006. The first data column represents energy intensity of the economy, measured in 1,000 tonnes of oil equivalent (toe) per million $PPP. The smaller the number, the more efficiently energy is used to support economic activity in that country. For the world, the energy intensity of the global economy is 0.19; of the top-20 emitting nations, 13 equal or better the world average. Seven countries, Japan, Mexico, Germany, the United Kingdom, Italy, Spain, and Turkey equal or better the efficiency of the EU-27, at 0.13; China, the Russian Federation, Ukraine, and South Africa are the least efficient, at 0.31 or worse.

In general, the higher the number in column one, the more least-cost options that nation should be able to find for reducing energy use without adversely affecting the overall economy. Improvements could come, for example, from upgrading boilers, substituting gas-combined cycle electricity generation, improving the efficiency of the electricity grid, or upping the efficiency of the vehicle fleet.

The second data column in **Table 7** reflects the carbon content of the mix of fuels comprising energy use, measured as tons of carbon (C) per 1,000 tonnes of oil equivalent. The world average is 670. Of the top-20 GHG emitters, China has the highest emissions for the energy it uses, at 900 tons of carbon per 1000 tonnes of oil equivalent; France—with nuclear power dominating its electricity generating sector—is lowest, at 390. The United States is just over the world average, at 680.

The smaller the number, the less CO_2 being emitted by the energy used. Higher numbers would generally reflect a higher proportion of coal combusted in the electricity-generating, manufacturing, and heating sectors and a low transportation fleet fuel economy; lower numbers would generally reflect a higher proportion of hydropower, renewables, or nuclear power in the electricity, manufacturing, and heating sector, and a high transportation fleet fuel economy. Again, in many cases, the higher the number, the more least-cost options for lowering CO_2 emissions without adversely affecting the overall economy, for example by substituting natural gas for coal or renewables for oil.

The third data column in **Table 7** contains each nation's intensity of carbon emissions for the energy sector; it is the product of the first and second data columns. (Note that this intensity number is for CO_2 emissions only, and is thus different from *greenhouse gas intensity*, which includes CO_2 plus five other gases.) The higher the number, the less efficiently the economy is using carbon-emitting energy. The highest intensity nations are Ukraine, China, the Russian Federation, and South Africa; the lowest are France and Brazil, meaning that they get the most economic output for the emissions of CO_2 from the energy they use. The United States at 130 is slightly more efficient that the world average of 138, but less efficient than, for example, the European Union-27, at 86, and Japan and Turkey, both at 88.

The last column in the table provides data on total emissions from energy use for 2006[24] – a year later than the same data series in column one in **Table 3**.

Another question is the relationship between new economic growth and emissions, which are often influenced by the degree of industrialization and the prices and availability of different fuels. **Table 8** compares this by providing information on the annual rates of change of factors affecting CO_2 emissions from energy use. The first three data columns parallel the first three in **Table 7**, giving the rates of change during 1990-2005. In terms of CO_2 emissions, negative numbers mean that over time a nation is getting more economic activity for less energy (first data column) and more energy for less CO_2 (second data column). As **Table 8** shows, there are wide variations among nations. For example, China's economy made rapid progress in using energy

[24] As given, the emissions data are taken from CAIT tables, but in principle could be calculated by multiplying the intensity (column 4) times GDP; because of inconsistent data, the calculations in some cases diverge from the reported emissions, though the general magnitudes and the relative positions of nations are right.

more efficiently (energy intensity of -5.1% per year), even though the energy it used actually produced more CO_2 per unit of energy (+1.3% per year). A number of countries, including the EU-27, improved efficiency and reduced emissions per unit of energy used. The third data column, which should be the sum of the first two, is negative if, overall, the country is producing more economic activity for the CO_2 emitted. The fourth and fifth columns in **Table 8** give the rates of change of the nations' GDPs and total CO_2 emissions from energy use. A nation's rate of change of CO_2 intensity can be negative, but if GDP is growing faster than CO_2 intensity is declining, emissions will rise (the last column).[25]

Table 7. CO_2 Emissions Intensity of the Energy Sector: Top 20 Emitting Countries, 2006

Country	Energy Intensity (1,000 toe / million 2005 $PPP)	CO_2 Intensity of Energy Sector (Tons C / 1,000 toe)	CO_2 Intensity of Economy (Tons C / million 2005 $PPP)	Total CO_2 Emissions from Energy Use (MMTCE)
China	0.32	900	288	1,530
United States	0.19	680	129	1,561
EU-27	0.14	620	87	1,089
Russian Fed	0.38	650	247	433
India	0.22	640	141	341
Japan	0.14	650	91	331
Brazil	0.13	430	56	92
Germany	0.14	660	92	225
Canada	0.24	560	134	148
U.K.	0.12	640	77	147
Mexico	0.15	680	102	115
Indonesia	0.25	550	138	94
Iran	0.25	750	188	124
Italy	0.11	700	77	122
France	0.15	390	58	103
S. Korea	0.21	630	132	130
Australia	0.19	890	169	108
Ukraine	0.54	630	340	85
Spain	0.12	670	80	89
S. Africa	0.32	730	234	93
Turkey	0.11	760	84	65
WORLD	0.20	670	134	7,429

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010). CRS calculations.

[25] In principle, the sum of the first two data columns should equal the third data column, and the fifth column should be the sum of the third and fourth columns; however, because of data inconsistencies, the calculated numbers may not exactly correspond to the CAIT reported numbers. Nevertheless, the general relationships hold.

Table 8. Annual Percentage Rate of Change in Factors Affecting CO_2 Emissions from Energy Use: Top 20 Emitting Countries, 1990-2005

Country	Energy Intensity %	CO_2 Intensity of Energy Used %	Energy Sector CO_2 Intensity %	Per Capita GDP %	Total CO_2 Emissions of Energy Use %
China	-4.8	1.3	-3.5	9.2	6.0
United States	-1.4	-0.2	-1.6	1.8	1.0
EU-27	-1.2	-0.7	-1.8[a]	1.9	-0.1
Russian Fed	-1.3	-0.4	-1.7	0.1	-2.0
India	-2.1	1.2	-0.9	4.4	4.7
Japan	0.0	-0.3	-0.3	1.1	0.8
Brazil	0.0	0.3	0.3	1.2	3.4
Germany	-1.2	-0.7	-2.0	1.4	-0.9
Canada	-1.0	-0.2	-1.2	1.8	1.4
U.K.	-1.8	-0.7	-2.5	2.1	-0.2
Mexico	0.0	0.0	0.0	1.6	2.3
Indonesia	-0.7	1.8	1.1	3.0	5.3
Iran	1.4	0.2	1.6	2.8	6.1
Italy	0.0	-0.6	-0.6	1.1	0.7
France	-0.4	-0.8	-1.2	1.4	0.4
S. Korea	0.6	-0.8	-0.2	4.7	4.7
Australia	-0.9	0.5	-0.4	2.0	2.6
Ukraine	-0.8	-1.1	-1.9	-1.8	-4.9
Spain	0.0	0.1	0.1	2.2	2.9
S. Africa	-0.2	-0.3	-0.5	0.8	1.9
Turkey	-0.5	0.3	-0.1	2.5	4.1
WORLD	-1.4	0.0	-1.4	1.8	1.8

Source: Climate Analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010). CRS calculations.

a. When the third column is not the sum of the first two, the discrepancy reflects rounding or, possibly, data shortcomings.

The carbon intensity of energy use—that is, the consequences of fuel mix—is especially notable in looking at the energy mix of electricity generation, as discussed in the next section.

Carbon Intensity of Electricity Generation

Variations among countries of the carbon intensity of energy use (see **Table 5**) are strongly affected by the carbon intensity of electricity generation – in the United States electricity generation accounts for 41% of total CO_2 emissions.[26] Differences among countries are marked, as depicted in **Table 9**.

Choices among generating technologies are the primary driver of disparities among countries in the carbon intensity of their electricity generation. In general, countries with high numbers generate a substantial proportion of their electricity by burning fossil fuels, and countries with low numbers generate large quantities of electricity by nuclear facilities, hydropower, or other renewables. For example, France, with the lowest carbon intensity of electricity production of 20.3 in 2006, generated 79.2% of its electricity by nuclear power, 11.7% by hydropower and other renewables, and about 9.6% by conventional thermal. The United States, with a carbon intensity of electricity production in 2006 of 148, generated 19.4% of its electricity by nuclear power, 9.8% by hydropower and other renewables, and about 71% by conventional thermal.[27]

Although a nation's electricity-generating technologies are obviously affected by its resource endowments in terms of hydropower and fossil fuels, choices can be made, as exemplified by France. In 1980, France's electricity was generated 27% by hydropower, 24% by nuclear, 27% by coal, and 19% by oil. By 1990, with electricity production up over 60%, nuclear had risen to a 75% share, whereas coal and oil had fallen to 8% and 2% shares, respectively.[28] Not only did nuclear power account for all the growth in electricity generation during the period, but it displaced half the coal-fired and more than three-quarters of the oil-fired electricity generation. In 1990, the electricity produced by nuclear power exceeded France's total amount of electricity generated 10 years earlier.

France's transition to nuclear power meant that its CO_2 intensity (i.e., CO_2 emissions/GDP) declined between 1980 and 1990 at a rate of -4.9% per year, and CO_2 emissions declined at a rate of -2.6% per year. Thus, between 1980 and 1990, France's total CO_2 emissions declined by 23%—at the same time its per capita GDP was growing by 20.4% (+1.9% per year).[29] Thus **equation 3** yields a negative growth in emissions (numbers do not add precisely, due to rounding):

France: CO_2 Emission Drivers, 1980-1990

(Annual rate of change, %)

Population		Per Capita GDP		CO_2 Intensity		CO_2 Emissions
(0.5)	+	(1.9)	+	(-4.9)	=	(-2.6)

[26] Environmental Protection Agency, *Human-Related Sources and Sinks of Carbon Dioxide* http://www.epa.gov/climatechange/emissions/co2_human.html

[27] Energy Information Administration, *International Energy Statistics*. http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=12 Totals add to slightly more than 100% because offsetting pump-storage generation is not included.

[28] International Energy Agency, *Electricity Information 2002* (OECD, 2002), p. II.285.

[29] Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

During the 1990s, the United Kingdom made a major shift from coal to natural gas in the generation of its electricity. In 1990, the United Kingdom's electricity was generated 21% by nuclear, 1% by natural gas, and 65% by coal. In 2000, with electricity generation up 17%, nuclear's share was 23%, whereas coal's share had dropped to 33% and natural gas's share had risen to 39%.[30] Because natural gas produces less total CO_2 per kilowatt hour than coal (at a ratio of about 0.6 to 1 on a Btu basis[31]), CO_2 intensity in the United Kingdom declined between 1990 and 2000 at a rate of -2.8% per year, and CO_2 emissions declined at a rate of -0.5% per year. Thus, between 1990 and 2000, total CO_2 emissions in the United Kingdom declined by 4.5% (-0.5% per year)—at the same time its per capita GDP was growing by 23.6% (+2.1% per year).[32] Thus **equation 3** yields a negative growth in emissions (numbers do not add precisely, due to rounding):

United Kingdom: CO_2 Emission Drivers, 1990-2000

(Annual rate of change, %)

Population		Per Capita GDP		CO_2 Intensity		CO_2 Emissions
(0.3)	+	(2.1)	+	(-2.8)	=	(-0.5)

The examples of France and the United Kingdom show that for a period of time, at least, greenhouse gas intensity improvements can be sufficient to absorb growth in population and economic activity, so that actual emissions decline. The examples also show that the introduction of new technology can cause sudden shifts in emission rates.

The United States has also had periods when its CO_2 emissions declined. From 1980-1986, U.S. CO_2 intensity declined at a rate of -3.6% per year, and emissions declined at a rate of -0.5% per year. But after 1986 the rate of intensity decrease slowed: between 1987 and 2003, the intensity rate averaged about -1.7% per year. After 2003, through 2006 (the last year of CAIT's data), the rate of intensity decrease speeded up to an average annual -2.6%. Nonetheless, throughout the 1987-2006 period, the decrease failed to compensate for population and per capita GDP growth, so CO_2 emissions rose at 1.1% per year.[33] Over the longer term, therefore, emissions have risen: in terms of **equation 3**, U.S. CO_2 emissions for 1980-2005 are as follows (numbers do not add precisely, due to rounding):

United States: CO_2 Intensity, 1980-2005

Population		Per Capita GDP		CO_2 Intensity		CO_2 Emissions
(1.1)	+	(2.0)	+	(-2.2)	=	(0.8)

[30] International Energy Agency, *Electricity Information 2002* (OECD, 2002), p. II.683.

[31] If gas combined-cycle technology is considered, the ratio could be 0.4 or 0.5 to 1.

[32] Climate Analysis Indicators Tool (CAIT), version 7.0. (Washington, DC: World Resources Institute, 2010).

[33] Climate Analysis Indicators Tool (CAIT), version 7.0. (Washington, DC: World Resources Institute, 2010).

Table 9.Carbon Intensity of Electricity Generation: Top 20 Emitting Countries, 2006

Country	Intensity (gC/kWh)
China	230.5
United States	148.4
EU-27	96.6
Russian Fed	[a]
India	254.6
Japan	113.6
Brazil	22.3
Germany	134.3
Canada	49.6
U.K.	135.5
Mexico	147.7
Indonesia	184.7
Iran	146.5
Italy	113.6
France	20.3
S. Korea	127.5
Australia	244.0
Ukraine	118.1
Spain	92.4
S. Africa	238.2
Turkey	122.7
WORLD	143.7

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

a. Not available.

Carbon Intensity of Travel

The transportation sector is one of the fast-growing sources of emissions (see **Table 6**) – and it is proving one of the most intractable to reducing greenhouse gas emissions. Studies indicate that nations vary considerably in the energy efficiency and greenhouse gas emissions intensity of their transport sectors, but data are limited for making inter-country comparisons of the carbon intensity of passenger miles or of ton-miles. For example, one effort examining vehicle miles shows substantial variations among several nations, with the United States being the highest emitter per passenger vehicle[34] (**Figure 1**). To some extent, these variations reflect differing

[34] Feng An, et al., *Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A Global Update*, International (continued...)

geographic, cultural, and infrastructure circumstances among the nations; however, as with the carbon intensity of electricity generation, a substantial cause of the variations is deliberate policies, such as fuel efficiency standards, emission standards, fuel taxes, and choices of investments in transportation infrastructure.

For the United States, the Bureau of Transportation Statistics provides data on the energy intensity of passenger modes (**Table 10**).

Table 10. Energy Intensity of Passenger Modes: United States, 1970-2006

(Btus per passenger-mile)

Passenger Modes	1970	1980	1990	2000	2005	2006
Air, certified carrier						
Domestic	10,185	5,742	4,932	3,883	3,222	3,098
International	10,986	4,339	4,546	3,833	3,813	3,691
Highway						
Passenger car	4,841	4,348	3,811	3,589	3,585	3,525
Pickup, SUV, minivan	6,810	5,709	4,539	4,509	4,077	4,016
Motorcycle	2,500	2,125	2,227	2,273	1,784	1,754
Transit motor bus	—	2,742	3,723	4,147	3,393	3,262
Amtrak	—	2,148	2,066	2,134	—	—

Source: Bureau of Transportation Statistics: http://www.bts.gov/publications/national_transportation_statistics/html/table_04_20.html.

Two important points emerge from **Table 10**. First, transportation efficiency for several modes has improved over time. Air traffic gained efficiency in the transition to jets and larger aircraft. Vehicular passenger miles have gained efficiency, but at a slowing pace. On the other hand, transit motor bus efficiency per passenger mile has gone up and down. Second, the choice of transportation mode, which can be affected by infrastructure investments and other public policies,[35] substantively affects passenger-mile efficiency. Amtrak and, by extension, commuter rail, is considerably more efficient than any of the other choices, except motorcycles. Moreover, within the highway mode, efficiency varies significantly: in 2000, passenger cars were 20% more efficient on average than pickups, SUVs, and minivans, but in 2006 improvements in the latter had reduced the difference to 12%.

All in all, it appears that policy choices can affect the energy intensity of travel, and thus opportunities for improvement exist. Because there is clearly a limit on greenhouse gas emission reductions to be achieved by heightened efficiencies in the transportation sector, interest turns to alternative fuels that do not generate greenhouse gases, including renewables and hydrogen. Brazil has made considerable progress in substituting ethanol for gasoline (40% by volume); however, the U.S. promotion of ethanol is still a small proportion of gasoline consumption (3.6%

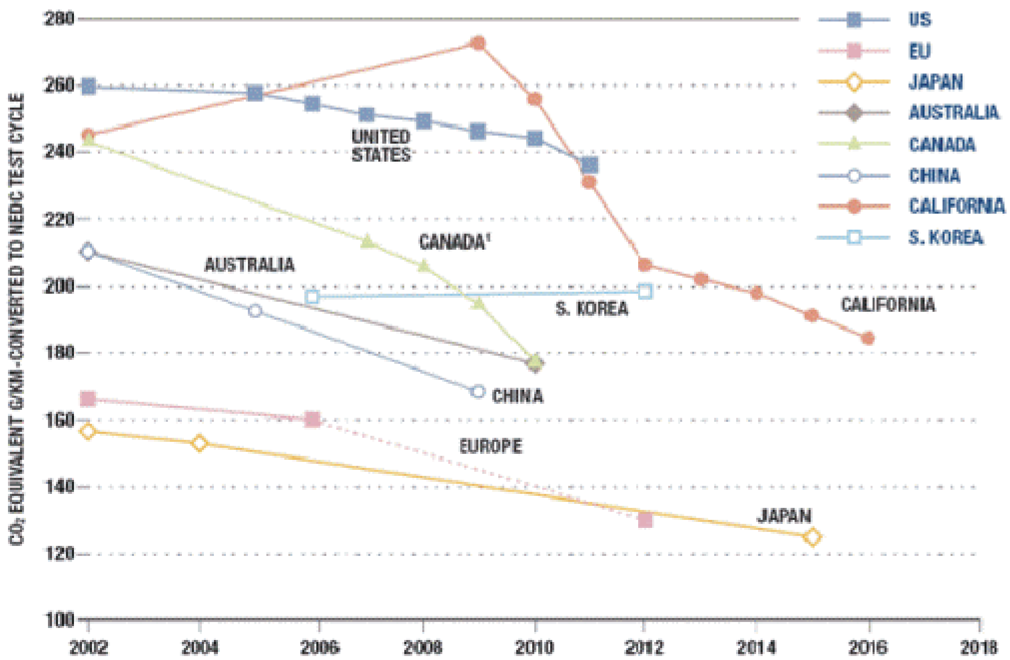
(...continued)

Council on Clean Transportation (July 2007), p. 8.

[35] For example, the London "congestion tax" is intended to shift commuters out of passenger cars and onto public transit.

by volume in 2006), and there are questions about the net impact of ethanol use on CO_2 emissions.[36] Hydrogen remains a distant possibility.

Figure 1. Actual and Projected GHG Emission for New Passenger Vehicles by Country, 2002-2018



Source: Feng An, et al., *Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A Global Update*, International Council on Clean Transportation (July 2007), p. 8.

Note: Solid lines denote actual performance or projected performance due to adopted regulations; dotted lines denote proposed standards; Values normalized to NEDC last cycle in grams of CO_2-equivalent per km.

1. For Canada, the program includes in-use vehicles. The resulting uncertainty on new vehicle fuel economy was not quantified.

Effects of Land Use on Intensity

Land use changes can affect emissions (**Table 3**) and intensity (**Table 11**). They have been excluded from most analyses in this report because the data are limited and less robust than most of the emissions data, and because for most nations, taking it into account changes little.

Taking into account land use changes and forestry is highly time dependent: as nations clear land, develop their agriculture, and harvest forest resources, their emissions will rise; but for many nations, these activities occurred long ago. Only for those nations now at the point in their development where agricultural land clearing and logging are important activities, do substantial emissions result. Today, this is most notable in Indonesia and Brazil. In 2005, their emissions attributable to land use changes and forestry practices accounted for 71% and 64%, respectively,

[36] See CRS Report R40155, *Selected Issues Related to an Expansion of the Renewable Fuel Standard (RFS)*, by (name redacted) and (name redacted).

of their total GHG emissions. And as can be seen in **Table 11**, incorporating land use changes and forestry greatly increases the greenhouse gas intensity of their economies.

Even though land use changes may have a small effect on emissions for most countries, and the data lack robustness, including it in analyses can identify those situations where it is undeniably important and for which interventions might pay large dividends in terms of curtailing greenhouse gas emissions or sequestering CO_2.

Table 11. Land Use Changes: Impact on Intensity of Greenhouse Gas Emissions—Top 20 Emitting Countries

Country	Intensity 2005 (excluding land use) tCeq/million $PPP(all 6 GHG)	Intensity 2005 (including land use) tCeq/million $PPP(all 6 GHG)	Intensity difference, with land use minus without land use	% difference
China	372	369	-3	-1
United States	153	150	-3	-2
EU-27	105	105	0	0
Russian Fed	313	322	9	3
India	208	—[a]	—	—
Japan	96	—	—	—
Brazil	174	490	316	182
Germany	103	—	—	—
Canada	178	194	16	9
U.K.	91	—	—	—
Mexico	136	144	8	4
Indonesia	226	790	564	250
Iran	236	—	—	—
Italy	93	—	—	—
France	80	—	—	—
S. Korea	142	—	—	—
Australia	236	—	—	—
Ukraine	512	—	—	—
Spain	100	—	—	—
S. Africa	289	—	—	—
Turkey	136	148	8	6
WORLD	182	208	26	14

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

a. Not available.

Cumulative Emissions

That economic growth is a major underlying cause of the rise in greenhouse gas emissions is evident when one examines cumulative emissions: nations that achieved economic growth in the 19th and 20th Centuries account for the majority of the emissions over time. Moreover, as greenhouse gas emissions are long-lived in the atmosphere, their effect cumulates over time. A justification for developed nations taking the lead on reducing emissions, while giving developing ones the opportunity to increase emissions from activities that are necessary for economic development, is not just that developed nations are wealthier but also that they account for the bulk of cumulative emissions affecting climate. Data to assess cumulative emissions are limited. In general, data are available only for CO_2 and are calculated from fuel use estimates; land use changes over long time spans are important, but data are scanty or unavailable. CAIT provides figures for CO_2 emissions from fuel use, only from 1850, and not including land use changes (**Table 12**).

Because climate-forcing depends on the cumulative emissions, not current emissions, it is easy to see from **Table 12** why developing nations feel that developed ones should take the lead. Given CAIT data, the United States and the European Union-27 account for over half the cumulative CO_2 emissions from energy use since 1850.

The data on cumulative emissions and on including or excluding land use changes (see **Table 11**) highlight why individual nations are so differently affected by proposals to reduce greenhouse gas emissions. Setting a baseline year for determining a nation's emissions means that countries that developed early could do so with no restrictions on the use of fuels and other resources regardless of their potential impact on climate, while those nations just now undergoing development might face restrictions. The emissions of already developed nations are embedded in their baselines. Similarly, whether certain activities such as land use changes are included or not affects what is in the baseline. The greenhouse gas emissions of Brazil and Indonesia, for example, increase markedly when emissions from land use changes of the last few decades are counted; but comparable land use changes in many other countries (e.g., the United States) happened in earlier centuries, and the resulting emissions count only toward cumulation, not against any current baseline.

Table 12. Cumulative CO_2 Emissions from Energy: Top 20 Emitting Countries, 1850-2006

(Excludes Land Use Changes)

Country	Cumulative Emissions (MMTCE)	Percentage of World	Rank in World
China	27,075	8.6	2
United States	91,088	29.0	1
EU-27	83,447	26.6	
Russian Fed	25,404	8.1	3
India	7,487	2.4	8
Japan	12,155	3.9	6
Brazil	2,581	0.8	21
Germany	21,937	7.0	4

Country	Cumulative Emissions (MMTCE)	Percentage of World	Rank in World
Canada	6,860	2.2	9
U.K.	18,623	5.9	5
Mexico	3,212	1.0	15
Indonesia	1,788	0.6	25
Iran	2,211	0.7	23
Italy	5,132	1.6	12
France	8,810	2.8	7
S. Korea	2,699	0.9	20
Australia	3,470	1.1	14
Ukraine	6,856	2.2	10
Spain	2,915	0.9	17
S. Africa	3,492	1.1	13
Turkey	1,490	0.5	29
WORLD	314,056	100.0	

Source: Climate analysis Indicators Tool (CAIT), version 7.0 (Washington, DC: World Resources Institute, 2010).

Interactions of the Variables

Numerous subtle and indirect interactions occur among population, income, intensity, energy use, land use changes, and emissions. These interactions affect policy choices concerning climate change because of their implications for other important social policy initiatives and objectives—most importantly, policies to promote economic development and income growth. These interactions also make difficult the projection of trends over time.

Economic development and growing incomes interact with population growth in two ways. First, birth rates tend to decline as incomes rise,[37] reducing one of the upward pressures on emissions. Most high-income nations have annual birth rates of 0.5% or lower, compared with developing nations with birth rates that in some cases exceed 2% per year. Second, the economic opportunity that many developed nations offer means they may have relatively high immigration rates, so their population growth is higher than their birth rate.[38] Overall, most demographers expect the rate of population growth to slow, although world population is projected to exceed 9 billion in 2050, with most of the increase in the developing world.[39]

[37] This is not a simple cause and effect, but reflects evolutionary changes in areas such as education, cultural expectations, women's rights, access to birth control, and health care—all of which may be affected by social policy.

[38] For example, for the United States, the U.S. Census Bureau projected that in 2010, U.S. population growth would be 1%, with immigration accounting for just under half the increase (about 45%). For 2050, the projection is a growth rate of about 0.8%, with immigration accounting for more than half the increase (about 60%). http://www.census.gov/population/www/projections/summarytables.html

[39] See http://www.un.org/News/Press/docs//2007/pop952.doc.htm.

Economic development and energy use are closely intertwined. The substitution of fossil fuel energy for human and animal power has been an important driver of the industrial revolution and consequent higher incomes. Indeed, for many, industrialization is synonymous with economic development. Yet at some point in development, the growth in incomes becomes at least partially detached from energy use, as energy costs lead to attention to energy efficiencies and as economies shift toward post-industrial services. Public policies can affect the relationship between economic development and growth and energy use in many ways, including taxation, infrastructure development, and research and development. The UNFCCC assumes that developing nations will inevitably have to exploit more energy as they give priority to reducing poverty. A key element of the climate change debate is how to decouple that economic development-energy use link.[40]

Income and emissions are related in another way, as well. In general, low-income people in developing nations focus their efforts on survival, whereas nations and individuals with higher incomes are likely to have more time and money to attend to environmental needs and amenities. Thus, while richer nations consume more goods and services, including energy, per capita, they also have generally been the most aggressive in addressing pollution and other environmental insults. This empirical relationship is known as the Environmental Kuznets Curve. However, its applicability to CO_2 emissions has been questioned,[41] and to the degree that it does exist for conventional pollutants such as sulfur dioxide, it reflects policy choices to constrain emissions.

These interactions have both short-run and long-run implications. For most nations most of the time, the combination of population growth and per capita GDP growth has more than offset forces tending to depress emissions, so emissions have increased. Overall, the most critical interaction is the one between per capita GDP growth and resource uses, especially energy, but also including cement manufacture, agricultural practices, deforestation, waste disposal, and the consumption and release of certain chemicals.

Changes in Intensity To Meet Climate Stabilization Goals

What might be required to "prevent dangerous interference with the climate system" remains debatable. The answer actually depends on the concentration of greenhouse gases in the atmosphere, not the level of emissions at a given point in time. Ultimate goals, then, are typically expressed in terms of what concentration would be required to keep global warming below a certain amount with a certain probability.[42] Models are then used to assess what emission reductions would be required to keep concentrations below the target level.

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[40] CRS Report RL32721, *Greenhouse Gas Emissions: Perspectives on the Top 20 Emitters and Developed Versus Developing Nations*, by (name redacted) and (name redacted).

[41] The entire March issue of the *Journal of Environment & Development*, vol. 14 (2005) is devoted to this topic; see especially Joseph E. Aldy, "An Environmental Kuznets Curve Analysis of U.S. State-Level Carbon Dioxide Emissions," pp. 48-72. Also, William R. Moomaw and Gregory C. Unruh, "Are Environmental Kuznets Curves Misleading Us? The Case of CO_2 Emissions," in *Environment & Development Economics* (Cambridge University Press, 1997), pp. 451-463.

[42] See, for example, M.G.J. den Elzen and M. Meishausen, "Meeting the EU 2°C climate target: global and regional emission implications," Report 728001031/2005, Netherlands Environmental Assessment Agency.

As noted earlier, the Copenhagen Accord is an agreement of the Parties to the UNFCCC to begin establishing actions to follow on the Kyoto Protocol. The Copenhagen Accord[43] does not mandate specific reductions, but sets a goal of reducing global emissions "so as to hold the increase in global temperature below 2 degrees C, and take action to meet this objective consistent with science and on the basis of equity."

The United States has declared that its Copenhagen Accord target commitment is for a quantified economy-wide emissions reduction for 2020 "in the range of 17%" from 2005, "in conformity with anticipated U.S. energy and climate legislation, recognizing that the final target will be reported to the Secretariat in light of enacted legislation."[44]

U.S. Greenhouse Gas Intensity: Trends and Targets

Analyzing and projecting the values and the rates of change for the variables population, income, intensity, and emissions depend on the baseline, the time period in question, and assumptions about changes over time. For the purpose of thinking about the United States slowing and then reversing its increase in greenhouse gas emissions, the historic trends in population, income growth, and greenhouse gas intensity indicate the magnitude of the challenge:

United States: Trends in Drivers of GHG Emissions, 1990-2005

(Annual rate of change, %)

Population		Per Capita GDP		GHG Intensity		GHG Emissions
(1.1)	+	(1.8)	+	(-1.9)	=	(1.0)

To simply stop the growth in GHG emissions, the three factors on the left side of the equation must sum to zero. Population growth is slowing: the actual rate for 2000-2006 was slightly over 0.9%, and the U.S. Census Bureau projects it to fall to +0.8% by 2050.[45] Assuming that population continues to grow at +0.9% through 2020, and that per capita GDP grows at the rate of +1.8% of 1990-2005, then GHG intensity would have to decline at the rate of -2.7% per year to stabilize emissions.

But the U.S. target for the Copenhagen Accord is to reduce GHG emissions for 2020 to 17% below 2005 emissions. Taking the CAIT emissions data for 2005 of 1,892 MMTCE (excludes land use changes and forestry and international bunkers[46]), the 2020 target would be 1,570 MMTCE. This would require an emissions reduction of -1.2% per year for 2005-2020 (actually, emissions grew through 2007, before turning down during the recession in 2008). If one assumes that 2010 GHG emissions were at the 2005 level and that the annual trends of +0.9% population and +1.8% per capita GDP continue[47] through 2020, what rate of intensity decline would be

[43] http://en.cop15.dk/files/pdf/copenhagen_accord.pdf

[44] http://unfccc.int/home/items/5264.php. The U.S. commitment adds the following note: "The pathway set forth in pending legislation [i.e., H.R. 2454, S. 1733] would entail a 30% reduction in 2025 and a 42% reduction in 2030, in line with the goal to reduce emissions 83% by 2050."

[45] http://www.census.gov/population/www/projections/summarytables.html

[46] Accounting for these exclusions changes the emissions only to 1,896 MMTCE, or +0.2%—irrelevant in terms of likely errors in reported emissions.

[47] It is important to recognize that we are looking at trends over an extended time; these assumed average trends blur short term variations (e.g., higher rates of intensity decline in 2004-2005, or possible variations from the recession that started in 2008). *The Economic Report of the President, 2010*, forecasts growth rates through 2020 (see Table 2-3, p. (continued...)

necessary to achieve the 2020 goal? The answer is, it would take a rate of intensity decline of about -4.6% per year[48] beginning in 2010, to reach the level of 1,570 in 2020.

United States: Trends in Drivers of GHG Emissions, 2010-2020, to Meet Copenhagen Accord Target

(Annual rate of change, %)

Population		Per Capita GDP		GHG Intensity		GHG Emissions
(0.9)	+	(1.8)	+	(-4.6)	=	(-1.9)

This represents a substantial, ongoing improvement in intensity, from a GHG intensity of 153 MMTCE/million$PPP in 2005, to an intensity of 86 in 2020—but perhaps not impossible, when one considers that in 2005 France's intensity level was 80.

Over the longer term, much more aggressive goals have been proposed: the U.S. target for the Copenhagen Accord appended a note suggesting a goal for 2050 of an 83% reduction from 2005 levels of GHG emissions,[49] which would limit U.S. emissions to 321 MMTCE. Assuming population and per capita GDP grow from 2010 to 2050 at the average annual rates of 0.85% and 1.8%, respectively, then given the emission rate at the cap, U.S. greenhouse gas intensity in 2050 would be about 8 MMTCE/million$PPP—an extremely low-carbon economy. Or, in terms of rate of change, intensity would have to decline between 2005 and 2050 at an average rate of about -6.6% per year.[50]

To give perspective to rates of intensity decline, consider an illustrative scenario in which, for each of the 10 years 2016-2025, two 1,000-megawatt nuclear electrical generating facilities go into service (or equivalent generating capacity based on renewables), replacing existing coal-fired facilities. Each plant would displace approximately 6 million tons of carbon per year; when all 20 coal-supplanting plants were in service in 2025, they would be displacing 120 million tons of carbon per year. All else equal, displacing this much carbon would accelerate the rate of decline in intensity for 2016-2025 by about -0.5% per year. This example, which lowers emissions and intensity only incrementally, shows that large declines in intensity would require multiple initiatives. To meet the goal of reducing economy-wide emissions to 17% of 2005 levels by 2050 implies some mix of making tremendous gains in energy efficiency, shifting to energy sources that emit virtually no CO_2, and developing the capacity to capture and sequester enormous amounts of CO_2.

(...continued)

75), that rise to over 4% for 2011-2013, then decline to 2.5% for 2019-2020—or in terms of the per capita data presented in this report, subtracting population growth gives rates of approximately 2.5% annual per capita growth for 2011-2013, declining to 1.7% for 2019-2020.

[48] Achieving this could include, besides direct reductions in emissions, offsets from reductions made and paid for in other countries, as well as reductions from land use changes and sequestration.

[49] http://unfccc.int/home/items/5264.php The U.S. commitment adds the following note: "The pathway set forth in pending legislation would entail a 30% reduction in 2025 and a 42% reduction in 2030, in line with the goal to reduce emissions 83% by 2050."

[50] Achieving this could include, besides direct reductions in emissions, offsets from reductions made and paid for in other countries, as well as reductions from land use changes and sequestration.

Global Greenhouse Gas Intensity

As has been noted, world greenhouse gas intensity has been declining, but not at a rate sufficient to prevent rising GHG emissions (numbers do not add precisely, due to rounding):

World GHG Emission Drivers, 1990-2005

(excludes land use changes and forestry and international bunker)

(Annual rate of change, %)

Population		Per Capita GDP[51]		GHG Intensity		GHG Emissions
(1.4)	+	(1.7)	+	(-1.6)	=	(1.6)

An in-depth analysis of policies and programs for reducing global greenhouse gas emissions is far beyond the scope of this report. But if greenhouse gases are to be reduced, the imperative to reduce intensity is clear. Simply put, more people at higher standards of living means more goods and services, especially energy—to cook, heat and cool homes, to manufacture goods, to transport people and goods, etc.

To decouple those increases in the numbers of consumers and their consumption from increases in greenhouse gas emitting energy uses implies policies fostering greater efficiency in using energy and/or use of non-greenhouse gas-emitting forms of energy, such as renewables or nuclear. But greater efficiency ultimately reaches limits from the laws of physics; alternative fuels run into the facts that, in most places, fossil fuel, either coal or natural gas, is the least expensive fuel for generating electricity and heat, and oil is the least expensive fuel for powering transport.

Beyond the energy sector, moreover, there are many other areas where policies may affect GHG emissions. Land use and agricultural and forestry policies can have direct implications for emissions, and could reduce intensity. The non-CO_2 gases, many of which pose particularly long-term climate implications, offer cost-effective opportunities for reductions from certain industrial processes, landfills, and fuel production.

Perhaps most importantly, at the global scale, the possibility exists for identifying and exploiting least-expensive opportunities for reducing greenhouse gases, thereby increasing the efficiency with which economies use greenhouse gas-emitting technologies. This depends, however, on global instruments for accounting for and verifying such reductions. Reaching practical agreements on international mechanisms (e.g., for a carbon tax or a cap-and-trade system to obtain economic efficiencies among nations in reducing emissions) requires divergent national goals to be focused on what is, ultimately, a global issue. The global nature of climate change challenges national sovereignty. The UNFCCC, the Kyoto Protocol, the Asia-Pacific Partnership, and the Copenhagen Accord are efforts in multilateral approaches to reducing emissions, but their individual and complementary successes remain to be seen.

[51] Economic contractions of several newly independent nations following the breakup of the former Soviet Union depressed global GDP, so this rate will likely rise in subsequent decades.

Conclusion

In the end, the interactions of the variables, population, income, and intensity of emissions (**equation 1)**, together with the inexorable force of compounding growth rates over time (**equation 2**) are inescapable conditions determining both the risks of climate change and the costs, benefits, and tradeoffs of options for responding. If climate change poses a genuine risk to the well-being of mankind, the nations of the world, individually and collectively, face two fundamental challenges: adopting and implementing policies and encouraging the development and use of technologies that emit lower levels of greenhouse gases, and maintaining a sufficiently high rate of intensity decline over the long term to ensure declining emissions.

In 1992, Congress enacted the Energy Policy Act of 1992 (EPACT, P.L. 102-486), which contained provisions to implement the United Nations Framework Convention on Climate Change (UNFCCC), which had been signed earlier in the year.[52] The UNFCCC's objective to stabilize "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" was echoed in EPACT, which called for a National Energy Policy Plan to "include a least-cost energy strategy ... designed to achieve [among other goals] ... the stabilization and eventual reduction in the generation of greenhouse gases.... "[53]

In ratifying the UNFCCC, the United States agreed to several principles for achieving this objective, including the following:

- "[D]eveloped country Parties should take the lead in combating climate change and the adverse effects thereof."[54]
- "Parties should take precautionary measures to anticipate, prevent or minimized the causes of climate change and mitigate its adverse effects."[55]
- "Parties have a right to, and should, promote sustainable development.... " Climate change policies should take "into account that economic development is essential for adopting measures to address climate change."[56]

The UNFCCC's linking of sustainable development and climate change mitigation reflects the perceived need to decouple economic development and growth from non-sustainable, greenhouse gas-emitting energy technologies.

As this report suggests—

- An expanding global population is an important driver for economic growth. As affirmed in the UNFCCC, climate change policies are to take "into full account

[52] The United States signed the UNFCCC on June 12, 1992, and ratified it on October 15, 1992 The UNFCCC entered into force on March 21, 1994.

[53] Section 1602(a)

[54] UNFCCC, article 3.

[55] Ibid.

[56] Ibid.

the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty."[57]

- Economic development may reduce population pressure in the long-term but creates increasing demand for resources that, employing current technologies, contribute to greenhouse gas emissions. Although economies become more efficient over time, those efficiencies have yet to overcome the combination of expanding population and growing economies without the intervention of governments.
- Satisfying the energy needs of dynamic economies is increasing the demand for coal and other fossil fuels for economic and other reasons. To meet the massive reductions in greenhouse gas emissions in the long term required by various stabilization scenarios would seem to require the development and deployment of commercially available technologies to shift economies substantively away from fossil fuels, and/or the large-scale capture and sequestration of the emissions of CO_2 from coal and other fossil fuels. The UNFCCC recognizes the "special difficulties of those countries, especially developing countries, whose economies are particularly dependent on fossil fuel production, use and exportation, as a consequence of action taken on limiting greenhouse gas emissions."[58]

Breaking the current dynamic of increasing populations and economic growth pushing up greenhouse emissions would depend on developing "sustainable" alternatives—both in improving the efficiency of energy use and in moving the fuel mix toward less greenhouse gas-emitting alternatives. In the UNFCCC, developed nations committed to taking the initiative by "adopt[ing] national policies and tak[ing] corresponding measures on the mitigation of climate change ... [that] will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention.... "[59] Such development paths are critical not only for any domestic program, but also participation by developing countries in any global greenhouse gas stabilization program may be at least partially dependent on the availability and cost of such technologies.

As stated by the UNFCCC,

> The extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments under the Convention related to financial resources and transfer of technology and will take fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties.[60]

The Copenhagen Accord places new emphasis on technology development and its transfer among nations and represents an important component of the United States'—and other developed nations'—response to this principle. It remains to be seen whether the proposed funds are forthcoming, and how they are dispersed. Fostering technological change depends on two driving

[57] UNFCCC, Preamble.

[58] UNFCCC, Preamble.

[59] UNFCCC, article 4(2)(a).

[60] UNFCCC, article 4(7).

factors: exploiting new technological opportunities (technology-push) and market demand (market-pull).[61]

Currently, U.S. policy is oriented primarily to the technology-push part of the equation, with a focus on research and development (R&D). In contrast, the European Union (EU) is complementing its research and development efforts by constructing a multi-phased, increasingly more stringent market-pull for greenhouse gas-reducing technologies and approaches, including taxes and regulatory requirements overlain by the EU's Emissions Trading System.[62]

The market-pull side focuses on market interventions to create demand, which poses questions of—

- Whether, how, and to what extent to use price signals to change behaviors and to stimulate innovation of technologies that increase energy efficiency or that emit less greenhouse gases. Direct taxes on energy or on greenhouse gases could be one approach, whereas the concept of shifting taxes from incomes to consumption would be a broader one.
- Whether, how, and to what extent to use regulatory actions to change behaviors and to require technologies that increase energy efficiency or emit less greenhouse gases. A direct regulatory effort would be a renewable power standard for electricity-generating facilities, which requires some specified portion of electric power to be generated by renewables, such as water power, solar, or wind (whether nuclear power might count is an open question). Heretofore, especially in the United States, regulatory efforts curtailing greenhouse gas emissions commonly originated in response to other objectives, such as reducing health-damaging air pollutants or enhancing energy security by fostering substitutes for imported oil. In these cases, reductions in greenhouse gases were coincidental ("no regrets"); further co-reduction opportunities remain (e.g., methane from landfills). However, the objective of reducing greenhouse gases as the primary object of regulations is increasingly coming to the fore, especially in some states.[63]

The technology-push side focuses on research and development. It raises questions as to what R&D programs should be supported at what levels:

- Over the short-to mid-term, how can existing technologies be made more sustainable? How can energy (and other resources) be used more efficiently? What alternatives can be pursued?
- What are the relative federal and private roles in selecting and financing R&D of specific technologies?
- Perhaps most important for the longer run, what breakthrough research should be pursued? Over the past 100 years, a number of technological changes have

[61] L. Clarke, J. Weyant, and A. Birky, "On the Sources of Technological Change: Assessing the Evidence," *Energy Economics*, vol. 28 (2006), pp. 579-595.

[62] See CRS Report R41049, *Climate Change and the EU Emissions Trading Scheme (ETS): Looking to 2020*, by (name redacted).

[63] See CRS Report RL33812, *Climate Change: Action by States to Address Greenhouse Gas Emissions*, by (name redact ed).

> occurred (e.g., in nuclear power, computing, and communications) that demonstrate the low success rate of predicting technological and societal changes far into the future. At present, at least two technological breakthrough possibilities can be discerned: fusion power, which conceivably could wean economies from fossil fuels, and sequestration,[64] which could capture and store carbon dioxide—and perhaps even remove excess from the atmosphere. Other breakthroughs are surely possible—including serendipitous discoveries that cannot be conceived of now.

If the ultimate, 2050 target for reducing greenhouse gas emissions is as aggressive as 83% below 2005 levels, as in some proposals, then fundamentally at issue is whether the risks of climate change can be addressed only by incremental "muddling through" or whether some extraordinary, aggressive effort is needed. Certainly, there are many opportunities for incremental and iterative policies to reduce greenhouse gases, to conserve energy, to find alternative energy sources, to make vehicles more energy efficient, to enhance carbon sequestration through afforestation and refined cropping practices, to deter deforestation and land use changes that increase CO_2 emissions, and so on. In addition, the potential for a substantial supply of natural gas offers the United States the possibility of buying time (similar to what the U.K. did in the 1990s) to allow a combination of research and development and market forces responding to a government-imposed carbon price to providing longer term opportunities. The incremental nature of such a response provides flexibility, while a time frame of decades offers hope of unpredictable breakthroughs or the discovery that climate change is not so threatening as some fear.

Conversely, given the drivers increasing emissions, such as population growth and economic development and growth, it is hard to see how incremental changes affecting intensity will achieve the rate of intensity decline sufficient to reduce emissions to the proposed levels, even over decades.[65] From this perspective, an intense, aggressive pursuit of breakthroughs—even with high costs and high risks of failure—has to be weighed against the costs and risks of failing to prevent potentially dangerous interference with the climate system.

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64 See CRS Report RL33801, *Carbon Capture and Sequestration (CCS)*, by (name redacted).

65 However, some pollution control efforts have had dramatic successes: lead has been essentially eliminated as an air pollutant; regulated auto emissions have been reduced by over 90% from unregulated levels; between 1990 and 2005, sulfur dioxide emissions from acid rain program sources dropped by about 35%; and electricity generated rose about 30%.