ENERGY EFFICIENCY AND GREENHOUSE GAS EMISSION REDUCTIONS: SOME INTERNATIONAL RESULTS

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Twenty-one country case studies of future energy consumption and carbon emissions have been provided to the Intergovernmental Panel on Climate Change and included in its reports. This paper reviews the results of these studies with emphasis on the role of energy efficiency improvements as a means of reducing future carbon emissions. All of the case studies, which evaluated options for reducing emissions, identified efficiency improvements as a key component of their options to reduce future carbon emissions.

INTRODUCTION

Global climate change has recently become one of the key environmental issues driving debates over energy policy in the United States and internationally. This paper summarizes recent preliminary analyses of the potential for reducing energy-related greenhouse gas emissions, and focuses primarily on the role of energy efficiency.

Atmospheric concentrations of several greenhouse gases--notably carbon dioxide (CO_2), methane, Chlorofluorocarbons (CFCs) and related chemicals, and nitrous oxide--are increasing rapidly (IPCC, Working Group 1, 1990). These gases all share a property of absorbing infrared energy radiated from the Earth's surface, warming the lower atmosphere. Figure 1 illustrates the relative contributions of the principal gases to increases in the absorption of infrared energy over the decade from 1980-1990. While greenhouse gas concentrations will most likely continue to increase, considerable uncertainty exists about the rate and magnitude of global warming associated with these increases.

Efforts to stabilize atmospheric concentrations of greenhouse gases will be difficult due to the importance to national economies and personal comfort of activities that create emissions, and to the size of reductions needed to stabilize emissions. Energy production and consumption account for nearly 60% of the increases in absorption of infrared energy in the decade from 1980-1990 (see Figure 1), and emissions from these activities are expected to increase over time. Due to the long atmospheric lifetimes of most greenhouse gases, large reductions in emissions from current levels will be necessary to stabilize atmospheric concentrations of greenhouse gases or even reduce the rate of increase of these concentrations.

A balanced approach to responding to global warming is appropriate. A major research effort is under way but may take decades to resolve scientific uncertainties. The United States Government and other industrialized nations have indicated interest in near-term actions to reduce risk of climate change parallel with efforts to improve scientific understanding. Initial actions in the US include a commitment to phase out CFCs, the President's proposed reforestation program, and energy efficiency initiatives recently announced by the Department of Energy.

Recent international discussions on climate change have been coordinated primarily through the

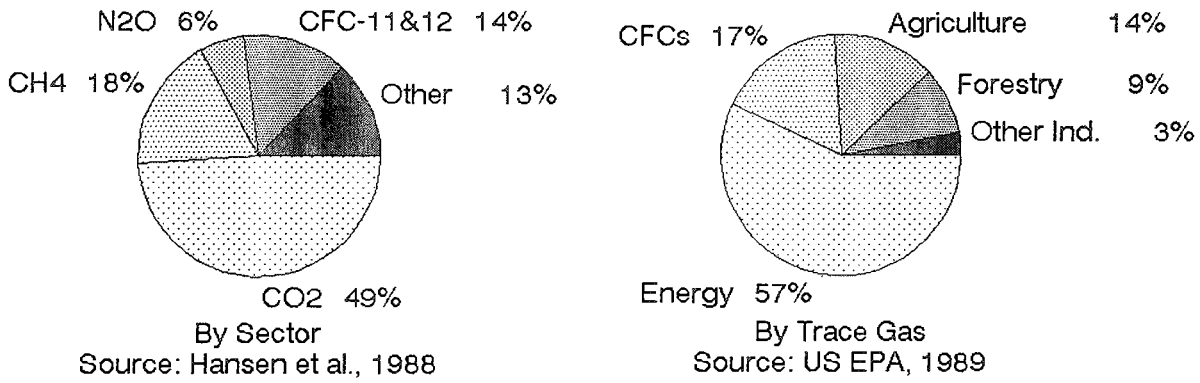

Figure 1. Current Contribution to Greenhouse Warming

Intergovernmental Panel on Climate Change (IPCC), established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). Information is being developed and exchanged in a collaborative process involving most of the major interested governments and international organizations. The Response Strategies Working Group (RSWG) has focused on policies to reduce emissions of greenhouse gases. Within the RSWG, the Energy and Industry Subgroup (EIS) has coordinated and compiled country analyses of energy-related emissions and options for reducing emissions. In developing its initial report, this group was able to assemble results of twenty-one individual country case studies of energy and carbon emissions. These countries include Australia, Brazil, Canada, China, Federal Republic of Germany, Finland, France, Hungary, India, Indonesia, Japan, Mexico, Netherlands, Norway, Poland, Republic of Korea, Switzerland, Union of Soviet Socialist Republics, United Kingdom, United States, and Venezuela.

REFERENCE SCENARIO

Each of the studies submitted to the EIS represented a scenario of future energy use and emissions under reference case assumptions--assuming no major international policy initiatives to respond to global climate change concerns. An expert group compiled results for country reference scenarios, supplemented with regional data from the International Energy Agency, and integrated them into a single global reference scenario (see US/Japan Expert Group, 1990). This global reference scenario is illustrative and falls within the range of plausible futures. Future energy consumption and emissions are difficult to predict reliably, especially as distant as 2025, due to the inherent uncertainty surrounding key variables such as population growth, level and structure of economic activity, carbon intensity of energy systems, and development and dissemination of new technologies.

Table 1 and Figures 2-3 summarize primary energy consumption and carbon emissions from this reference scenario through the year 2025. The results show a rapid increase in primary energy consumption globally and a corresponding rapid growth in carbon emissions--well over a doubling of both global energy consumption and carbon emissions by 2025. This growth in emissions presents a major challenge to all who are concerned with designing and evaluating climate change response options and illustrates the importance of any policy options which can be implemented to reduce the growth of energy consumption.

However, many of the participating countries already are engaged in or planning policy initiatives to reduce the energy intensity of their economies and have incorporated these expected results into their reference scenarios. China, for example, already places a high priority on programs to reduce energy intensity primarily for economic reasons and plans to continue to improve at a rate of 2.7 percent per year for the entire projection period. Similarly,

Table 1. Reference Scenario Results

	----GDP Growth---- (1985=100)			Primary Energy Use (exajoules)			--CO_2 Emissions--- (billion tons C)			--CO_2 per capita-- (tons C/capita)		
	1985	2000	2025	1985	2000	2025	1985	2000	2025	1985	2000	2025
Global Totals	100	160	330	328.2	462.1	776.9	5.15	7.30	12.42	1.06	1.22	1.56
Developed	100	155	280	234.7	308.0	434.6	3.83	4.95	6.94	3.12	3.65	4.64
North America	100	148	241	85.4	108.2	142.1	1.34	1.71	2.37	5.08	5.73	7.12
Western Europe	100	147	249	54.7	64.8	81.3	0.85	0.98	1.19	2.11	2.29	2.68
OECD Pacific	100	177	341	19.2	29.6	42.2	0.31	0.48	0.62	2.14	3.01	3.68
USSR & Eastern Europe	100	163	346	75.5	105.4	169.0	1.33	1.78	2.77	3.19	3.78	5.02
Developing	100	185	563	93.4	154.0	342.3	1.33	2.35	5.48	0.36	0.51	0.84
Africa	100	152	483	13.5	21.0	52.9	0.17	0.28	0.80	0.29	0.32	0.54
Centrally Planned Asia	100	214	799	31.2	47.0	91.9	0.54	0.88	1.80	0.47	0.68	1.15
Latin America	100	152	360	19.1	27.5	55.0	0.22	0.31	0.65	0.55	0.61	0.91
Middle East	100	219	667	8.0	19.2	43.2	0.13	0.31	0.67	1.20	1.79	2.41
South and East Asia	100	194	603	21.6	39.3	99.2	0.27	0.56	1.55	0.19	0.32	0.64

(annual rate of change)

	----GDP Growth----		-Energy Intensity-		-Carbon Intensity-	
	1985 2000	2000 2025	1985 2000	2000 2025	1985 2000	2000 2025
Global Totals	3.2%	2.9%	-0.9%	-0.8%	0.0%	0.0%
Developed	3.0%	2.4%	-1.1%	-1.0%	-0.1%	-0.0%
North America	2.6%	2.0%	-1.0%	-0.9%	0.0%	0.2%
Western Europe	2.6%	2.1%	-1.4%	-1.2%	-0.2%	-0.1%
OECD Pacific	3.9%	2.7%	-0.9%	-1.2%	0.0%	-0.3%
USSR & Eastern Europe	3.3%	3.1%	-1.0%	-1.1%	-0.2%	-0.1%
Developing	4.2%	4.6%	-0.8%	-1.3%	0.5%	0.2%
Africa	2.8%	4.7%	0.2%	-0.9%	0.5%	0.6%
Centrally Planned Asia	5.2%	5.4%	-2.3%	-2.5%	0.5%	0.2%
Latin America	2.8%	3.5%	-0.4%	-0.7%	-0.0%	0.1%
Middle East	5.4%	4.6%	0.7%	-1.2%	-0.3%	-0.1%
South and East Asia	4.5%	4.6%	-0.4%	-0.8%	1.0%	0.3%

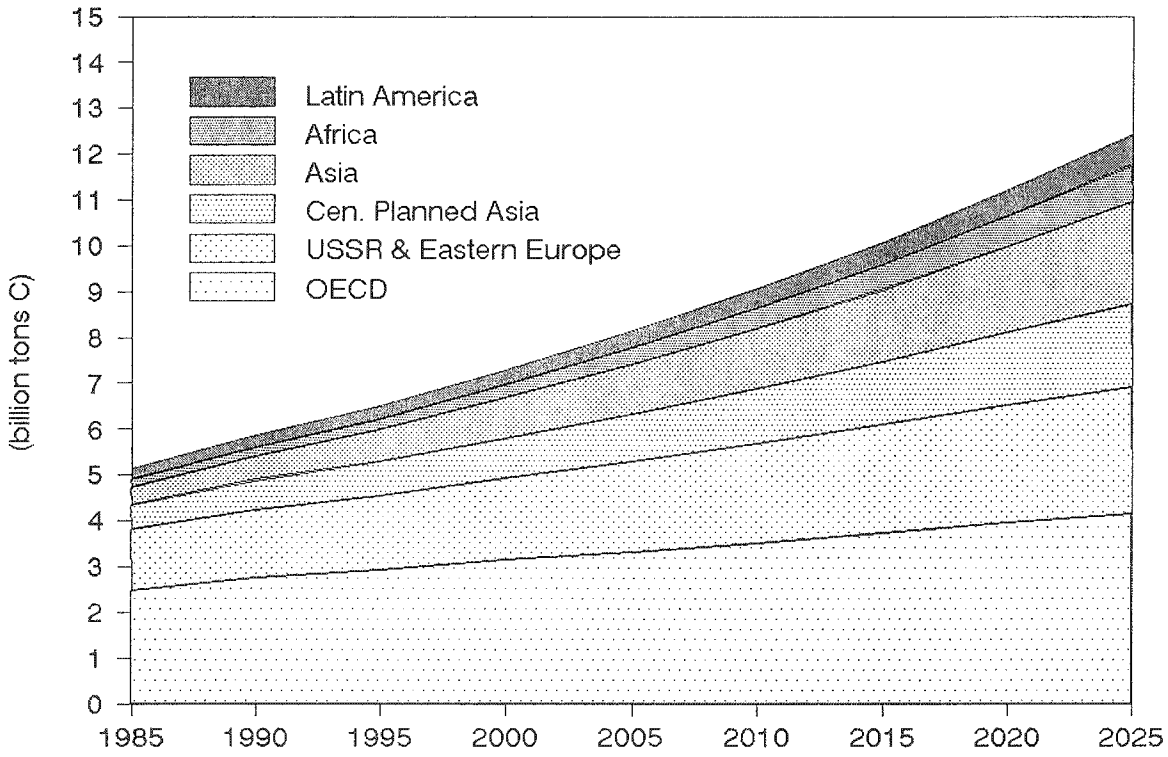

Figure 2. CO_2 Emissions by Region

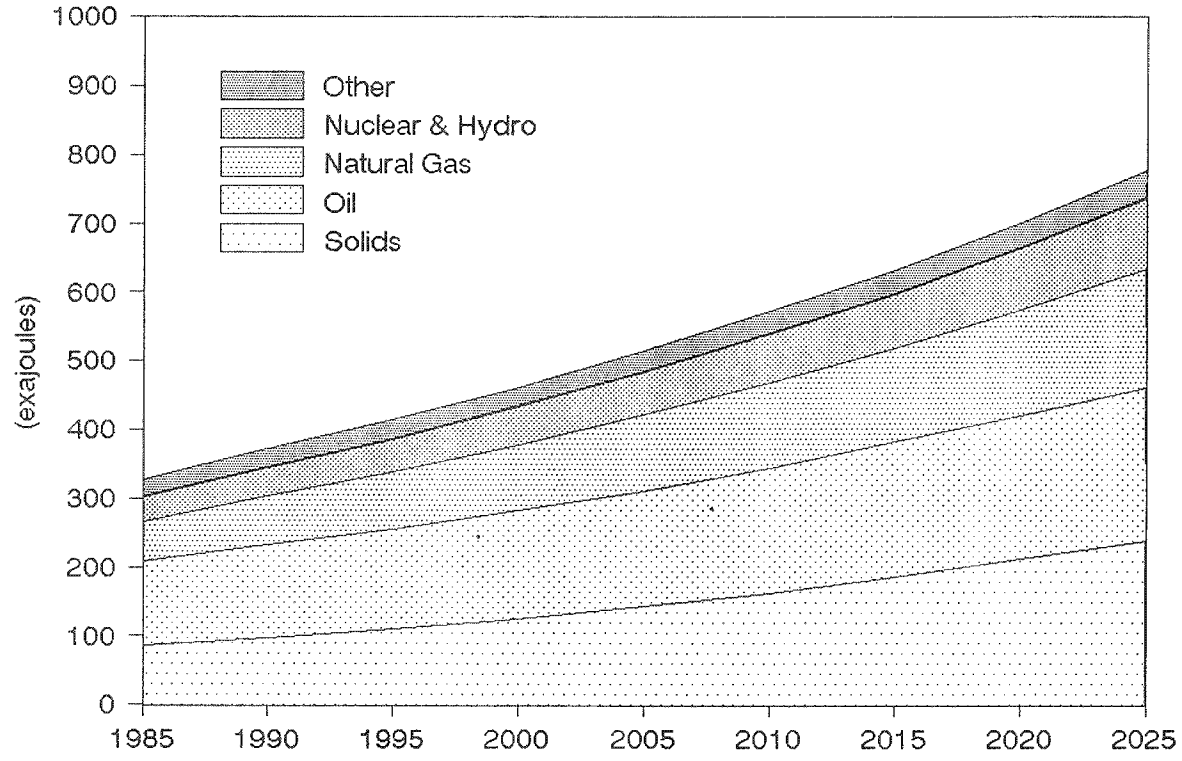

Figure 3. Primary Energy Demand by Energy Type

the Federal Republic of Germany (FRG) and France have programs in place and planned which are expected to markedly reduce the energy intensities of their economies regardless of any international agreements on climate change.

In the reference scenario, significant absolute growth in primary energy use and carbon emissions occurs in all regions, but rates of growth differ, reflecting differences in regional economic growth rates, energy policies, and resource endowments. Fossil fuels continue to dominate energy supply in all regions. Energy use and carbon emissions grow fastest in the developing countries, which assumedly will experience faster economic growth than industrialized countries, keeping pace with more rapid population growth while improving living standards. In spite of these increases, carbon emissions per capita in the developing countries stay well below those in the industrialized countries. As shown in Table 1, annual per capita carbon emissions for the developing countries as a whole increase only from about 0.4 tons per capita in 1985 to about 0.8 tons per capita in 2025. During the same period, annual emissions in North America increase from about 5 tons to over 7 tons per capita.

ANALYSIS OF RESPONSE OPTIONS

The following summary and analysis of the response options reflect the different types of response options evaluated in the country studies as well as the wide range of approaches used and the different ways used to present the results. These differences precluded the development of an integrated options scenario. Instead, the results of the options scenarios are reviewed for broad regions where similarities or patterns are found. In every country for which options analysis was available, energy efficiency was identified as a key component. Table 2 summarizes the results of the individual country analyses.

Western Europe

Within the OECD countries, several Western European countries produced options analysis with somewhat similar results, suggesting a broad pattern for the region. Assumptions of future economic growth for these countries are similar, and the policy scenarios suggest significant potential for reducing the energy intensity (energy use per dollar Gross Domestic Product, GDP) of the economies over time and stabilizing or even reducing emissions. These scenarios differ for some of the countries, notably the FRG, France and Switzerland, which assume major programs to promote energy efficiency, resulting in significant declines in energy intensity in the reference scenarios.

In **France**, efficiency improvements have been a major goal of national energy policy since the early 1970s. From 1973 to 1988, CO_2 emissions in France actually declined 26 percent while GDP increased 40 percent. About one-third of the decline is due to conservation policies, with the other two-thirds resulting from rapid expansion of nuclear power. In the reference scenario, aggregate energy efficiency improves at a rate of 1 percent per year, due to structural changes in the economy and to continuation of the current government policies and programs to reduce energy consumption.

In the response option scenario, the French government analysts estimated that the rate of energy efficiency improvement could be increased to 1.5 percent per year through more aggressive government policies--primarily regulations in the buildings sector, taxes in the transportation sector, and expanded information, research, and incentive programs across all sectors. These added policies reduce growth in energy consumption over 30 percent relative to the reference scenario. With additional fuel substitution measures, the response options scenario holds CO_2 emissions roughly constant through 2010.

The reference scenario for the **Federal Republic of Germany** assumes a continuation and expansion of current government policy which encourages energy conservation and efficiency improvements. In addition, the study assumes a slight decline in population by 2010. The impact of unification with the German Democratic Republic has not been included in this analysis. Largely as a result of government tax policies which increase energy prices and programs to promote upgrading of energy-consuming equipment, primary energy use will decline to 3 percent less than 1987 levels by 2010. Combined with greater use of natural gas to replace

Table 2. Results of Country Specific Policy Analysis

Country	Average GDP Growth Rate	Primary Energy Use (exajoules) Initial[a] Year	-Forecast-[a] Ref.[b]	Pol.[c]	Carbon Emissions (billion tons C) Initial Year	-Forecast-- Ref.	Pol.
Western Europe							
FRG	2.3%	11.4	11.0	9.9	197	184	164
France	2.4%	8.5	11.4	10.5	94	117	95
Netherlands	2.2%	2.6	4.1	n/a[d]	40	71	28
Norway	n/a	1.2	1.4	1.3	10	12	10
Switzerland	2.0%	1.2	1.1	n/a	14	12	n/a
United Kingdom	2.4%	9.0	15.4	n/a	158	242	n/a
Other OECD							
Australia	3.1%	3.4	5.3	n/a	67	109	n/a
Canada	2.6%	10.2	16.1	n/a	114	175	107
Japan	3.5%	18.7	28.1	26.2	294	422	363
USSR & Eastern Europe							
USSR	3.2%	54.4	117.2	59.9	899	1752	773
Poland	2.8%	5.3	11.4	5.7	119	255	100
Hungary	2.0%	1.3	1.9	1.2	21	30	18
Developing							
Brazil	3.2%	6.0	15.2	9.6	41	129	63
China	5.6%	29.0	86.0	73.2	503	1719	1360
India	4.9%	8.1	36.6	29.0	98	620	480
Indonesia	3.0%	1.8	9.3	7.7	22	141	111
Rep. of Korea	5.9%	2.4	10.2	7.5	44	166	103
Mexico	3.5%	4.5	12.0	9.1	68	199	133
Venezuela	4.3%	1.7	7.1	6.5	23	67	52

[a] Data for each country study are provided for initial year and forecast year which are as follows: FRG (1987,2010), France (1988,2010), Netherlands (1985,2030), Norway (1985,2000), Switzerland (1988,2010), United Kingdom (1985,2020), Australia (1985, 2005), Canada (1985, 2005), Japan (1988,2010), and all others (1985,2025).
[b] Ref. - Reference Scenario
[c] Pol. - Policy Scenario
[d] n/a - Not Available

coal and oil, CO_2 emissions decline by 7 percent by 2010.

The response option scenario provided by the FRG focuses almost exclusively on improving efficiency. Through a combination of doubling of taxes on fossil fuel producers and consumers, and additional energy conservation promotion measures, energy demand declines a further 10 percent below the levels in the reference scenario for 2010, a level 17 percent below 1987 levels. In addition the energy pricing policies produce increases in renewable energy production. The combined effect is to reduce CO_2 emissions to 20 percent below 1987 levels by 2010.

In the reference scenario provided by the **Netherlands** energy consumption increases 47 percent, and CO_2 emissions increase 64 percent by 2030. Even though average energy intensity in the economy declines 27 percent during the period, economic growth causes increases in energy use, and greater reliance on coal causes more than proportional increases in CO_2 emissions. The first set of response options evaluated is a series of efficiency and conservation measures, including policies to promote mode shifts in transportation, increased recycling of basic materials, and energy efficiency standards for buildings and appliances. These measures offset growth in CO_2 emissions through 2000 and reduce energy consumption 22 percent below baseline levels in 2030. A range of additional advanced efficiency technologies, combined with greater use of natural gas, nuclear power and renewable energy technologies, reduces CO_2 emissions 9 to 26 percent below 1990 levels in 2030.

Other OECD Countries

A few case studies from industrialized market economies outside of Western Europe present a slightly different picture. In Australia, Canada and Japan, energy intensity improves in the reference scenarios. However, overall rates of growth in energy consumption and carbon emissions tend to be higher than projected for Western Europe. Analysis of response options is very preliminary in all three countries but suggests considerable difficulty in achieving stabilization or absolute reductions in carbon emissions. Nonetheless, all of these countries do identify some cost-effective, near-term opportunities for improving efficiency of energy use as a key component of response options.

For **Australia**, options include efficiency improvements in residential appliances, retrofitting and improved design of residential buildings, and improved energy intensity in industry. Although a response option scenario was not developed, implementation of these energy efficiency measures along with increased use of natural gas and renewable energy, were estimated to reduce carbon emissions a maximum of about 11 percent of reference scenario emissions for 2005.

The study for **Canada** examined about 140 individual energy policy measures aimed at reducing carbon emissions and focused primarily on end use energy efficiency improvements and electricity generation. In aggregate, economically attractive end use measures reduce reference case carbon emissions by 72 million metric tons (10 percent) in 2005. Additional technically feasible end use measures reduce emissions in 2005 an additional 10 percent. The transportation sector accounts for 50 percent of the emission reductions, with industrial measures contributing 22 percent, and measures in the residential and commercial sectors each accounting for about 14 percent. All economic measures, including those for electricity generation, reduce growth in emissions 80 percent by 2005 while all technically feasible measures reduce emissions 12 percent from 1989 levels.

The impact of policies in the study for **Japan** reflects assumptions about rapid economic growth combined with considerable improvements in energy intensity in the reference scenario. Preliminary evaluation of policies identified some cost-effective additional efficiency improvements which could reduce energy consumption 7 percent from the projected level by 2010. In combination with other fuel switching measures, the overall impact of policies is to reduce emissions growth 20 percent.

USSR and Eastern Europe

The USSR and Eastern Europe currently account for about one quarter of global carbon emissions. These nations rank among the most energy-intensive

in the world, typically about 80 percent more energy-intensive than Western European countries. Energy use and CO_2 emissions grow significantly in the reference scenarios. However, policies currently being considered or enacted in these countries to promote market economy decisions and "restructuring" could cause significant reductions in energy consumption and carbon emissions.

In the reference scenarios, economic growth in the region increases demand for consumer amenities toward Western European levels. Structural shifts toward production of consumer goods and away from the heavy current emphasis on basic materials production reduces energy consumption per unit of GDP. As energy supply currently acts as a constraint on economic growth in these countries, more aggressive polices to promote structural change would allow more rapid economic growth. All three of the country studies available for this region emphasize two common themes: (1) structural shifts are necessary for economic growth and will reduce growth in energy consumption; and (2) additional energy conservation measures can also significantly reduce energy consumption at less than the cost of supplying additional energy.

In the USSR reference scenario, continuation of current trends in energy use results in a doubling in energy consumption by 2025. Rapid progress in restructuring the economy produces significantly higher economic growth but lowers carbon emissions 25 percent from the reference levels for 2025. A range of identified additional measures to improve end use energy efficiency also reduce energy consumption and carbon emissions at less than the marginal cost of additional energy supply. Successful structural change combined with aggressive implementation of cost-effective efficiency measures could allow significant economic growth while holding carbon emissions stable at roughly current levels.

In Poland, the situation is in many ways similar to that in the USSR. The high energy intensity of the economy combined with the heavy reliance on coal results in high emissions of CO_2 as well as severe local air and water pollution problems. The country is already in the process of shifting from central planning to a market system, and attempting to conserve and protect environmental resources as well. In the reference scenario, both energy consumption and carbon emissions double by 2025. A successful transition to a market economy could reduce growth in emissions by 75 percent, resulting from less energy intensive economic activity and also some shifting from coal to natural gas due to removal of heavy current subsidies on coal prices. A range of identified cost-effective energy efficiency measures could reduce energy consumption at no net economic cost. These measures in combination with structural change could stabilize carbon emissions at current levels through 2025.

In Hungary, the economy is also very energy intensive, despite the fact that the country imports about half its energy, with energy prices close to market levels. In the reference scenario, continuation of current trends results in a growth in energy consumption and CO_2 emissions of about 50 percent by 2025. Structural change reduces this growth by a third. Successful implementation of additional economic energy efficiency measures, combined with structural change, reduces carbon emissions to 20 percent below current levels by 2025.

Developing Countries

Country level scenarios for seven key developing countries account for a substantial majority of the current and projected emissions from developing countries as a whole. While considerable variation exists between countries, several trends are apparent. In all of these countries, relatively rapid growth in population and economic activity leads to substantial increases in CO_2 emissions despite the fact that all but one of the countries analyzed assumed significant reductions in energy intensity in the reference scenario.

The analysts in developing countries identified increased energy efficiency as a precursor to economic development, leaving aside global environmental problems. The reference scenarios incorporate measures to promote efficiency improvements in most countries. These measures are most dramatic in China, where energy intensity declines at an average rate of 2.7 percent per year through 2025. This decline results from a continuing commitment of the government to implement aggressive policy

measures to increase efficiency primarily for economic reasons.

Long term economic growth expected in developing countries will also, over time, change the structure of economic activity, altering patterns of manufacturing and service industries and within manufacturing, of energy intensive and other industries. In the reference scenarios for developing countries, energy intensity declines as production of non-primary goods becomes a larger share of total production relative to primary (energy intensive) goods. This decline occurs despite an increase in the absolute level of production and production per capita of steel, aluminum, paper, cement, and other highly energy-intensive primary goods.

The current stock of capital goods in developing countries is relatively small and often very energy inefficient. As an example, steel manufacturing consumes 39 gigajoules (GJ) per ton of output in China and India compared to 18 to 20 in Japan and the US. Cement manufacturing consumes 4.8 and 5.6 GJ/ton respectively in China and India compared to around 3 GJ/ton in developed market economies. This capital stock should grow rapidly as economies grow, providing a significant opportunity for penetration of more efficient technologies, suggesting that large improvements in energy efficiency may be possible in much of the developing world.

Table 3 shows the improvements in unit energy consumption that are assumed in the scenarios for some key end uses for individual countries. The table shows improvements assumed in the reference scenarios as well as total efficiency improvements after implementation of response options. Average energy consumption for cars today, for example, tends to be lower for Asian countries than for Latin America, due in part to the average size of cars. The potential for reductions in unit energy consumption is, therefore, larger in Latin America than in Asia because reductions in size can be achieved.

On the other hand, where current unit energy consumption is low, faster economic development, particularly in Asia, could increase demand for amenities, leading to acquisition of larger cars, more appliances, and greater saturation of both. This trend can offset some of the gains from more efficient end use technologies.

As stated above, rapid economic growth exceeds the significant improvements in energy intensity assumed in reference scenarios for all developing countries. Energy consumption in all of these countries grows dramatically by the year 2025, with increases ranging from about 150 percent for Brazil to over 350 percent for Indonesia. In general, CO_2 emissions grow proportionally with energy use. However, all of these countries have identified opportunities for additional efficiency improvements which could reduce the rates of growth in energy consumption. The response options scenario for Venezuela is the least optimistic, with growth in energy consumption reduced by only 10 percent from the reference scenario. Other countries' estimates are generally in the range of 20 to 40 percent reductions in the growth of energy consumption. Brazil provides the most significant scenario of policy-induced efficiency improvements, resulting in a decrease of 60 percent in growth in energy consumption by 2025.

CONCLUSIONS

The analyses summarized in this paper represent first steps in developing a better understanding of the possible response options available to address concerns about increasing greenhouse gas concentrations and potential climate change. A great deal of additional analysis and documentation is needed. Many of the studies have evaluated economic costs and specific policy implementation measures in a cursory fashion, if at all. More careful comparison and standardization of assumptions and methodologies between countries and different analytic groups is needed and would improve our ability to generalize and compare strategies across regions and countries.

Nevertheless, even the preliminary results available to date suggest strongly that a significant potential exists for energy efficiency improvements over the next few decades beyond what would be induced by market forces. The available case studies suggest that much of this incremental efficiency improvement could be achieved at no net costs to national economies and could enhance economic growth. In addition, the studies suggest that very significant reductions in the rate of growth in CO_2

Table 3. Assumptions for Unit Energy Consumption In Developing Countries

	-Biomass Cooking- (GJ/Year)			-Refrigerators-- (kWh/year)			------Cars------ (liters/100 km)		
	1985	Ref.	Pol.	1985	Ref.	Pol.	1985	Ref.	Pol.
China	42.0	25.0	22.0	400	348	348	10.2	6.2	5.2
India	30.6	27.6	24.5	300	200	150	9.4	6.2	5.2
Indonesia	16.5	13.2	9.9				9.4	6.2	5.2
Rep. of Korea	12.6	10.3	10.3	389	622	467	10.2	9.4	7.3
Brazil	53.0	53.0	42.4	666	1000	400	13.1	7.3	5.3
Mexico							19.6	6.7	5.5
Venezuela	33.5	26.8	20.1	900	540	540	23.5	7.1	5.9
	-----Trucks----- (liters/100 km)			-----Steel------ (GJ/ton)			-----Cement----- (GJ/ton)		
	1985	Ref.	Pol.	1985	Ref.	Pol.	1985	Ref.	Pol.
China	3.10[c]	1.71[c]	1.55[c]	39	21	19	4.8	2.6	2.4
India	24	19	16	39	33	28	5.6	5.0	4.2
Indonesia	25	18	13						
Rep. of Korea	22	16	14	23	17	14	3.8	2.9	2.5
Brazil	23	18	9	26	24	13	4.1	3.7	2.1
Mexico									
Venezuela	50	25	15	30	26	24	5.7	4.6	4.1

[a] Ref. - Reference Scenario for 2025
[b] Pol. - Policy Scenario for 2025
[c] Units for trucks in China are megajoules per ton-kilometer

emissions--and in some cases stabilization or net reductions--could be achieved through policy-induced efficiency improvements. However, given the potential for rapid growth in emissions, major policy-induced measures would be necessary to reduce global emissions of CO_2 low enough to stabilize atmospheric concentrations.

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