The Role of Building Energy Efficiency in Managing Atmospheric Carbon Dioxide

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Recent reports by the Intergovernmental Panel on Climate Change and the US Department of Energy note that buildings account for 25-30% of total energy-related carbon dioxide (CO_2) emissions. This means building energy use contributes 10–12% of the increasing net radiative forcing that is inducing global warming. On average, between 1980 and 1990, CO_2 emissions from buildings have grown by 1.7% per year with rates of growth four times greater in developing countries. The high growth in developing countries is mainly due to changes in structural factors (demographics, economic growth) and increases in the amount of energy services demanded by energy consumers. Experience in OECD countries has shown that technologies and policies exist to significantly reduce energy demand in buildings. Some of the main policy instruments to reduce energy demand include energy efficiency standards for buildings and appliances, voluntary agreements, financial/economic incentives, and market transformation programs. When converted to carbon emissions, energy forecasts of the World Energy Council suggest that business-as-usual trends will result in building CO_2 emissions growing by 2.6% a year to the year 2020, with the vast majority of the growth taking place in non-OECD countries. Significant opportunities to help raise building energy efficiency at home and abroad exist, should countries begin to more fully commit to mitigating greenhouse gases. Commitments by countries to contain the growth of greenhouse gas emissions in an economically sound manner is likely to induce significant increases in the investment in energy-efficient technologies.

CLIMATE CHANGE AND THE GROWTH OF CARBON DIOXIDE

Pollution has always accompanied human existence. Smoky caves, fouled waters, smoggy cities and regional deposits of acid rain are examples of the price paid for the development of agriculture and urbanization. The industrial revolution greatly exacerbated environmental and human damage, and pollution is now a constant in today's landscape.

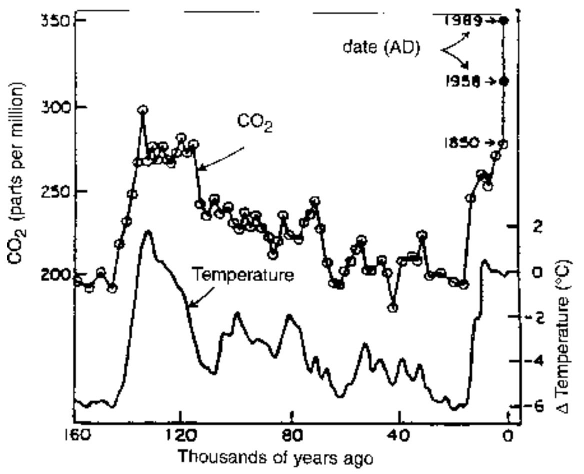
As the human population increases, environmental impacts expand geographically. One effect is the potential change in global climate from an accumulation of greenhouse gases in the atmosphere. To address this issue, the United Nations Environment Programme and the World Meteorological Organization in 1988 formed the Intergovernmental Panel on Climate Change (IPCC) tasked with providing the most up-to-date assessment of human effects on climate and human health. The most recent summary for policy makers, the IPCC second assessment report, notes that the continued accumulation of greenhouse gases in the atmosphere is in fact leading to measurable climate change (IPCC 1995a).

Although, the science of climate change and predictions of future scenarios are still not fully understood, radiative forcing by increased absorption in the troposphere of infrared radiation from the earth's surface (the greenhouse effect) has been documented to result from higher concentrations of greenhouse gases (GHGs), primarily carbon dioxide (CO_2), methane and chlorofluorocarbons. Increased net radiative forcing in the absence of any counterbalancing phenomena will eventually lead to increasing global mean temperatures at the earth's surface and in the lower atmosphere (IPCC 1995b). Correlation of data from ice-core samples agree with climate simulation model results to show a clear and direct relationship between concentrations of atmospheric carbon dioxide and global temperature (shown in Figure 1). Although the majority of CO_2 emissions result from natural source/sink cycles on land and in the oceans, human-made (anthropogenic) emissions now account for all of the total increase in carbon dioxide concentrations in the atmosphere.

Since the industrial revolution and the near global conversion to a fossil-based energy system, emissions of CO_2 have grown geometrically, leading to unprecedented levels of over 350 parts per million (see Figure 1). Concurrently, the measured temperature record shows a relatively steady increase in average global temperature since 1895. Global temperatures have steadily warmed by about 0.5° C since 1965 in a temperature range higher than has existed for the past 100,000 years (IPCC 1995b; Jones, Wigley & Briffa 1994).

Since 1950 global CO_2 emissions from energy-related activities have grown 3.2% annually to an estimated 6188 million tonnes (Mt) of carbon in 1991.[1] North America accounts for

***Figure 1.** A Long-Term Perspective on CO_2 Concentrations and Global Average Surface Temperatures*



Source: Lorius et al. 1990

nearly a fourth of world emissions, followed by Eastern Europe and the former Soviet Union (19%), Western Europe (15%) and Centrally Planned Asia (12%).[2] The fastest growth in emissions has taken place in the Middle East and Centrally Planned Asia (both about three times the world average), followed by countries in the Far East (Marland, Andres & Boden 1994).

What is the role of buildings in global CO_2 emissions? Carbon dioxide accounts for 56% of the net radiative forcing. Energy-related carbon dioxide emissions account for 74% of all anthropogenic CO_2 emissions, or about 41% of the net radiative forcing (IPCC 1992).[3] *The use of energy in human activities related to buildings accounts for about 25–30% of the energy-related CO_2, making it 19–22% of all anthropogenic CO_2 and 10–12% of net radiative forcing* (EIA 1994a; EIA 1994b; Levine et al. 1996a).

Figures 2 and 3 show global energy related per-capita and total CO_2 emissions for 1990. As the figures show, emissions from OECD countries and countries with economies in transition account for the vast majority of total global emissions, and are eight to ten times greater than emissions from the developing world on a per-capita basis (Marland, Andres & Boden 1994).

THE INTERNATIONAL RESPONSE

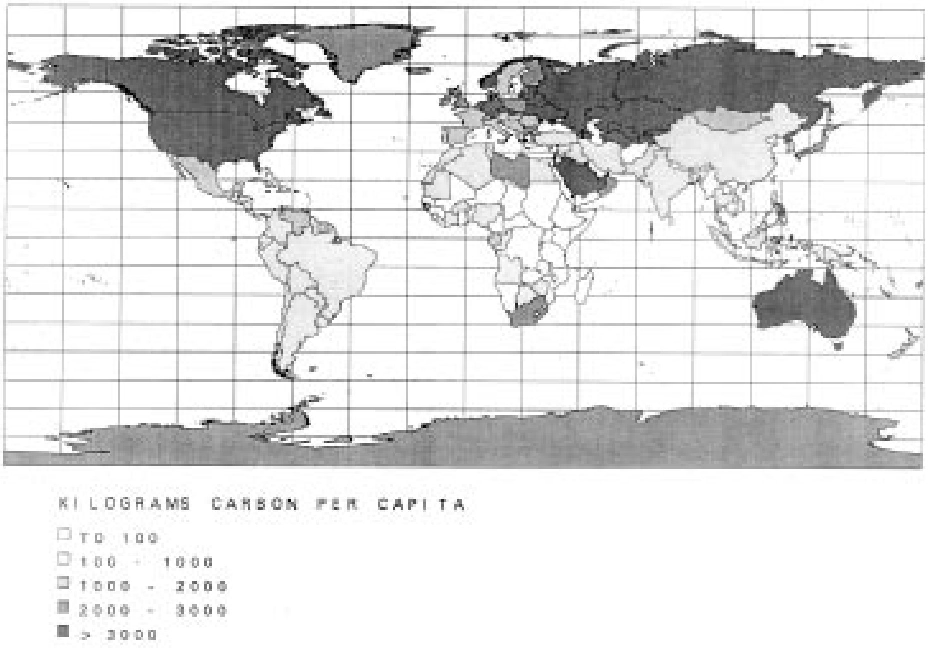
The potential ecological damage that could result from a radical shift in our current climate regime due to the increase in CO_2 concentrations in the atmosphere has spurred the international community to action. The Framework Convention on Climate Change (FCCC) signed by 155 countries at Rio de Janeiro in 1992 (and ratified by 151 countries) pledges that industrialized countries will seek to stabilize greenhouse gas concentrations to levels that will not interfere with the climate system, that all signatories will undertake studies to estimate current emissions levels and adaptation and mitigation potential, and that mechanisms for financial and technical assistance will be made available to help developing countries comply with the goals of the Convention (UNEP et al. 1995a). The structure of the Convention calls upon the Conference of Parties (COP) to finalize the details of the Convention and oversee its implementation. Negotiations, however, are still ongoing, with no agreement on an implementing framework (including the role of joint-implementation) or on a process for attaining domestic approval within signatory countries.

In order to comply with the commitments of the FCCC, signatories have agreed to inventory current GHG sources and sinks, and to produce studies that estimate current emissions as well as the potential to reduce or mitigate the growth of future emissions. Most Annex-1 parties (industrialized nations) have submitted national communications to the FCCC, but the communications of more than 100 non-Annex I parties (developing nations and economies-in-transition) still need to be produced (Fankhauser & King 1996; UNEP et al. 1995a).[4]

Industrialized countries and international organizations play a key role in the provision of technical assistance to those non Annex-1 countries that do not have the full resources to undertake comprehensive studies without additional support (see Table 1). As the table indicates, a large amount of technical assistance has been made available to non-Annex-1 countries to help improve analytical capabilities for assessing sources and sinks of greenhouse gases, as well as various mitigation strategies; however, additional support is still needed. Including the 30 countries that have not yet signed the FCCC, a total of 60 countries have received no technical assistance or support to comply with reporting requirements. The Global Environmental Facility has been instructed by the first Conference of Parties in Berlin, 1995, to provide priority, full-cost coverage to non Annex-1 countries to ensure the timely submittal of national communications (Fankhauser & King 1996).[5]

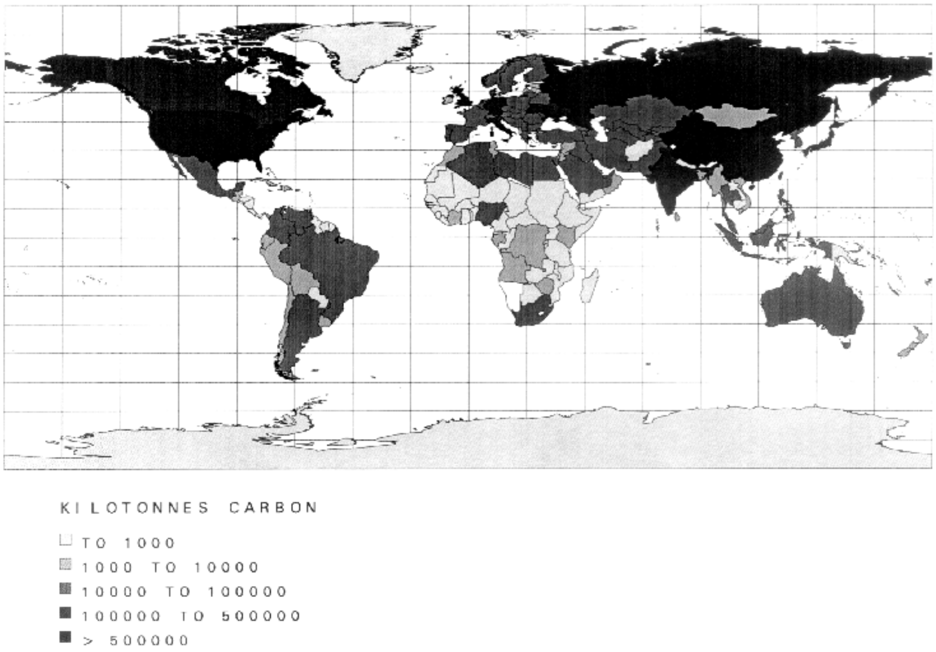
The U.S. Country Studies program has focused on the provision of technical and analytical support to 55 countries for preparation of emissions inventories, mitigation and adaptation analysis, and the development of national implementation plans. The goals of the program include 1) building human and infrastructure capabilities, 2) providing analytical tools with hands-on training, and 3) promoting the exchanging of information among participating analysts

Figure 2. *Per-Capita Carbon Emissions by Country*



Source: Marland, Andres & Boden 1994

Figure 3. *Total Carbon Emissions by Country*



Source: Marland, Andres & Boden 1994

Table 1. *Technical Assistance Supporting UN FCCC Objectives*

Project	Countries Receiving Assistance	Funds Allocated (Million %)	Areas of Assistance
United States: U.S. Country Studies Program	55 countries (global)	$35	Emissions inventory, mitigation, adaptation, national plans
United Nations Environment Program, Center for Energy and the Environment (UNEP/Risø)			GHG Abatement Cost Studies
Global Environmental Facility (GEF) Enabling Activity Projects (Individual countries focus)	19	$12.5	Sources and Sinks, Impacts and Adaptation; Response Strategies
GEF Enabling Activity Projects (Regional and global focus)	63+	$43.8	Regional responses, Sources and Sinks, Impacts and Adaptation
German Agency for Technical Cooperation (GTZ)	12	$2.9	Inventories, effects, mitigation technological options and mitigation policy options
Other bilateral assistance (Denmark, the Netherlands, Japan)			Sources and Sinks, Impacts and Adaptation
Asian Development Bank (ADB)			Response strategies, Impact Assessments
Organization for Economic Cooperation and Development (OECD)			
Environmental Development Action in the Third World (ENDA-TM)	20+		GHG Abatement cost studies, inventories, policy options

Source: Fankhauser & King 1996, UNEP et al. 1995a

(Dixon et al. 1996). Berkeley Lab has headed the U.S. Country Studies effort to provide support for analytical studies on the potential for mitigating future carbon dioxide emissions. U.S. Country Studies support was distributed in two rounds and is ongoing. By summer, 1996 most of the twelve round one countries will produce final results, while round two country results will be completed in late 1996 and early 1997. Workshops and the production of a mitigation analysis guidebook has significantly improved all countries' technical capability to undertake future analysis.

Few non-Annex-1 countries have completed comprehensive assessments that include well developed response strategies. Of the assessments that have been completed, reducing the growth of greenhouse gas emissions from energy sector activities plays a key role in stabilizing future emissions, along with fuel switching measures and the development of renewable energy sources (IEA 1995a; Tichy 1995; UNEP 1994). Most of these assessments find that a quarter or more of future emission reductions can be achieved at negative marginal cost, although the cost estimates can vary tremendously depending on the assumptions made for the baseline scenario (Sathaye 1995).

CARBON DIOXIDE EMISSIONS FROM BUILDINGS: TRENDS AND POLICIES

Carbon dioxide emissions resulting from energy use in buildings are an important element of overall greenhouse gas emissions. This section will first discuss the historical growth in carbon dioxide emissions and then survey technologies and polices that can mitigate future growth.

Historical carbon emissions from buildings

There are two recent estimates of the extent of carbon dioxide emissions caused by energy use in buildings. The Intergovernmental Panel on Climate Change (IPCC) suggests that buildings-related emissions account for nearly 30% of total global CO_2 emissions from energy use (19% from the residential sector and 10% from the commercial sector) (Levine et al. 1996a). The IPCC report further notes that the rate of growth in emissions from developing countries was over four times the average world rate between 1973 and 1990 (4.4%), and that the share of emissions from the developing world has grown from an estimated 11% of the world total in 1973 to 19% in 1990.

Another recent analysis of the carbon emissions by the Energy Information Administration (EIA) confirms this trend (EIA 1994a; EIA 1994b). In the EIA analysis, which covers 65 countries that use over 90% current world energy use, residential and commercial sector carbon dioxide emissions account for about 25% of total emissions. The EIA also found growth rates of emissions in developing countries similar to those of the IPCC report (see Table 2). The flat growth in Eastern Europe and the former Soviet Union reflects the economic restructuring occurring in the region. According to the International Energy Agency, total energy-related emissions from the former Soviet Union fell by 13% between 1988 and 1992, with similar proportional drops occurring in the buildings sector as well (IEA 1995a).

Table 2. *Carbon Dioxide Emissions from Buildings*

Region	Share of Total Emissions in 1990	Average Annual Growth Rate in Building Emissions 1980–1990
OECD countries	60%	1.1%
EE/FSU	18%	0.0%
Developing countries	22%	4.7%
China	10.1%	5.5%
Other Asia	19%	6.3%
Latin America	14%	3.3%
Africa	17%	6.0%
Middle East	25%	7.8%

Source: EIA 1994a; EIA 1994b

Key factors affecting building carbon emissions

Growth in carbon emissions from buildings can be explained by several key factors that include demographics (population growth and urbanization), changes in the demand for various energy services (space conditioning, lighting, cooking), types and quantities of fuels consumed, and the overall level of energy use per person (in the residential sector) or per unit of output (GDP) in the commercial sector.

The high rates of growth in CO_2 emissions in developing countries can be attributed to the fact that many have experienced strong growth in all three of these factors. Population has continued to expand, as has the demand for increased amounts of more carbon-intensive energy services. In many developing countries, especially in Asia, residential electricity consumption has grown at rates greater than 5% annually (Meyers et al. 1990). Although there has been continued reduction in the carbon intensity of energy services due to technology improvements, the demand for more services has overwhelmed these intensity reductions. Without a shift in programs and policies to reduce future energy demand, this trend in developing countries will continue (Levine et al. 1992; OTA 1991; WEC 1995).

In OECD countries, total residential CO_2 emissions remained flat (460 MtC) while per capita emissions generally declined for the most part due to changes in fuel mix, increased end-use efficiency, and appliance saturation. This relatively constant total residential emissions masks a shift among the various residential end uses. An almost 2% annual growth rate in emissions from household appliances, along with a lesser increase from lighting, compensates for small decreases in space heating, water heating, and cooking as shown in table 3 (Schipper, Haas & Scheinbaum 1996). In the commercial sector, electrification has caused emissions to rise at an even greater rate (Sezgen & Schipper 1995; WEC 1995).

Table 3 compares carbon dioxide emissions from the residential sector by end-use in four groupings of OECD countries. As the table indicates, total emissions in OECD countries increased by 0.6% annually between 1973 and 1990, with shares of emissions associated with appliances growing at over twice the average. The share of appliance carbon dioxide emissions grew from 20% in 1973 to 27% in 1990. Space heating, however, is still the largest carbon dioxide

***Table 3.** Residential Sector Carbon Dioxide Emissions in Selected OECD Countries (MtC) and Average Annual Growth Rate by End-Use (Percent)*

	1973					1990					
End-Use Service	US	Eur-3	Japan	Nord-4	OECD Total	US	Eur-3	Japan	Nord-4	OECD Total	AAGR 1971–1990
Space heating	138	87	6	11	242	125	71	13	7	216	− 0.7%
Water heating	40	25	6	3	75	40	19	11	2	73	− 0.2%
Cooking	13	10	3	0	27	13	7	3	0	24	− 0.6%
Lighting	18	4	2	0	24	19	3	3	0	25	− 0.4%
Appliances	68	11	10	1	90	92	14	17	1	124	+ 1.9%
Total	277	137	27	16	458	289	115	47	11	462	+ 0.6%

Values for Europe-3 includes Germany, France, and the United Kingdom. Nord-4 includes Denmark, Sweden, Norway and Finland.
Source: Schipper, Haas & Scheinbaum 1996.

emissions source. When space heating emissions are normalized for heating area and outside temperature, European countries (Germany and the UK) exhibit the highest intensities, although intensities in most OECD countries have fallen by 2–3% annually since 1973 due to improved construction practices (Schipper, Haas & Scheinbaum 1996).

The potential for reducing building carbon emissions

The experience of nations worldwide over the past two decades has demonstrated society's ability to constrain its energy appetite (Bevington and Rosenfeld, 1990; Schipper and Meyers, 1992). The development and adoption of new technology to make energy production and consumption more efficient have had a dramatic effect on the more industrialized countries. For example, between 1973 and 1991, the U.S. economy has grown by 56% while its energy requirements have increased by only 14% (DOE 1995). Similar trends have taken place in other OECD countries as well. In addition to the shift that OECD countries have undergone toward less material-intensive economies, and relatively modest population growth, technologies have improved that have significantly reduced end-use consumption. Some of the key new efficient technologies and practices that reduce energy consumption in buildings are shown in Table 4. For developing countries and economies in transition, strong increases in the demand for building energy services have tended to outweigh technological improvements (OTA, 1991; WEC, 1995).

The technical energy-efficiency improvements shown in table 4 include improvements to the building shell, improved management of energy demand, and improving the efficiency of various end-uses. Non energy-efficiency measures to reduce carbon emissions include fuel-switching to less carbon-intensive fuels for electricity generation, including the use of renewable-based energy systems.

Improved technologies, particularly when applied in combination, hold the potential to reduce per-capita household and commercial energy demand in the long-term significantly. An analysis of homes in the Pacific Northwest found that by using existing conventional technologies, space heating savings of 40% were achieved (Meier and Nordman, 1988). Design and analysis of new residential homes in Davis California under the a Pacific Gas and Electric research project found energy savings of 60% and greater for heating, cooling, hot water, lighting and refrigeration uses by incorporating existing efficient technologies (Davis Energy Group Inc., 1994). The companion paper to this study presents estimates of the potential for reducing energy demand in buildings.

Although there is significant variation between countries and regions, recently prepared scenarios estimate potential reductions in the OECD countries of 6–16%, while studies of countries with economies in transition as well as developing

Table 4. *Energy-Efficient Technologies and Practices for Buildings*

Service	Technology/Practice
Space conditioning	Gas-fired, condensing furnaces High efficiency heat pumps (more efficient compressors) Air conditioner efficiency measures (e.g., thermal insulation, improved heat exchangers, advanced refrigerants, more efficient motors, more efficient compressors, etc.) Centrifugal compressors, efficient fans and pumps, and variable air volume systems for large commercial buildings
Appliances	Advanced compressors, evacuated panel insulation (refrigerators) Use of horizontal axis technology (clothes washers) Heat pump dryers Higher spin speeds in washing machine spinner
Cooking	Efficient gas stoves (ignition, burners) Improved efficiency of biomass stoves (developing countries)
Lighting	Compact fluorescent lamps Improved phosphors Solid state electronic ballast technology Advanced lighting control systems (including daylighting and occupancy sensors Task lighting
Motors	Variable speed drives Size optimization Improvement of power quality Use of synchronous and flat belts, controls
Building envelope	Energy-efficient windows Advanced insulation Reduced air infiltration
Controls	Building energy management systems

Source: WEC 1995

countries have even greater potentials of 25–44% when comparing aggressive energy efficiency scenarios to business-as-usual trends (Levine et al. 1996b).

Significant debate exists as to the best approach to properly estimate the cost of GHG emission reductions in the buildings sector, depending on the modeling framework and assumptions made in the analysis (Hourcade et al., 1995). However, given the tremendous growth of electricity demand forecasted in developing countries, significant opportunities exist to implement policies and programs that will reduce carbon emissions in this sector at little or no cost, when viewed in several modeling frameworks (Mongia, P., Sathaye, J. & Mongia, N., 1994).

In many cases, governments and utilities have played key roles in encouraging successful efficiency policies. For example, the promulgation of appliance standards by the U.S. government has resulted in expected reductions of household energy demand of 1.1 exajoule (EJ) per year by 2000, about 10% of total projected residential energy use in the US for that year and a cumulative savings of 45 EJ by 2015 (McMahon, Pickle & Turiel 1996); U.S. utility demand-side management programs, a product of mainly state public regulatory commissions, saved around 0.6 EJ between 1990 and 1994 (EIA 1995). We anticipate that these energy savings would result in similar percentage reductions in sectoral carbon emissions and could offer a useful model for developing countries seeking to reduce carbon emissions.

Part of the variation in the potential studies noted in Levine et al. (1996b) reflects the aggressiveness in which energy efficiency and carbon dioxide reduction policies are assumed to be implemented. A wide variety of policy instruments exist including building and appliance efficiency standards, voluntary programs, market transformation programs, utility demand-side management, energy pricing, and research and development. Key characteristics of these policies are listed in Table 5. Effective policies can overcome barriers in consumer decision-making (such as lack of information or high transactions costs) that result in less than optimal purchases of efficient products.

A key issue is the ability to implement policies in developing countries, where a significant cost-effective potential for electricity-efficiency improvement in the residential sector exists. First costs dominate the decision to purchase a lamp or an appliance. Cheaper models are often less electricity-efficient. The challenge is one of implementing programs which induce consumers to purchase products that use electricity more efficiently.

The Ilumex project being implemented in Mexico provides one illustrative example of how lighting efficiency might be improved. The project involves the electric utility company distributing compact flourescent lamps at a subsidized price, in order to increase their market penetration for household lighting in Guadalajara and Monterey. The economic analysis indicates that the project will bring substantial net economic benefits to Mexico, the utility and the average consumer (Sathaye et al., 1994). In the absence of subsidies, the payback period for the consumer is longer than two years. By sharing some of the anticipated net benefits, the utility company can lower the payback period, while saving electricity at a cost lower than that for new generation capacity. A Mexico-wide expansion of the project will defer peak capacity by up to 2.58 GW and reduce carbon emissions of 458,000 tonnes annually. The project implementation is going ahead smoothly and about 600,000 cfls have been purchased at a subsidized price ($8 instead of $14) in the two cities by end of March 1996.

WHAT DOES THE FUTURE HOLD?

Given the historical growth in building carbon dioxide emissions, especially in developing countries, it is not surprising that most forecast scenarios see a future that, in the absence of strong policy intervention, is not very different from historical trends. For example, a recent study by the World Energy Council forecasts that energy used by buildings may

Table 5. *Key Characteristics of Selected Policy Options*

	Can Affect:				
Policy	New Building Construction	Existing Building Retrofit	Appliance Selection	Energy Savings Potential (1)	Direct Cost to Government
Energy taxes	Yes	Yes	Yes	High	Negative
$ Incentives	Yes	Yes	Yes	High	High (2)
Building codes	Yes	(3)	(4)	Medium	Low
Appliance standards	No	No	Yes	High	Low
IRP	Yes	Yes	Yes	High	Low
R&D	(5)	(5)	No	Variable	Medium
Information programs	Yes	Yes	Yes	Low	Low

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(1) Energy savings will of course vary; this table shows *potential* assuming aggressive implementation (e.g., high energy taxes).
(2) If incentive is offered by utility, the direct cost is borne by the utility (which is in many cases run by the government).
(3) Some cities, such as San Francisco, require existing buildings to meet energy codes as a condition of change in ownership.
(4) Most code requirements apply to the building shell only; however some codes apply to appliances as well.
(5) R&D's effects are long-term.
Sources: Levine et al. 1996a

more than triple by 2020, with the majority of growth in carbon emissions occurring in non-OECD countries (WEC 1995). When the World Energy Council business-as-usual scenario is converted to equivalent carbon emissions, we find the geographic distribution of emissions growth shown in Figure 4.[6]

An earlier study by Sathaye and Ketoff of 17 developing countries (Sathaye and Ketoff, 1991) found similar results, with carbon emissions nearly quadrupling between 1985 and 2025.[7] Interestingly, the study also suggests that as many of the countries' household sectors develop, they substitute renewable biomass fuels for commercial energy sources such as kerosene and LPG. This leads to a reduction in the share of residential energy use (from 37% to 20% of delivered energy) during the forecast period, but an increase in carbon emissions.

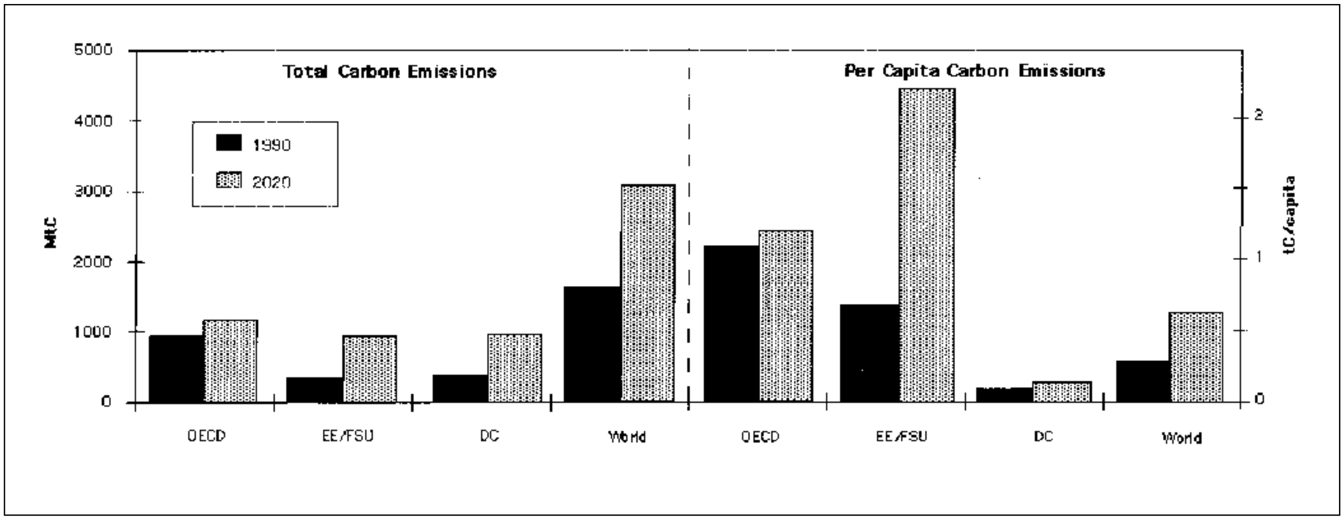
As figure 4 indicates, the growth of total and per capita carbon dioxide emissions is much more rapid in non-OECD countries. In the EE/FSU total carbon dioxide emissions and per capita emissions grow at 3.6% and 3.9% annually. In developing countries the comparable estimates are also high at 3.2% and 1.4%, compared to the 0.8% and 0.4% annual growth in these two parameters in the OECD countries. The high rate of growth in total carbon dioxide emissions in the EE/FSU region in this business-as-usual scenario results from an assumption of significant structural shifts towards a less heavy-industry based economy and high rates of growth in the demand for residential and commercial energy services. The 3.2% growth in developing countries total carbon dioxide emissions results from the combination of economic and population growth and increasing electrification.

Can such energy demand be satisfied? And what of the FCCC objectives in which Annex-1 countries have committed to containing the growth of greenhouse gas emissions to 1990 levels? While studies have shown that it may be possible to reduce carbon emissions to 1990 levels in industrialized countries at little or no cost, the tremendous growth in energy demand forecast in developing countries suggest that containing emissions in the near term to today's levels will require significant increases in the rate of investment in, and use of, energy-efficient technologies in those countries (Krause, Koomey & Sanstad, 1995).[8]

Although several policies for improving energy efficiency (and reducing CO_2 emissions) have been implemented in developed market economies, the transfer of successful policy skills to developing countries often requires establishing more effective energy efficiency markets and institutions. In addition to the provision of much more capital for energy efficiency, many countries need considerable support to establishing functioning institutions that can promote efficiency (both public and private), as well as investment in human infrastructure (training).

As this paper suggests, significant potential exists to reduce the rate of future emissions in the building sector by promoting more rapid uptake of efficiency technologies. As non-Annex-1 countries prepare to submit inventories and prepare national action plans, it is clear that significant opportunities to help raise building energy efficiency at home and abroad

Figure 4. *The Business-as-Usual Future of Carbon Dioxide Emissions: Projections of Total Carbon Dioxide Emissions and Per-Capita Carbon Dioxide Emissions by Region*



will exist should countries begin to more fully commit to reducing the growth of carbon dioxide emissions.

ENDNOTES

1. All CO_2 emissions are calculated in terms of carbon equivalent for this paper. Emissions are presented both on a total and per-capita basis.

2. Countries in Centrally Planned Asia include: Vietnam, North Korea, Mongolia, and China.

3. Adding the 18% of anthropogenic methane emissions that are energy-related, we find that energy contributes a total 46% to net radiative forcing (IPCC 1992).

4. According to the Secretariat of the FCCC, as of 11 August 1995, 27 national communications have been submitted by Annex I Parties to the United Nations Framework Convention on Climate Change (UNEP et al. 1995a).

5. A total of 76 communications are due before the end of 1998 (Fankhauser and King 1996).

6. In this conversion it was assumed that non-OECD regions would be switching to a less-carbon intensive fuel mix for electricity generation, but that the share of electricity and gas in building energy use would increase. 1990 baseline emissions were based on (Marland, Andres & Boden 1994) and (WEC 1995). Energy to carbon conversion was based on (UNEP et al. 1995b). The scenario assumes no net imports of electricity across regional boundaries. 2020 emissions are based on (IEA 1995b) and (WEC 1995).

7. In the Sathaye and Ketoff study, carbon emissions expands from 900 MtC in 1985 to 3635 MtC in 2025, a rate of 3.5% annually.

8. Significant debate between FCCC signatories has occurred as to whether the commitment to contain emissions would be on a total or a per capita basis, with the FCCC Conference of Parties agreeing to the former measurement. This poses a stronger challenge to countries such as China who have a small per capita buildings CO_2 contribution, but a very large total contribution, and tends to excuse countries like United Arab Emirates or Singapore who have a high per-capita energy-related CO_2 contribution, but a small total contribution.

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