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Carbon Emissions Trends for Developing Countries and Countries with Economies in Transition*

By Katja Schumacher and Jayant Sathaye**

Summary

Developing countries' share in greenhouse gas emissions is expected to increase rapidly. Countries undergoing transition to market economies experience rapid changes with effects on their greenhouse gas emissions. However, there are vast uncertainties surrounding the future development of these countries. In this paper, we analyse carbon emissions trends for fourteen developing and economies in transition. We assess the contribution of each of four factors — population, economic growth, energy intensity, and carbon intensity — to the historical and projected increase in carbon emissions, and the differences between the historical and projected changes in each factor. We describe the primary causes behind each of the factors by country and across countries. The analysis reveals that the primary factors contributing to historical carbon emissions growth vary across countries, however, economic growth is the primary factor driving future projections in most cases. In addition, we find that per capita income growth is projected to be associated with lower energy use per unit of output in future. Other factors remain important as well. In order to reduce carbon emissions growth, it will be necessary to address all relevant factors.

Introduction

Concern about the impacts of increasing levels of greenhouse gases (GHG) in the atmosphere have led the majority of nations to ratify the United Nations Framework Convention on Climate Change since 1992.¹ In the 1997 Kyoto agreement the industrialised countries, Russia, the Ukraine and most of Eastern Europe nations agree to cap their GHG emissions averaged over the period 2008 to 2012 at levels ranging from 7% below to 10% above their 1990 levels. The other, mainly developing, countries did not commit to limits on the growth of their GHG emissions.

With high economic and population growth, GHG emissions in developing countries are projected to increase rapidly in the future, and match those from the industrialised countries by 2020.² However, vast uncertainties surround the actual paths developing countries' emissions and emissions from countries undergoing transition to a market economy will follow. The uncertainties stem from economic, political, technical and structural transformations happening in these countries. As a result, emissions scenarios developed just a few years ago differ substantially from more recent projections which will

differ again from scenarios that may be developed in the near future.

Typically, developing countries emit less carbon dioxide per capita but more per unit of GDP compared to the industrialised nations. Developing countries use fewer fossil fuels than industrialised countries, but they use these fuels less efficiently. With economic growth, this disparity is likely to diminish over the next few decades. High economic growth tends to lead to a higher effective turnover of the capital stock which facilitates the adoption of more modern and efficient technology. In addition, the long-run substitution elasticity between capital and energy is much

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¹ UNFCCC (1992).

² Houghton et al. (1992).

higher than the short-run elasticity.³ Together with structural changes toward less energy-intensive economic activities, we expect countries' energy intensity (and thus carbon intensity) to decrease in the long term.⁴ While in the short or medium term fluctuations in world energy prices and other factors may lead to rising energy and carbon intensity, in the long term price fluctuations alone have surprisingly little ability to explain energy consumption.⁵ The technologies being used in the developing world today are far superior to what the industrialised world used at the same income level decades ago. Improved technology and structural change create the possibility that the developing world can achieve high income levels with lower energy use and associated carbon emissions per unit of GDP.

A first step in evaluating these issues is to assess the factors that contribute to the carbon emissions from a country. Such an assessment will help to better understand the primary factors that were responsible for historical emissions growth, and to contrast these with those responsible for growth of projected emissions over the next few decades. The historical trend can provide a good guide to future scenarios. However, one has to recognise that unexpected radical changes, such as the economic

collapse and subsequent restructuring of Eastern Europe and the Former Soviet Union or financial crises such as the Asian crisis in 1997, can significantly change future energy and emissions growth rates.

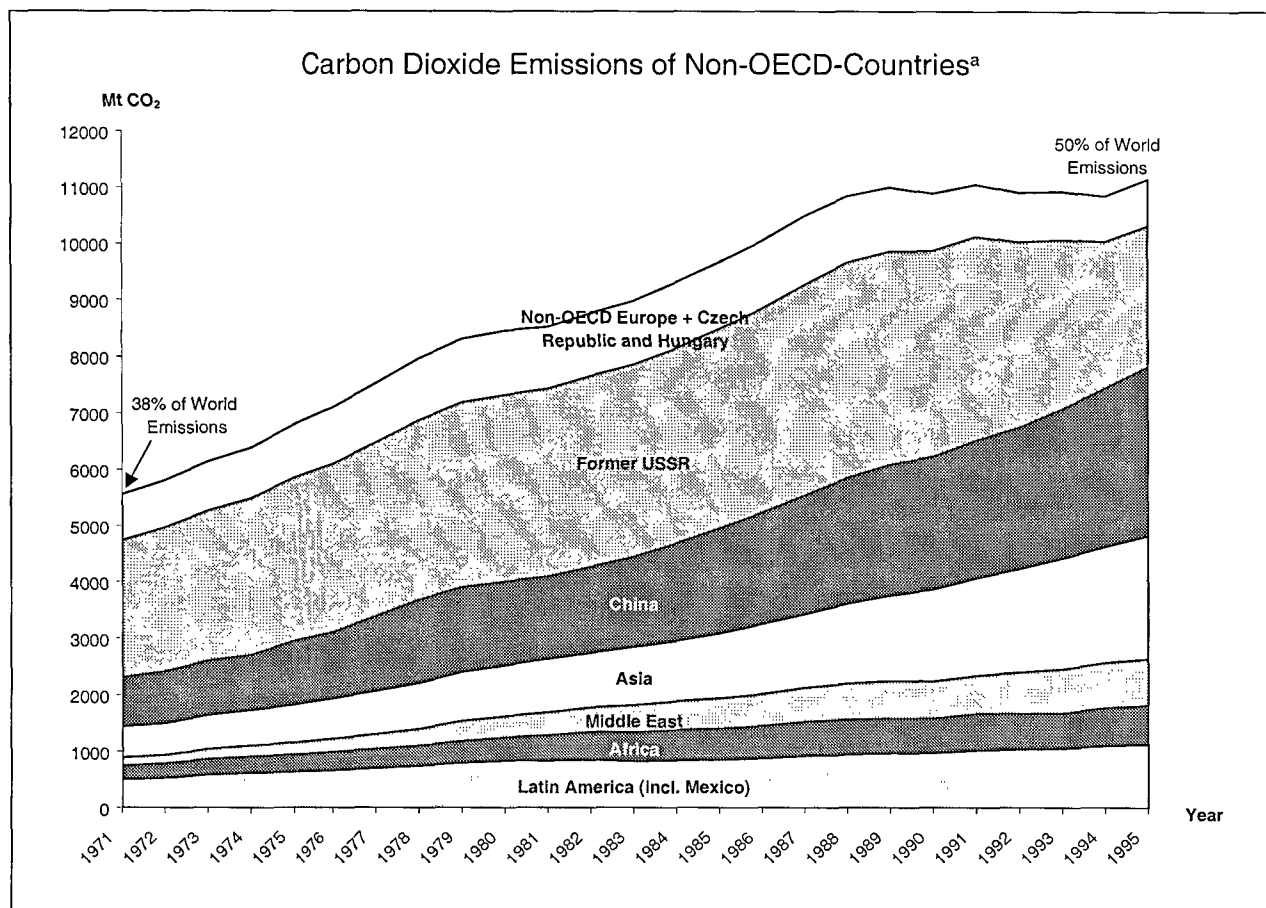
In this paper, we analyse the historical data and future scenarios on carbon emissions for fourteen developing countries and economies in transition. In the first section, we provide some background information on carbon emissions from these countries and their importance in the world. After describing the methodology and data used, we examine the long term evolution of carbon emissions from energy use. The analysis reveals the contribution of each of four factors — population, economic growth, energy intensity, and carbon intensity — to the historical and projected increase in carbon emissions, and the differences between the historical and projected changes in each factor. We describe the primary causes behind each of the four factors by country. We focus on the factors with long term effects on carbon emissions and do not address energy prices. We extend our analysis fur-

³ Sachs et al. (1999) and Panayotou (1999).

⁴ IIASA/WEC (1995).

⁵ Judson et al. (1999).

Figure 1



ther by separating energy intensity into two components: final energy use per unit of output and the ratio of primary energy to final energy. A cross-country comparison of carbon emissions trends and the contributing factors concludes the paper.

Background

The energy sector contributes the bulk of carbon dioxide emissions worldwide. Carbon dioxide emissions from fossil fuel burning increased from 14.73 Gt CO₂ in 1971 to 22.98 Gt CO₂ in 1997.⁶ Emissions from developing countries and countries in transition accounted for 5.56 Gt CO₂ in 1971, which equaled 38% of world carbon dioxide emissions⁷. In 1995, emissions from these countries had doubled to 11.16 Gt CO₂, while their share in world emissions had grown to about 50% (Figure 1).

World carbon dioxide emissions are projected to increase to between 25.7 and 44.4 Gt CO₂ by 2020, with a mid-range estimate at 36.3 Gt CO₂ equivalent to an average growth of 2% p. a. between 1996 and 2020.⁸ This is a significantly higher growth than the 1.6% p. a. between 1971 and 1995. Future scenarios show a steady increase in emissions from developing countries although at slowing rates compared to the past trends. Stabilising of CO₂ would not be possible without reducing the rapid growth of emissions from developing countries. Should China's emissions, for example, continue to increase at their rate for the period 1971-95, they would reach the U.S. emissions level of 5.38 Gt CO₂ by about 2006.⁹ India's emissions, growing at 5.8% p. a. between 1971 and 1995, will exceed the 1996 U.S. figure by 2028.

For reasons of data availability and comparability we have chosen in total fourteen countries within four regions for deeper analysis. The regions and countries are the following:

Region	Country
Africa	Nigeria, Egypt
Asia	Bangladesh, China, India, Indonesia, Thailand, South Korea
Latin America	Venezuela, Mexico, Brazil
Eastern Europe	Poland, Bulgaria, Czech Republic

Table 1 indicates the coverage of CO₂ emissions by these countries within a region and the total share of these countries within the world. For instance, the six Asian countries under consideration account for 83% of the total CO₂ emissions in Asia in 1971 and 88% in 1995. Except for Africa, our study countries account for more than 50% of CO₂ emissions in their region with increasing shares from 1971 to 1995 for all regions, except for Non-OECD Europe.

Table 1

Share of Regional and World CO₂ Emissions from the Study Countries:

	1971	1995
Africa	11%	20%
Asia	83%	88%
Latin America ^(a)	52%	64%
Non-OECD Europe ^(b)	64%	62%
World	13%	27%

(a) including Mexico, (b) including Czech Republic and Hungary.

Total carbon dioxide emissions from the fourteen countries amounted to 5949 Mt CO₂ in 1995, the equivalent of 27% of world carbon dioxide emissions. Their combined GDP holds a share of about 28% in world gross domestic product, while the share of total primary energy consumption is slightly lower at 23%. Population accounts to 3048 million, a share of 54% in the world. The numbers show the significance of these fourteen countries within their regions and the world.

Methodology

In order to analyse the relative contributions of population, economic growth, energy intensity and carbon intensity to past CO₂ emissions, we use decomposition analysis.¹⁰ Based on the IPAT identity as developed by Ehrlich and Holdren (1974)

$$\text{Impact} = \text{Population} * \text{Affluence} * \text{Technology}$$

we establish the simple identity¹¹

$$\text{CO}_2 = P * \text{GDP}/P * \text{E}/\text{GDP} * \text{CO}_2/\text{E} = P * A * I * C \quad (1)$$

The *impact*, carbon dioxide emissions, is the product of *population*, *affluence* as measured in per capita GDP, and both energy intensity (primary energy supply per GDP) and carbon intensity (carbon emissions per primary energy supply) describing the *technology* component. Energy intensity is denoted as *I* in equation (1) above, while carbon intensity is denoted as *C*. The energy/GDP ratio provides an indication of a nation's aggregate energy intensity or the energy needed to support a unit of eco-

⁶ IEA (1999).

⁷ These countries are called Non-OECD countries in the following. For the convenience of the analysis Korea, Mexico, the Czech Republic and Hungary are still included in the Non-OECD share although they have joined the OECD by now.

⁸ Houghton et al. (1992).

⁹ IEA (1998).

¹⁰ Sun (1998); Schipper (1997).

¹¹ Kaya (1989).

conomic activity; the CO₂/energy component provides information on the carbon intensity of the mix of fuels that supply primary energy. Changes in energy/GDP ratio may be caused either by structural change in the composition of GDP or by technical energy-efficiency improvements. Changes in the CO₂/energy component may be brought about by a change in the mix of fuels, for instance from coal to natural gas.

Historical Trends

For the analysis of historical trends, with data available in a consistent time series, we employ the complete decomposition approach. The complete decomposition approach uses a Laspeyres index with 'equal' distribution of the residual among the effects.¹² The special feature of this approach is that all factors but one are kept fixed in the (rolling) base year, and the residuals are separated and assigned to the different effects according to the principle of 'jointly created and equally distributed.'¹³ In accordance with this approach the change of CO₂ emissions in a given period is defined as equal to the sum of the effects of each factor: the population effect (P_{eff}), the affluence effect (A_{eff}), the energy intensity effect (I_{eff}) and the carbon intensity effect (C_{eff}):¹⁴

$$\Delta CO_2 = P_{eff} + A_{eff} + I_{eff} + C_{eff} \quad (2)$$

The exact specification of each effect is shown in Appendix 1.

Technical energy efficiency-improvements can be achieved through both more efficient end-use of energy and more efficient conversion of primary energy to final energy. In order to account for these different factors, we extend our historical analysis in breaking up energy intensity into two components: the final use of energy (TFC) per unit of national output and the primary use of energy (TPES) per unit of final energy consumption. The above identity (1) therefore changes to:

$$CO_2 = P * GDP/P * TFC/GDP * TPES/TFC * CO_2/TPES = P * A * I * U * C \quad (3)$$

An increase in the *conversion* (U) efficiency can be due to both a shift in the use of transformed energy versus direct energy (e.g., a decrease in the share of electricity consumption in total energy consumption) and improvements in transformation and distribution of primary energy (such as improvements in the conversion, transmission and distribution of electricity generation, improvements in petroleum refining and increased use of efficient CHP plants). The *intensity* component (I) now grasps the effects from structural change in the composition of GDP and from efficiency improvements in the final (end)-use of energy only.¹⁵

Accordingly, the change of CO₂ emissions in a given period is then defined as the sum of the population effect

(P_{eff}), the affluence effect (A_{eff}), the energy intensity effect (I_{eff}), the conversion effect (U_{eff}) and the carbon intensity effect (C_{eff})

$$\Delta CO_2 = P_{eff} + A_{eff} + I_{eff} + U_{eff} + C_{eff} \quad (4)$$

Future Trends

Future projections for economic output, population, primary energy supply and carbon emissions are usually given as average annual growth rates or as absolute values for the end year only. They do not include projections for each individual year in the future as needed for the complete decomposition analysis. For this reason, we slightly adjust the decomposition analysis to account for growth rates only.

Taking logarithms of the identity (1) yields:

$$\ln CO_2 = \ln P + \ln A + \ln I + \ln C \quad (4)$$

The derivative over time yields the average annual change in carbon emissions as:

$$\frac{\partial CO_2}{\partial t} * \frac{I}{CO_2} = \frac{\partial P}{\partial t} * \frac{I}{P} + \frac{\partial A}{\partial t} * \frac{I}{A} + \frac{\partial I}{\partial t} * \frac{I}{I} + \frac{\partial C}{\partial t} * \frac{I}{C} \quad (5)$$

Thus, average annual growth in carbon emissions is simply the sum of the average annual growth of the population, the affluence, the energy intensity and the carbon intensity effect. The growth is assumed to be exponential (as given by a log-linear time trend¹⁶ or exponential growth rate) so that no residual occurs. For reasons of lack of projected data on total final energy consumption we do not conduct the more detailed analysis regarding the energy intensity factor as introduced above for the historical analysis.

Data

The historical data on population, GDP, primary energy supply and final energy consumption as well as CO₂ emissions is derived from the International Energy Agency's (1998) data base. Data are available from 1971 to 1995.¹⁷

¹² Sun (1998).

¹³ Sun (1998).

¹⁴ Sun (1999).

¹⁵ More detailed analyses consider final energy consumption on a sectoral level. So far — as a result of high data requirements — such analyses have focused on industrialized countries. For an overview and an analysis of Germany and European Countries see Diekmann et al. (1999). For further cross-country comparison see Schipper et al. (1997).

¹⁶ A log-linear time trend is specified as $\ln y_t = r t + b$, with y_t = dependent variable, r = average annual growth rate, t = time variable, and b = intercept.

¹⁷ Data up to the year 1997 (IEA, 1999) became available during the course of our study only. We would not expect the results to differ much if we included these more recent years.

GDP data is reported in purchasing power parities in 1990 US \$ for each country. Total primary energy supply and total final energy consumption account for commercial energy sources only. For total primary energy supply, nuclear and hydro electricity are counted at their primary heat equivalents assuming an average thermal efficiency of 33 per cent. Hydropower output does not include output from pumped storage plants. For electricity generation in geothermal plants, the IEA statistics assume an average thermal efficiency of 10 per cent. Carbon emissions are those from fossil fuel burning only.¹⁸

The projected data make use of baseline scenarios that were derived from climate change country studies dating back to 1990.¹⁹ The base year for the projections ranges from 1985 to 1995, and the target year from 2010 to 2025. A unique feature of most of these studies is that the work was carried out by institutions within each country, rather than by consultants or experts from abroad. Institutions in industrialised countries provided technical assistance and training on methods and tools for analysis. The results thus present perspectives of analysts from the country being analysed.

Two different approaches, “*bottom up*” and “*top down*” are used for projecting scenarios in the energy sector. The bottom-up approach is engineering oriented and begins by characterising technologies and processes, combinations of which are then evaluated to assess their aggregate GHG emissions and costs. The top-down approach primarily evaluates the impact on a nation’s GDP of policy instruments, such as changes in carbon or fuel taxes. The studies evaluated in this paper are of the “*bottom-up*”-type. These lend themselves to analysis of the impact of including specific technologies on GHG emissions. While each analysis is country-specific, the assumptions regarding world energy prices do not differ very much, and are the same for all countries within each of the four larger studies.

The IEA statistics present energy data without including biomass. Collecting biomass data is problematic since biomass is not commercially traded and its consumption and energy content varies significantly within and across countries. In addition, the use of biomass is assumed to be carbon neutral, i.e., the net effect of carbon absorption during biomass growth and its subsequent release during combustion is nil. The net impact will depend on whether the biomass was derived from sustainably managed forests and/or plantations, but the studies which we evaluated do not provide data to make this determination.

The exclusion of biomass leads to biases in the analysis for countries only where biomass is a highly used source of energy. Over time these countries tend to substitute away from the use of biomass towards the use of more efficient commercial fuels. The substitution towards more efficient fuels reduces growth in overall energy con-

sumption. If biomass consumption is not included in the energy measure, growth in energy consumption will be overstated since only the additional use of commercial energy sources will be accounted for, while the reduction of biomass use is not taken into consideration.

Analysis of Historical and Projected Trends

In the following we present the decomposition of carbon emissions for each individual country within the four regions. The figures show the actual amount of carbon dioxide emitted in each year of the 1971–95 period versus the emissions that would have been achieved if only each factor had changed over time, and all other factors remained constant at their 1971 levels. In each year over the period, the changes of carbon emissions caused by each factor compared to the base year emissions sum up to the total amount of actual carbon dioxide emissions in that year.

In a second set of figures, we compare historical trends to future projections for each country. To ensure comparability we present the decomposition of historical trends employing the same methodology as for the future projections; that is, based on growth rates rather than individual yearly data points. However, to make use of the full range of time series data available for the past, we calculate the historical growth rates as a semi-logarithmic time trend as outlined above.

ASIA

Bangladesh

Carbon dioxide emissions in Bangladesh have increased at more than 7% p.a. in the past. As seen in Figure 2, the largest contribution has come from the higher energy/GDP ratio, followed by increases in population and per capita income. Energy intensity increased at a high rate in Bangladesh as biomass fuels were substituted by modern commercial fuels. The increase in energy intensity for Bangladesh would be lower if biomass consumption was counted in the energy measure. For the future, analysts project a significant lower energy intensity increase, because of energy efficiency gains that could be achieved in many end-uses.

¹⁸ IEA (1998).

¹⁹ Sathaye and Ravindranath (1998); Sathaye et al. (1991); UNEP (1994); Asian Development Bank (1998); Pereira et al. (1997); Sathaye et al. (1996); Simeonova et al. (1997); Tichy (1997); Molnár et al. (1997). Specifically, the projections for the six Asian countries are based on Asian Development Bank (1998), for Brazil on Sathaye et al. (1996), for Mexico and Nigeria on Sathaye (1991), for Venezuela on Pereira et al. (1997), for Egypt on UNEP (1994), and for Bulgaria, the Czech Republic and Poland on the U.S. Country Studies Program edited by Meyers et al. (1997). The projected population growth rates for the three Eastern European countries are derived from the U.S. Census Bureau (1998).

Carbon emissions are expected to grow at a slower rate in the future due to a sharp decrease in energy intensity, even though, at the same time, GDP per capita is expected to increase strongly. Affluence is projected to be the single main contributor to carbon dioxide emissions in the future. Population growth is projected to decline. Yet, it will remain high compared to other Asian countries. A decline in carbon intensity will continue to counterbalance the effects of the other factors, but less than in the past.

China

China provides a unique example. The development of the four factors contributing to carbon emissions differs distinctively from all other countries. Figure 3 provides the historical decomposition analysis for China. Increased economic activity, as given by per capita output, contributed substantially to carbon dioxide emissions over the twenty-four year time period. In fact, holding all other factors constant output growth alone would have led carbon emissions to reach levels far above the actual level of carbon emitted. Efficiency gains in the use of energy per unit of output effectively counterbalanced this activity driven increase. While energy intensity increased only in the early years, between 1971 and 1978, it shows a decreasing trend thereafter with accelerating rates in the early 1990s. Energy efficiency gains of the Chinese economy, stimulated by strong government programs since 1980, are outstanding.²⁰ About two-thirds of the decline in energy consumption in the industrial sector is attributed to improved energy efficiency alone. Furthermore, an increase in the import of some energy-intensive products added to the decline in energy consumption.²¹ Population growth contributed positively to carbon emissions. Although the relative importance of population to carbon dioxide emissions growth seems very low in China compared to other regions, the absolute magnitude is immense. By 1995, population growth had contributed 595 million tons of carbon, more than in any other region including those where population growth presents the main driving force of carbon dioxide emissions.

The comparison of historical and projected trends (Figure 8b) reveals that carbon emissions growth is projected to be lower in the future. The decline will be brought up by reduced growth of all contributing factors, except carbon intensity. Growth in affluence, will remain the dominant factor for carbon emissions growth, although its growth is projected to be slightly lower than in the past. Population growth is expected to add to carbon dioxide emissions in the future as in the past, although also at a lower rate of below 1%. Noteworthy, a more recent study²² shows a higher population growth rate than earlier ones, indicating pessimism about the success of family planning programs in the country. Energy efficiency improvement is projected to rise to 3.9% p. a., even as China is transitioning towards

a market economy and challenges exist to maintain the efforts to reduce energy intensity under the new market system. However, ongoing reforms in the energy pricing system, reduced subsidy payments and sustained levels of government investment into the promotion and implementation of efficiency programs are expected to facilitate continued efficiency improvements.²³ The rise in energy efficiency is projected to effectively counterbalance the contributions from other factors (affluence and population growth). While carbon intensity is projected to become a positive contributor to carbon emissions in the future scenario presented here, another scenario²⁴ predicts a sharp drop brought about by increased use of hydro (which is abundantly available in China, but at the same time is quite expensive and controversial due to negative externalities), nuclear (although the nuclear program has recently been scaled down considerably) and other forms of renewable energy.

India

India shows an almost exponential increase in carbon dioxide emissions over time (Figure 4). Growth of population and per capita GDP are the two most important contributors to historical carbon emissions. While population growth appears to be the main driver until 1987, growth in affluence surpasses population growth thereafter. Energy intensity plays a lower but still important role. All three factors steadily increased over time. The fuel mix, signaled by the CO₂/energy ratio, showed a negligible change over the historical period.

The historical trends are projected to continue in the future. Economic growth (GDP/capita) is expected to increase to about 4% p. a., while the projection for population growth is slightly lower than in the past (about 1.5% p. a.). Only energy intensity is expected to depart from its historical trend. Analysts expect energy intensity to drop sharply due to more efficient end-use and change in structural composition of the economy. Consequently, carbon emissions are projected to grow at a lower rate than in the past.

Indonesia, Thailand and South Korea

Since the development of carbon emissions and its four contributing factors in the three East Asian countries is fairly comparable, we group the results for the countries in this section. Similarly to India, carbon dioxide emissions followed an almost exponential path in the past

²⁰ Sinton et al. (1998).

²¹ Garbaccio et al. (1999).

²² Asian Development Bank (1998)

²³ Sinton et al. (1998).

²⁴ Asian Development Bank (1998).

Decomposition of the Changes in CO₂-Emissions in Asian Countries

Figure 2: Bangladesh

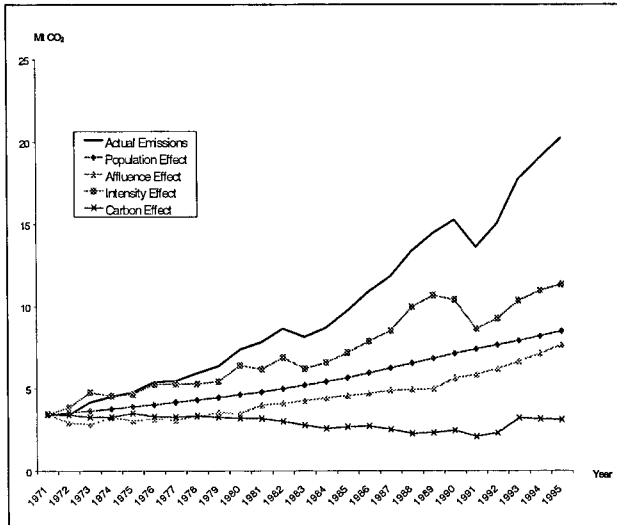


Figure 3: China

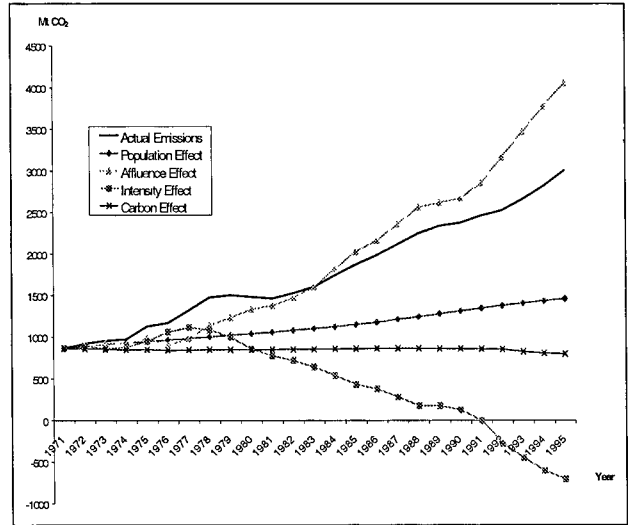


Figure 4: India

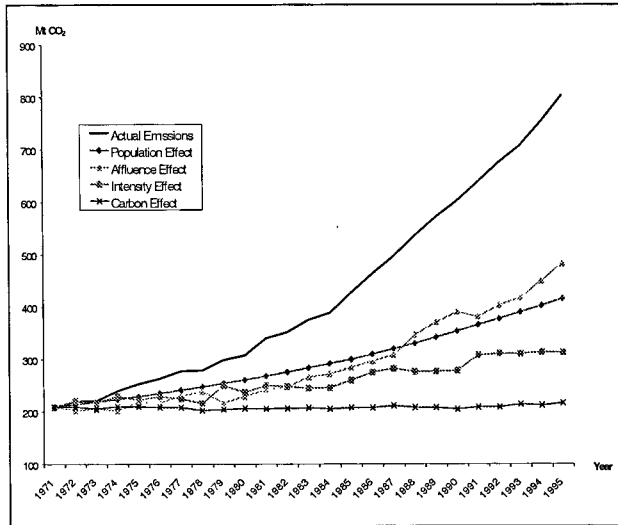


Figure 5: Indonesia

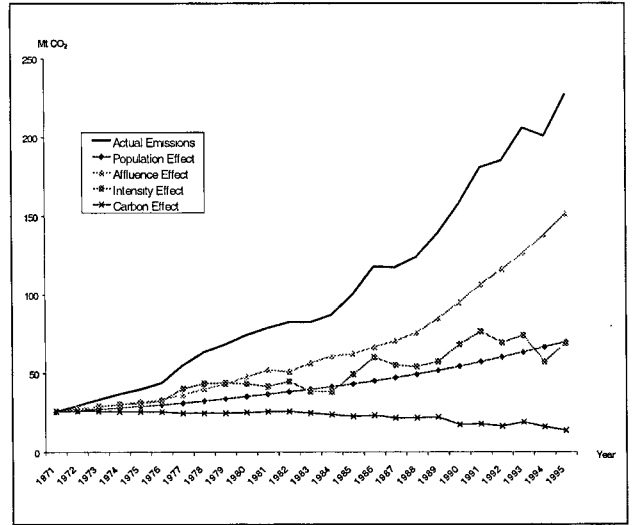


Figure 6: South Korea

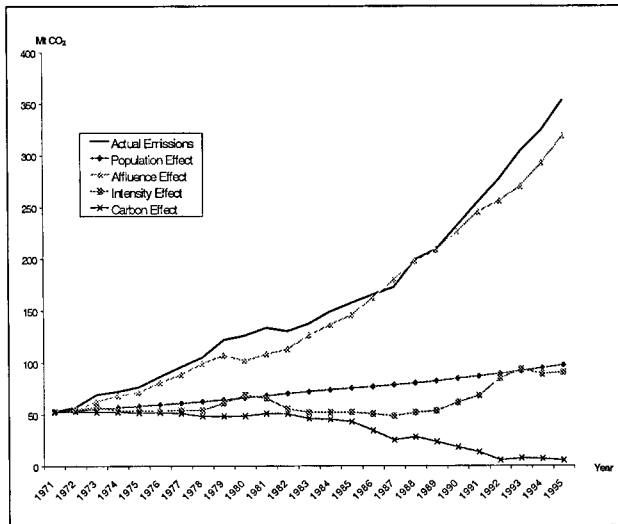


Figure 7: Thailand

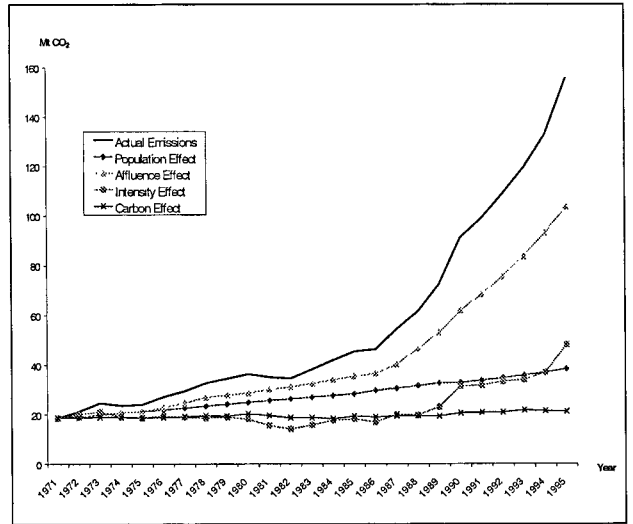


Figure 8a

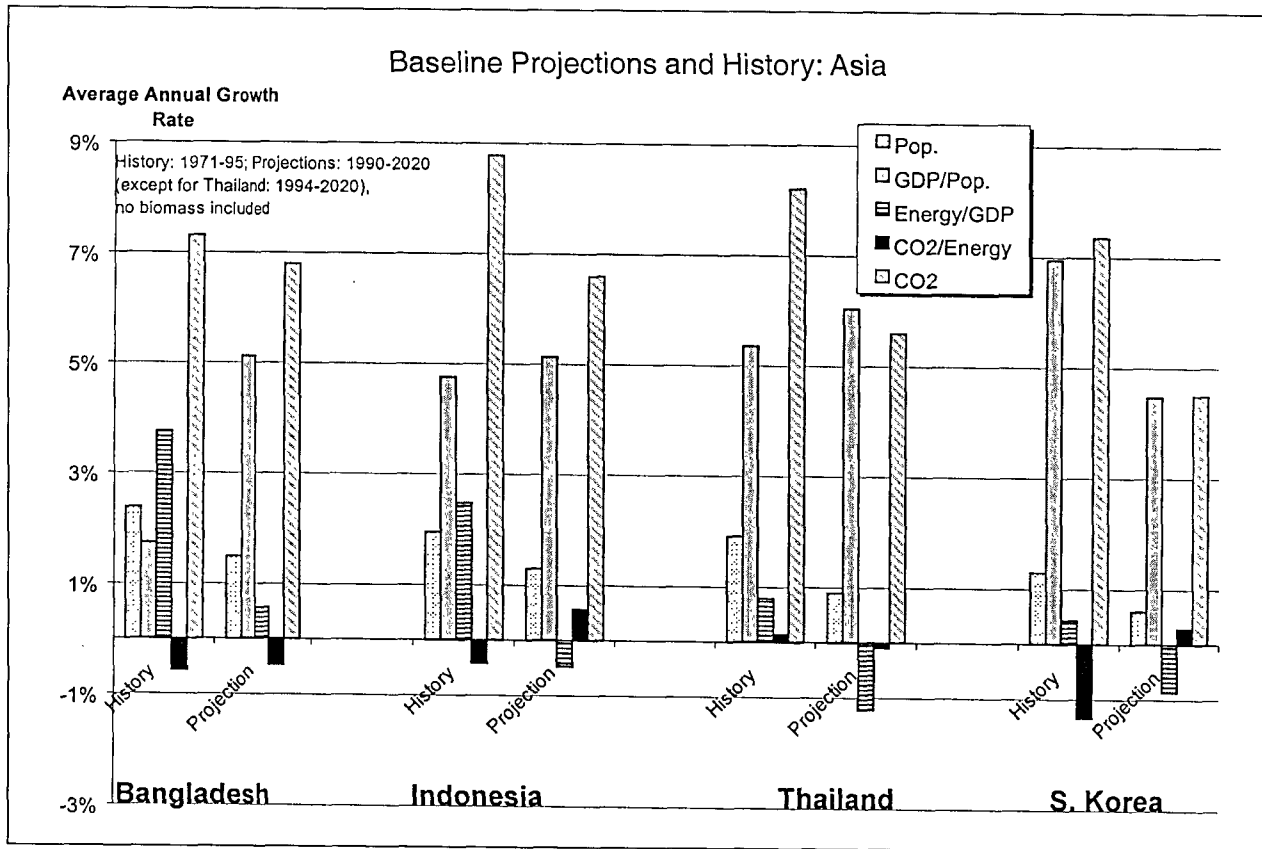
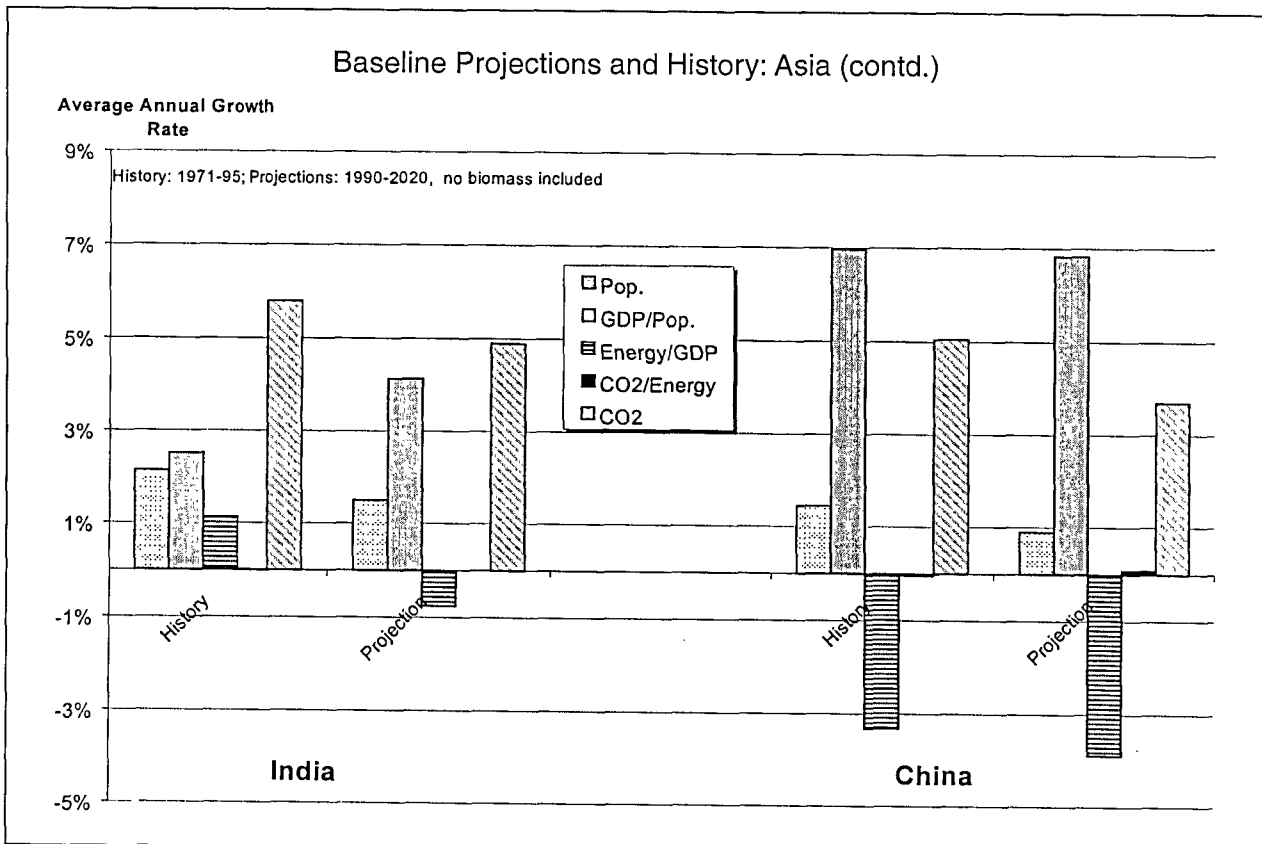


Figure 8b



(Figures 5, 6 and 7). The main driver of this increase in all three countries is growth in per capita income. Economic (GDP/capita) gains were impressive especially in 1985 to 1995. Population growth presents the second most important driver of carbon dioxide emissions in South Korea and Thailand, while it is energy intensity in Indonesia. The fuel mix, signaled by the CO₂/energy ratio, became less carbon intensive in all three countries over the historical period. The introduction of natural gas in these countries, and the increased share of oil for transportation are some of the reasons that caused the fuel carbon intensity to fall.

Carbon emissions in all three countries are projected to grow at substantially lower rates in the future. This occurs at the same time as economic growth is projected to stay high, or even advance over past rates (as seen for Thailand and Indonesia). For all three countries growth in per capita income is expected to remain the main contributor to carbon emissions. With high economic growth and a higher effective turnover of the capital stock as well as market restructuring energy intensity is projected to decline in the future with varying counterbalancing effects on carbon emissions. The rate of change in carbon intensity is expected to either slow or reverse so that the fuel mix is projected to become more carbon intensive in the target year. This increase in carbon intensity occurs, in part, because the countries move toward using increased amounts of coal for power generation.²⁵ An earlier study showed that many large developing countries planned to use coal for a larger share of their electricity generation rather than hydroelectricity.²⁶ Domestic renewable energy resources are limited in South Korea and Indonesia's island Java, where much of the energy demand occurs. It should be noted that the projections have been undertaken before the economic crisis hit East Asia in the mid-1990s. The recent economic decline in these countries will obviously lower projected rates and affect energy consumption and consequent carbon dioxide emissions.

LATIN AMERICA

Brazil

The decomposition analysis shows that, historically in Brazil, both economic (GDP/capita) and population growth played a major role for carbon dioxide emissions (Figure 9 and Figure 12). Between 1971 and 1989, the effects of economic growth exceeded the population effect, while between 1989 and 1992 economic problems led to a decrease in affluence and lowered its effect on carbon emissions. At the same time, however, energy use per unit

²⁵ Halsnaes (1996).

²⁶ Meyers et al. (1993).

Decomposition of the Changes in CO₂-Emissions in Latin American Countries

Figure 9: Brazil

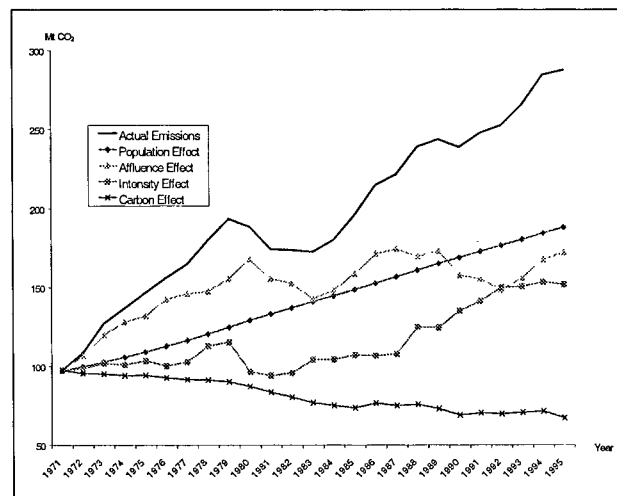


Figure 10: Mexico

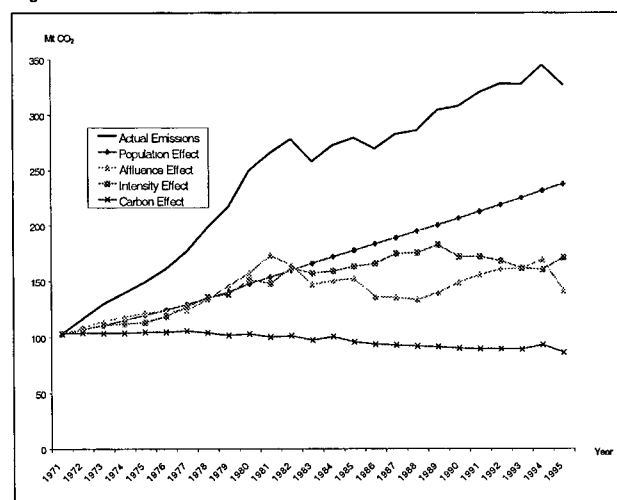
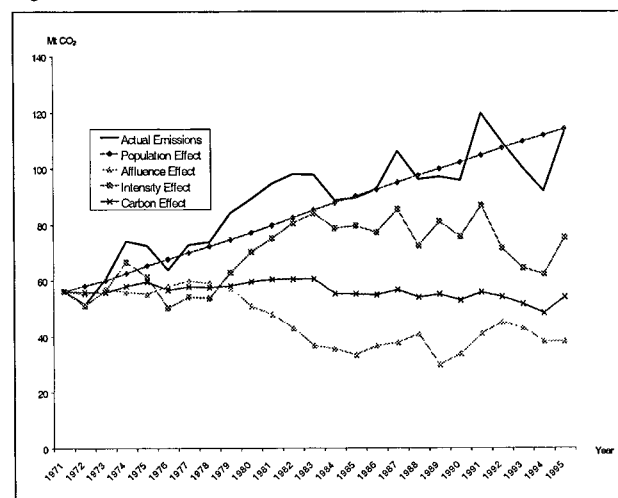


Figure 11: Venezuela



of output increased substantially, a trend that continued with few exceptions until 1995. Declining carbon intensity is the only factor counterbalancing the increases in carbon dioxide emissions. As more hydro and natural gas capacity came into place, over time, the fuel mix became less carbon intensive.

In contrast to the historical trends, the single most important contributor to future carbon dioxide emissions in Brazil is economic growth. It overwhelms the three other factors, reflecting the analysts' assumptions about strong economic growth (per capita GDP). Consequently, carbon dioxide emissions are projected to grow faster relative to historical trends. The increase is partly offset by a projected lower growth of population and substantial improvements in energy efficiency. These changes, however, will not be sufficient to reduce actual carbon emissions. The fuel mix is expected to become more carbon intensive in the future, as more natural gas and oil will penetrate electricity generation.

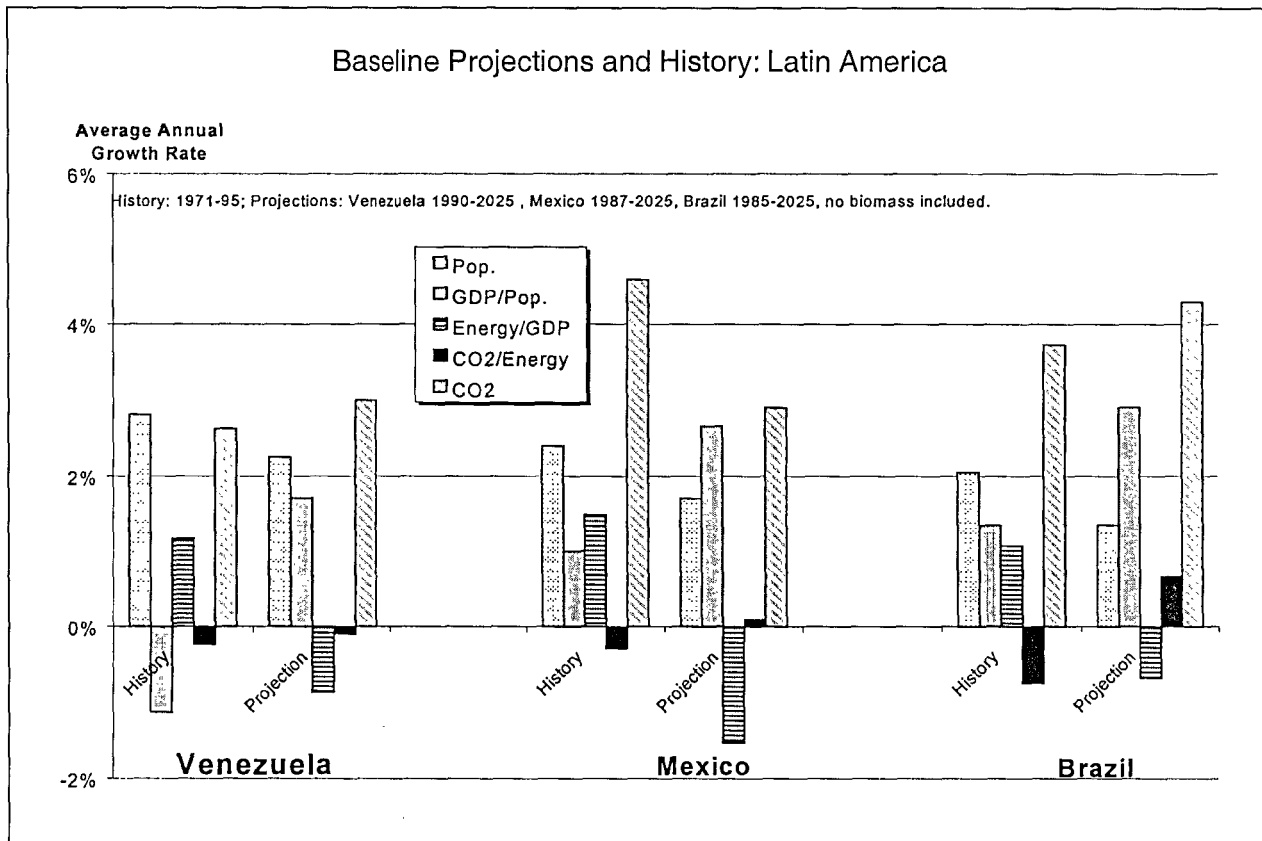
Mexico

Mexico has historically had the highest growth in carbon dioxide emissions among the three Latin American countries (Figure 10). Until 1982, growth in population,

affluence and energy intensity almost equally affected carbon dioxide emissions, while from thereon, population growth emerges as the most important contributor. The period after 1980 was a difficult one for Latin American countries when the economies were depressed. Mexico (and Venezuela) are net exporters of oil, and earned significant revenue until the mid-1980s. Since then both economies have seen a sharp decline in revenue from oil exports. Energy intensity is seen to be rising continuously until 1989. Thereafter, we find a decline in energy intensity at the same time as economic development speeds up again. Throughout the twenty-four year period, a decline in carbon intensity serves to counterbalance some of the effects from the other factors.

In contrast to Brazil, carbon dioxide emissions in Mexico are expected to grow at lower rates than in the past. This occurs even as GDP/capita growth is projected to be significantly higher, and as the fuel mix is projected to get slightly more carbon intensive since more oil and coal will be used to meet rising energy demands. A decline in energy intensity as indicated by the energy/GDP ratio brings down carbon emissions substantially. The projected negative rate reflects the analysts' optimism about improvement in energy efficiency, accompanied by some structural change.

Figure 12



Venezuela

Carbon emissions in Venezuela (Figure 11) grew at a modest rate of 2.6% p. a. compared to the Asian or other Latin American countries considered. Population growth presents the most important contributor to carbon emissions growth. In fact, had it been for population growth alone carbon emissions would have been higher than their actual level during some periods of time. Energy intensity appears to be the second major contributor to carbon emissions. Fluctuations in energy intensity notably shape the year to year pattern of actual CO₂ emissions. These fluctuations may be caused by unstable economic conditions. As a major oil exporting country, Venezuela benefited from high oil prices following the two oil crises. However, declining revenues from oil export added to other economic problems and led to an overall negative growth rate in GDP/capita over the study time period. The fuel mix, as in the other two Latin American countries, became less carbon intensive in Venezuela as the share of hydropower increased and some of the oil consumption was pushed out.

Although growth in GDP/capita is projected to be substantial for Venezuela, population growth is expected to remain the main contributor to carbon emissions in the future. Together the two factors lead to an increased growth in carbon emissions. At the same time energy intensity, as well as the carbon intensity of the fuel mix, are expected to decline due to further penetration of gas and hydroelectricity.

AFRICA

Egypt

In Egypt, high population growth has been a significant driver of carbon dioxide emissions in the past (Figure 13 and Figure 15). However, more importantly increases in affluence contributed to carbon emissions. The Egyptian economy is one of the few African economies with significant historical annual growth in GDP per capita (3.5%). This trend is expected to continue in the future. Had it been for economic (GDP/capita) growth alone carbon emissions would have amounted to 48.4 million tons of carbon dioxide in 1995. Actual CO₂ emissions, however, were higher at 90.6 million tons of CO₂ in 1995. Next to population and affluence, an increase in energy intensity added to total carbon emissions. Energy intensity rose continuously until 1991, although at modest rates compared to other (in particular African) countries. The fuel mix, signaled by the CO₂/energy ratio, became less carbon intensive over time partly offsetting the increase caused by the other factors. The decline was largely due to the increased use of natural gas, and the decline in coal use.

The projected energy/GDP ratio shows a sharp departure from historically observed changes. Energy intensity is projected to decline in the future largely because of energy efficiency improvements. At the same time the fuel mix is projected to get more carbon intensive as biomass, which is projected to decline in the future, is substituted by carbon-producing fossil fuels. However, together with

Decomposition of the Changes in CO₂-Emissions in African Countries

Figure 13: Egypt

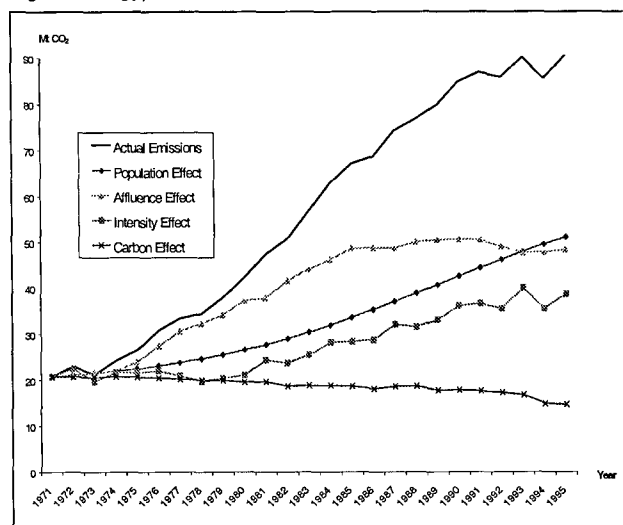
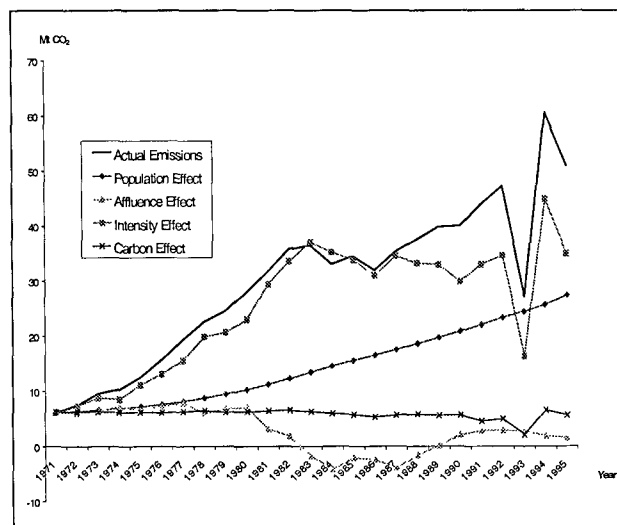


Figure 14: Nigeria



lower expected growth in population the sharp decline in energy intensity is expected to bring down the carbon emissions growth rate relative to the historical rate.

Nigeria

In Nigeria, as in Egypt, population growth has played a major role for carbon dioxide emissions growth. However, as seen in Figure 14, the single main driver of carbon dioxide emissions in the past was energy intensity which increased at about 5.7% per year. Nigeria is a major oil exporting country. Energy, in particular oil consumption rose significantly mainly due to low and subsidised oil product prices. The Nigerian economy benefited from high oil prices between 1973 and the mid-1980s. Subsequent to that period, however, the formal economy showed a negative growth in per capita income with ambiguous effects on carbon emissions. On the one hand, the downfall in economic production reduced carbon dioxide emissions, on the other hand increased oil and gas consumption during that period caused energy intensity to fall relatively less and contribute positively to carbon dioxide emissions. The overall effect was a temporary decrease in carbon emissions. For the same reasons as for Egypt, carbon intensity has been falling in the past.

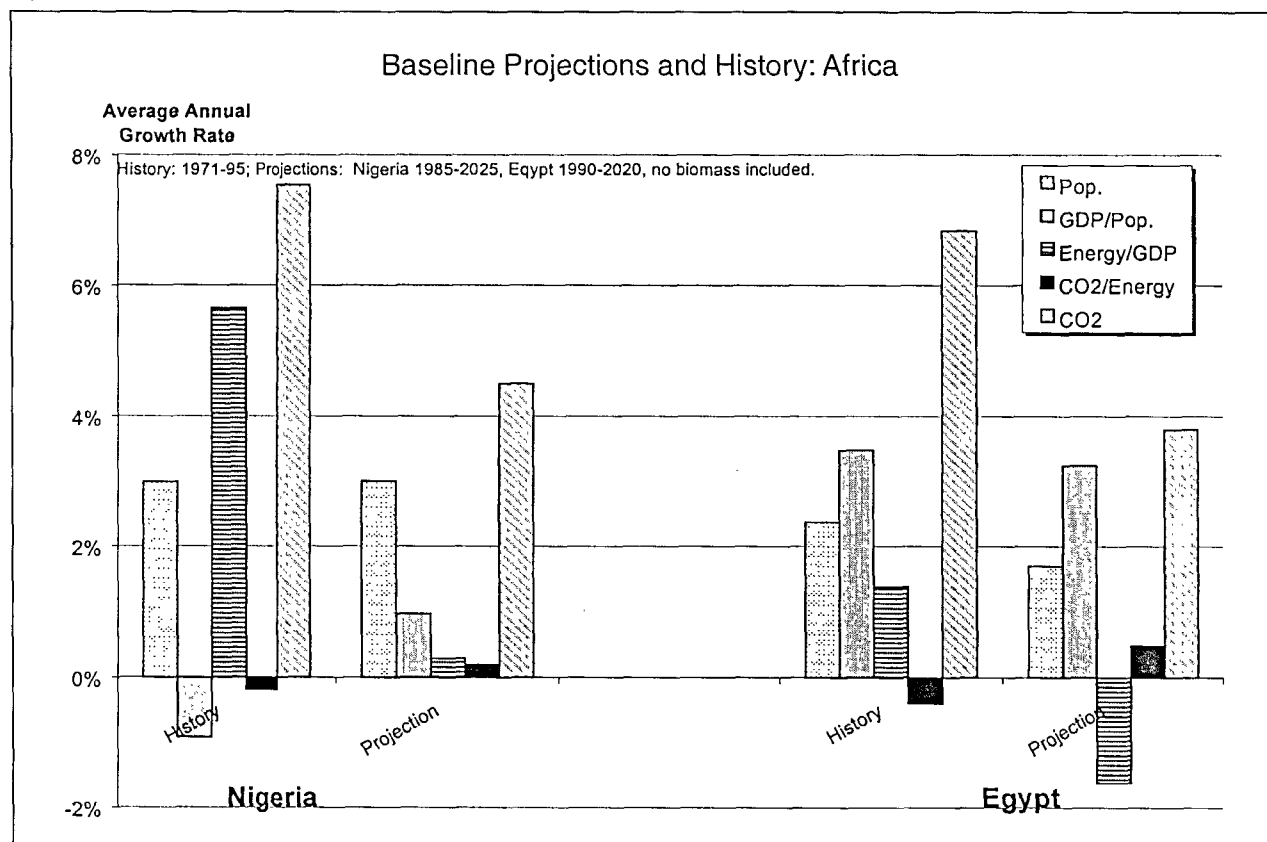
For the future, carbon emissions growth is projected to be much lower than in the past. This occurs even as the scenarios assume a faster growth in affluence than historically observed and as the fuel mix is projected to get more carbon intensive in the future. The sharp decline in the projected energy intensity ratio offsets both these factors and brings down the carbon dioxide emissions growth rates relative to the historical ones. Population growth is expected to remain about the same and will be the single main determinant of carbon emissions in the future.

EASTERN EUROPE

Bulgaria

The decomposition analysis (Figure 16) shows that economic growth (GDP/capita) has consistently been the single most important contributor to carbon dioxide emissions in the past. Had it been for the effects of affluence along (holding all other factors constant) carbon emissions would have peaked at twice the 1971 level in 1987. However, due to the positive influence of energy efficiency improvements and reduced carbon intensity of the fuel mix actual emissions increased only slowly until 1989.

Figure 15



With the collapse of the Eastern European economies in 1989, economic output and carbon emissions dropped substantially. Energy intensity which had been decreasing since the early 1980s continued its downward trend. With the stabilisation of the economy in 1992, energy intensity went up again and the decline in carbon emissions leveled off. The fuel mix as shown in the ratio of CO₂ emissions per unit of primary energy supply became less carbon intensive throughout the whole time period due to increased use of both natural gas and hydropower substituting oil and coal use. As in most Eastern European countries, population growth only played a minor role for carbon emissions.

In the future, economic growth is expected to remain the main single driver of carbon dioxide emissions. Although energy efficiency is projected to further improve and population to even decrease in the future, these effects will not be enough to stop the affluence effect from driving up carbon emissions. Carbon emissions are expected to grow at 2.7% p. a. in the future, the highest growth among the three Eastern European study countries. The carbon intensity of the fuel mix which is reported to slightly increase in the future adds to this trend. As Bulgaria is undergoing the transition to a market economy rapid changes in predicted growth rates are possible. More recent analyses may predict economic growth to be much lower, consequently affecting carbon emissions growth and growth of other factors.

Czech Republic

In the Czech Republic, increased economic activity, as given by per capita output, contributed substantially to carbon dioxide emissions over the twenty-four year time period (Figure 17). In fact, holding all other factors constant output growth alone would have led to carbon emissions substantially above the actual level of carbon emitted. Improvements in energy efficiency, lower carbon intensity of the fuel mix as well as low population growth effectively counterbalanced this activity driven increase. Carbon emissions slightly increased during the period 1971 to 1986. Economic output and carbon emissions dropped substantially following 1989. Moreover, a significant reduction in energy intensity added to the decline of carbon emissions. The breakdown and subsequent market restructuring forced inefficient industries to shut-down and to be replaced by more efficient technologies. Energy intensity increased slightly again during the period of economic stabilisation in 1991-92 and resumed its downward trend with the recovery of the economy in 1993.

From 1993 on, the transformation towards market economies spurred economic activity in the Czech Republic as in most other Eastern European countries. Projections, therefore, show substantially higher per capita growth rates than in the past. Energy efficiency improvements are expected to continue in the future with new expansions

Decomposition of the Changes in CO₂-Emissions in Eastern Europe

Figure 16: Bulgaria

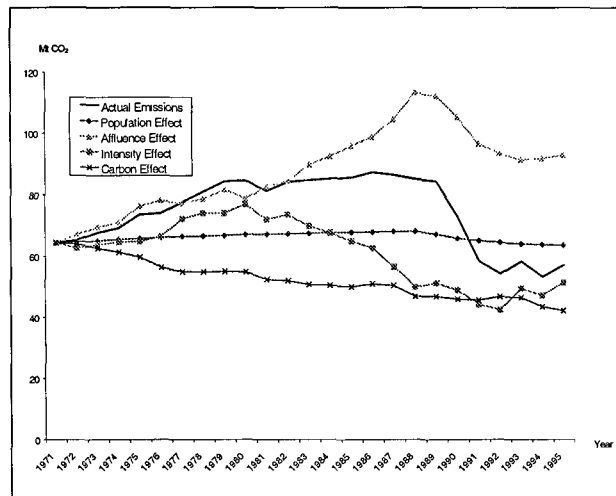


Figure 17: Czech Republic

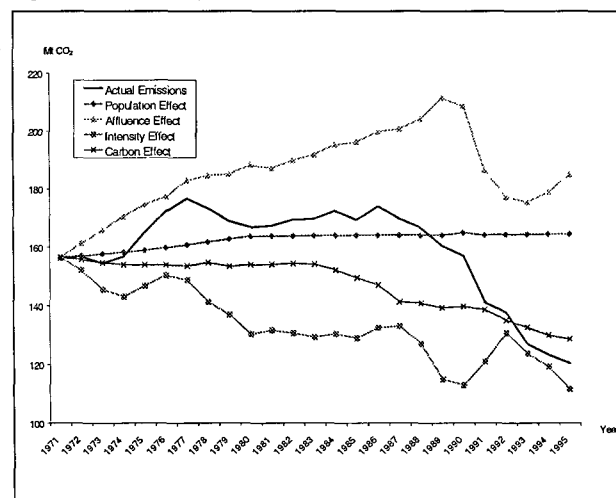
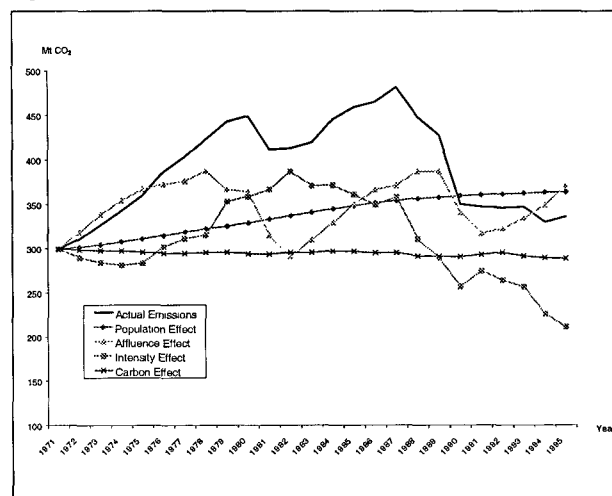


Figure 18: Poland



based on more modern production processes. Furthermore, the relatively less energy using service sector will assume a higher share in a market based system. The projections in Figure 19 reflect two assumptions on future economic growth. The optimistic, high growth scenario shows a corresponding higher decrease in energy intensity than the medium growth scenario. Carbon emissions are projected to rise in the future with higher growth in the optimistic scenario and a relatively small increase in the medium growth scenario. As in the past, the carbon intensity of the fuel mix is projected to decline as natural gas, hydro and geothermal energy will continue to substitute for coal use. Since population is predicted to be stagnant, its growth will not play any role for future carbon emissions.

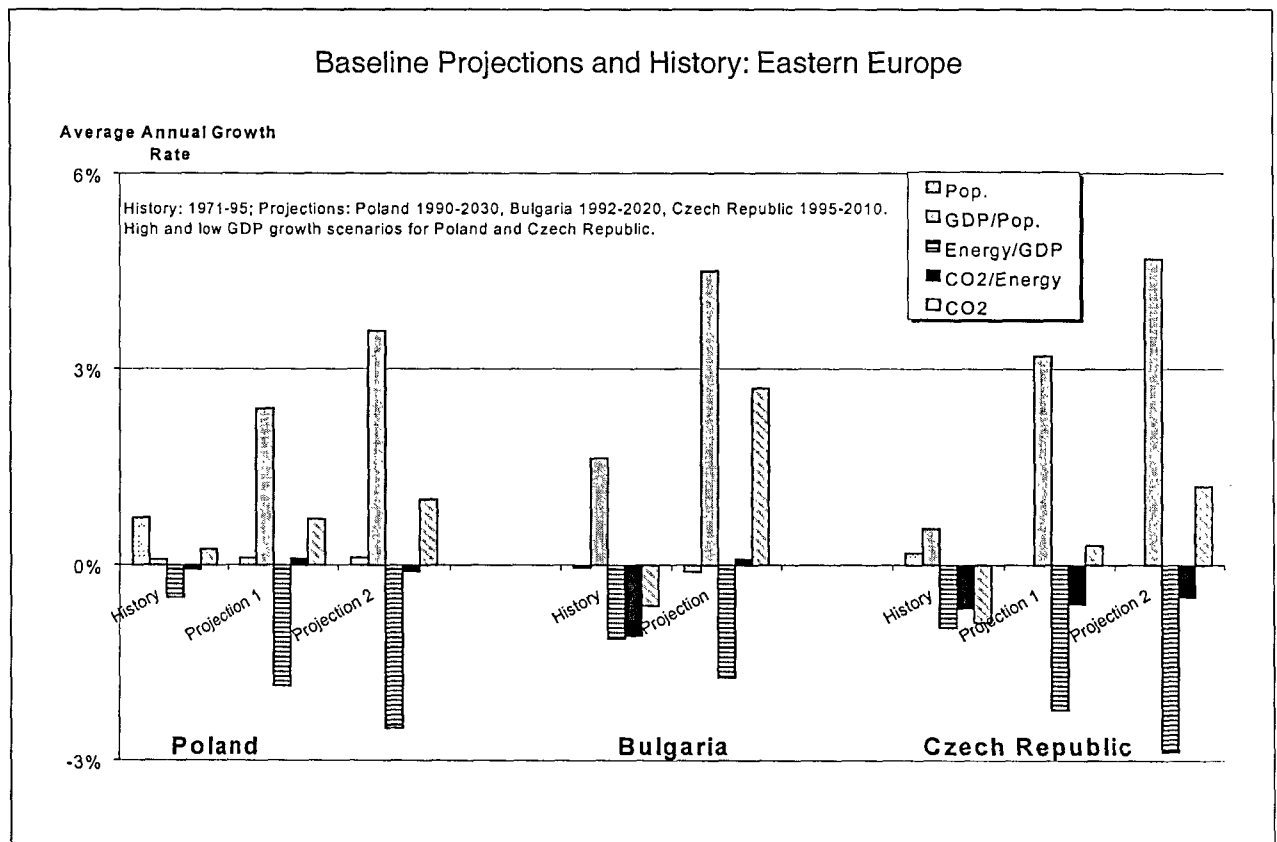
Poland

Carbon emissions in Poland have tended to rise and fall primarily in response to changing levels in affluence (Figure 18). A major economic breakdown can be observed in the early 1980s probably due to the oil price shock and again in 1989 when most Eastern European and Soviet Union systems collapsed. In contrast to the other two Eastern European countries, energy intensity was increasing in Poland until 1981 and only slightly decreasing thereafter. Only in 1989, energy intensity began to drop sharply, a trend that continued – with one exception –

until 1995. Since 1991, affluence is rising again. However, substantial improvements in energy efficiency had a stabilising effect on carbon emissions. The fuel mix, in Poland, became slightly less carbon intensive, mainly due to decreased coal consumption during the times of economic recession. It should be noted that, in Poland, over the total time period continuously rising population has had the most significant impact on carbon dioxide emissions growth.

Although historically very different, future projections for Poland are very similar to projections for the Czech Republic. Two scenarios – an optimistic high growth and a medium growth scenario – have been developed for Poland. In both cases, economic growth (GDP/capita) will be the most important driver of carbon emissions. For the same reasons as in the Czech Republic, energy intensity is assumed to decrease at faster rates in the higher growth scenario. The fuel mix is expected to decrease in the high growth scenario, as more resources are available for the employment of low emissions technologies, while it is assumed to increase slightly in the medium growth scenario (more use of abundantly available coal resources). Population growth is projected to be lower than in the past with only minor effects on carbon emissions. Overall, the development of all factors will cause carbon emissions to soar in the future.

Figure 19



Cross Country Comparison

Past Trends

In order to reveal parallels and differences across countries, the findings of the decomposition analysis for each of the countries under investigation are summarised in Table 2. The decomposition analysis as presented in the table allows for more detail regarding the energy intensity factor in accounting separately for end-use efficiency and conversion and primary use efficiency. The countries are listed in order of their CO₂ releases in 1995 in the table. Columns 2 to 4 provide data on actual 1995 and 1971 emissions and the ratio of 1995 to 1971 levels. The remaining columns are divided into three sets of information for each of the five factors, population, affluence, energy intensity, conversion efficiency and carbon intensity respectively. Each set of three columns indicates (1) the emissions levels that would have occurred if only the specific factor had changed, while the other factors had remained constant at their initial values; (2) the ratio between the 1995 and 1971 levels of the relevant factor; and (3) the rank of the relevant factor in terms of its contribution to changes in carbon emissions during this time period (1 = most important, 5 = least important).

The fourteen countries illustrate different development trajectories, ranging from among the highest per capita income in the developing world in South Korea to among the lowest in Bangladesh, Nigeria and India. In three countries – Indonesia, Thailand and Nigeria — CO₂ emissions increased more than eight-fold between 1971 and 1995. China saw the largest rise in absolute emissions followed by India and South Korea. For aforementioned reasons, the Eastern European countries show the lowest increase in carbon dioxide emissions. Carbon emissions less than doubled in the Czech Republic and Bulgaria, while they slightly more than doubled in Poland. Mid-range increases can be observed for the Latin American countries (2 to 3.2 fold).

Population growth made the greatest contribution to increases in carbon emissions for the three Latin American and the two African countries. In seven countries, increasing affluence was the primary factor contributing to increase in CO₂ emissions between 1971 and 1995. This finding was expected for most of the Asian countries, but it is somewhat surprising to see that gains in GDP per capita are also the primary determinants in Poland and Bulgaria. Affluence is the second most important factor in Brazil, Egypt and the Czech Republic. 1995 carbon emissions due to the affluence effect would have been lower than their 1971 values in Nigeria and Venezuela, the countries which experienced a decline in per capita income over the period.

The conversion efficiency of primary energy to final energy had a pronounced effect in Venezuela and Bang-

ladesh only. While the share of electricity in total final energy consumption was rising for these two countries, improvements in conversion efficiency were attained as more hydropower (in Venezuela) and natural gas came into place, substituting oil and coal consumption. Due to this effect alone carbon emissions would have been substantially lower than their actual 1995 levels. In contrast, a substantial increase in the share of electricity use with its associated conversion and transformation losses was the principle determinant of carbon dioxide emissions growth in the Czech Republic.

The increase in efficiency of final energy consumption per unit of output played a dominant role for reducing CO₂ emissions in China only. Efficiency of final energy use improved strongly in Eastern European countries as well, however, for reasons of shut-down of inefficient plants rather than for reasons of increased efficiency in existing plants. For three countries (Mexico, Thailand, Venezuela) increase in final-use energy intensity was the second most important factor to CO₂ emissions, while for Bangladesh it was the single most important factor.

Eleven out of the fourteen countries show reduced carbon intensity per unit of primary energy. Moreover, for the countries (India, Thailand and Nigeria) where carbon intensity actually increased over time, this factor had the lowest impact on total carbon emissions.

Projections

While in the past population growth was the major contributor to carbon emissions growth for several countries, GDP/capita shows up as the major factor in projections of emissions in the majority of the countries. Only for Venezuela and Nigeria population growth continues to be the main driving force. Four studies (Egypt, Bangladesh, Indonesia, and India) project population growth to be the second main contributor to CO₂ emissions growth. In most cases, urban population growth rates are higher than the average numbers reported here. Urban population growth, however, is more important because much of the modern fuel use and its consequent CO₂ emissions occur in cities. Consequently, future declines in population growth rates, brought about by disease or other causes, could significantly influence the carbon emissions growth for some countries.

For all countries, economic growth is projected to be higher and more stable in the future. As a result, economic structures are expected to shift towards an increasing share of the less energy-using service sector. Additionally, high economic growth will lead to more rapid capital stock turnover and to the acquisition of more modern and efficient technologies. Many of the studies thus project a negative correlation between GDP/capita growth and energy/GDP growth for the future (compare Figure 20). Hence, future energy/GDP growth rates are projected to

Table 2

1995 Carbon dioxide emissions by individual factors relative to 1971 levels

	Actual Carbon Emissions			Population			Affluence (GDP/capita)			Energy Intensity (TFC/GDP)			Conversion efficiency (TPES/TFC)			Carbon Intensity (CO ₂ /TPES)		
	Mt CO ₂ 1995	Mt CO ₂ 1971	Ratio 1995:71	Mt CO ₂ 1995	Ratio 1995:71	Factor Rank	Mt CO ₂ 1995	Ratio 1995:71	Factor Rank	Mt CO ₂ 1995	Ratio 1995:71	Factor Rank	Mt CO ₂ 1995	Ratio 1995:71	Factor Rank	Mt CO ₂ 1995	Ratio 1995:71	Factor Rank
China	3006.8	864.2	3.5	1459.6	1.7	2	4050.8	4.7	1	-876.7	-1.0	5	1065.6	1.2	3	764.1	0.9	4
India	803.0	208.6	3.9	416.1	2.0	2	483.1	2.3	1	242.7	1.2	4	271.4	1.3	3	224.1	1.1	5
South Korea	353.1	53.0	6.7	97.9	1.8	2	318.3	6.0	1	83.5	1.6	3	58.9	1.1	4	6.5	0.1	5
Poland	336.1	299.3	1.1	364.1	1.22	2	370.0	1.24	1	178.7	0.6	5	332.0	1.1	3	288.6	1.0	4
Mexico	327.6	103.4	3.2	238.1	2.3	1	141.8	1.4	3	156.6	1.5	2	108.5	1.0	4	96.1	0.9	5
Brazil	287.5	97.5	2.9	188.3	1.9	1	172.3	1.8	2	149.0	1.5	3	119.7	1.2	4	48.2	0.5	5
Indonesia	227.0	25.7	8.8	70.0	2.72	2	151.5	5.9	1	33.2	1.29	4	61.1	2.38	3	14.1	0.5	5
Thailand	155.6	18.6	8.4	38.4	2.06	3	103.6	5.6	1	39.1	2.10	2	25.8	1.4	4	23.1	1.2	5
Czech	120.4	156.4	0.8	164.5	1.1	3	185.0	1.2	2	42.6	0.3	5	226.0	1.4	1	128.1	0.8	4
Venezuela	113.2	56.3	2.0	114.3	2.03	1	38.2	0.68	4	112.2	1.99	2	31.9	0.6	5	41.7	0.74	3
Egypt	90.6	20.7	4.4	51.1	2.5	1	48.4	2.3	2	24.3	1.2	4	31.6	1.5	3	18.2	0.9	5
Bulgaria	57.2	64.4	0.9	63.7	1.0	3	93.0	1.44	1	26.4	0.4	5	88.7	1.38	2	42.9	0.7	4
Nigeria	50.9	6.2	8.3	27.4	4.4	1	1.6	0.3	5	16.7	2.7	3	23.2	3.8	2	6.7	1.1	4
Bangladesh	20.2	3.5	5.9	8.5	2.5	2	7.6	2.2	3	11.5	3.3	1	2.9	0.8	5	3.5	1.0	4

TPES = Total primary energy supply.
 TFC = Total final energy consumption.
 Rank: 5 = Most important contributor to an increase in CO₂ emissions.
 1 = Least important contributor to an increase in CO₂ emissions.

be substantially lower than historical ones – slowing down carbon emissions growth. Only two countries, Nigeria and Bangladesh, report an increasing energy/GDP ratio even as their economic growth steps up. The two countries are highly dependent on biomass as a fuel source. Including biomass into the energy measure would bring down their energy intensity growth to levels comparable to other countries. The decline in energy intensity is contrary to historical trends in at least 10 countries, where energy intensity increased substantially (Figure 21). Apparently, lower economic growth at lower levels of economic development was associated with a higher need of energy to produce that output.

The fuel mix becomes more carbon-intensive in the baseline scenario of a few countries as the share of fossil fuels increases. Some countries, Nigeria, Indonesia and India, for example, predict higher growth in CO₂/energy as a result of switching from biomass, which is assumed to have no net CO₂ emissions, to modern fuels like kerosene and LPG. Increased use of natural gas could offset this trend, however. Natural gas, where available, is the fuel of choice for private producers because it requires less investment per kW of unit capacity than coal power plants. Most of the scenarios show that although the fuel mix becomes more carbon intensive, the effect on total carbon

emissions will be more than offset by the energy/GDP decline.

Conclusions

The analysis shows that the primary factors contributing to *historical* carbon emissions growth vary across countries, however, economic growth is the primary factor driving *future* projections in most cases. In addition, we find that GDP/capita growth is projected to be associated with lower energy/GDP growth in future. This relationship is contrary to historical trends for many economies, where energy intensity increased substantially. Technology-transfer strategies can substantially contribute to the implementation of energy efficiency improvements in developing and transitioning countries. Ensuring that these improvements do occur will be important since they can offset the emissions increases that will arise from anticipated growth in affluence and other factors.

Next to economic (GDP/capita) growth, we find that population growth is projected to remain an important contributor to GHG emissions. Population growth can vary significantly across countries, and the presence of diseases, such as AIDS, can impact some countries to the

Figure 20

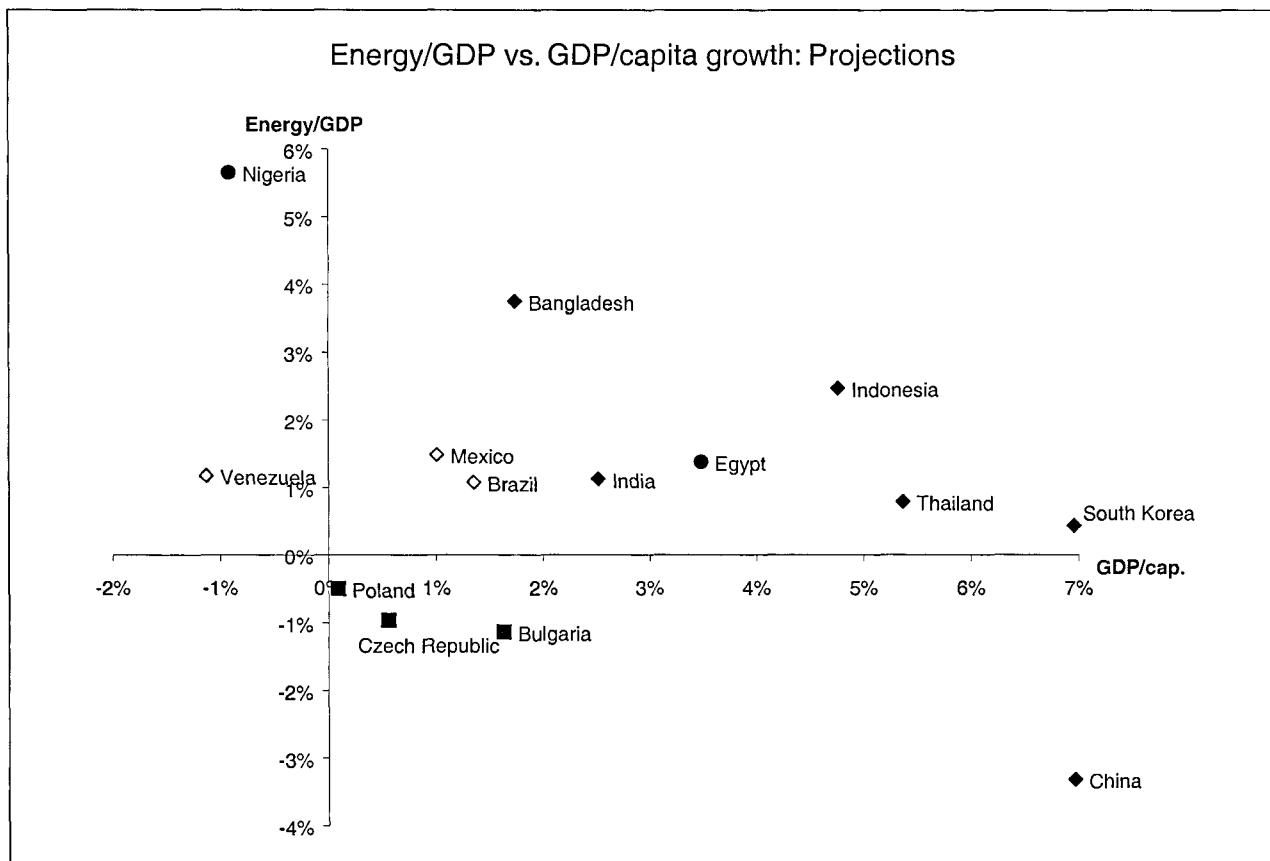
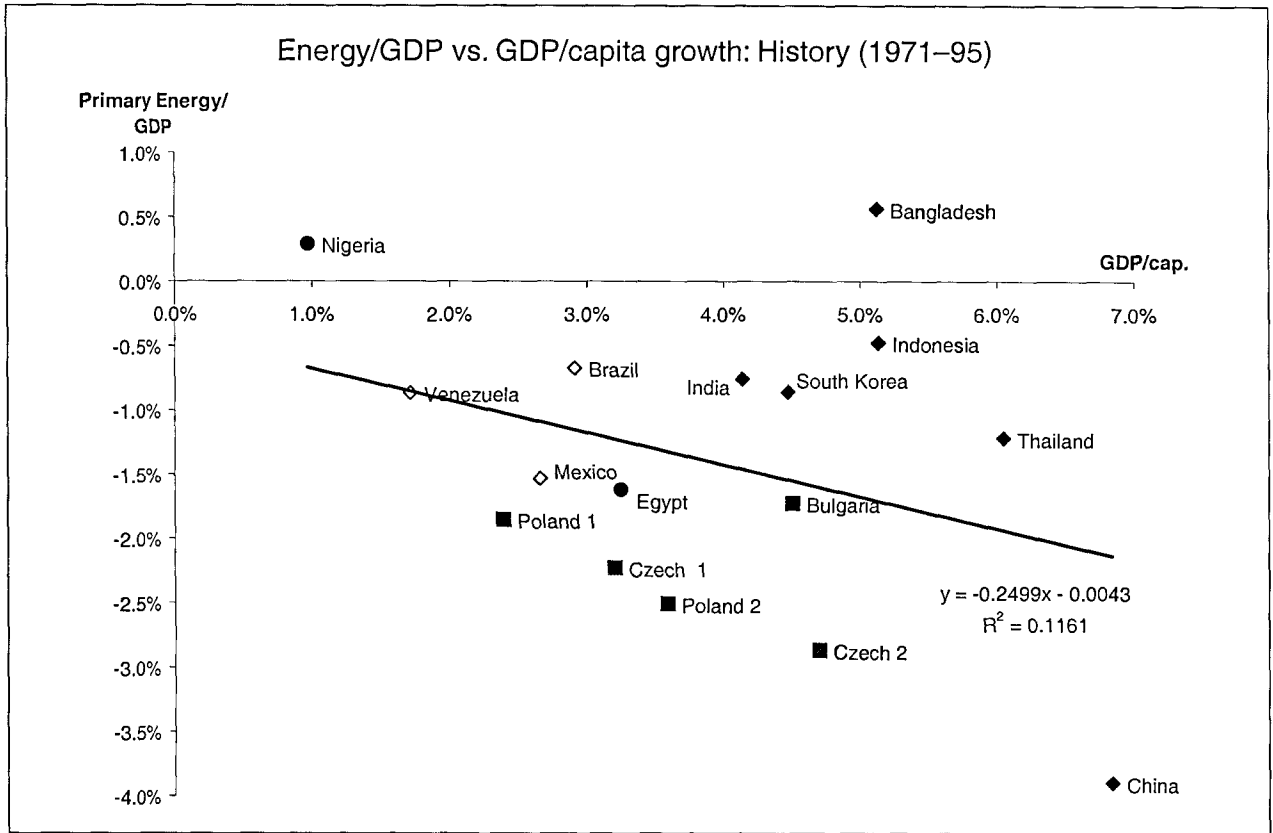


Figure 21



point of significantly changing their demographics, and reducing their emissions growth.

Our findings reveal a surprising diversity in the pattern of carbon emissions and the contributing factors among countries. We find that countries are not to be grouped according to their physical regions as it is usually done but that other country specific factors (biomass use, oil reserves, market transformation) can be more important for revealing common patterns. Furthermore, we see that patterns of development are very dynamic over time. The relative significance of the factors can change over time.

Our findings therefore suggest, that in the long term it will be necessary to reflect on strategies that affect all the

factors if we are to succeed in slowing carbon dioxide emissions. One should keep in mind, however, that the factors may not be independent of another in a dynamic sense. For instance, there is some reason to believe that affluence and population growth are correlated.²⁷ Higher per capita incomes are associated with lower fertility and mortality rates in developing countries. Similarly, as outlined above, higher economic growth (per capita income) can imply lower energy consumption per unit of output. Both these 'external' effects would additionally lower growth in carbon emissions.

²⁷ Gaffin (1998).

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Appendix 1

Calculation of the Effects Contributing to the Change in Carbon Dioxide Emissions

$$\begin{aligned}
 P_{eff} &= (\Delta P) * A^0 * I^0 * C^0 \\
 &+ \frac{1}{2}(\Delta P) * [(\Delta A) * I^0 * C^0 + A^0 * (\Delta I) * C^0 + A^0 * I^0 * (\Delta C)] \\
 &+ \frac{1}{3}(\Delta P) * [(\Delta A) * (\Delta I) * C^0 + A^0 * (\Delta I) * (\Delta C) + (\Delta A) * I^0 * (\Delta C)] \\
 &+ \frac{1}{4}(\Delta P) * (\Delta A) * (\Delta I) * (\Delta C)
 \end{aligned}$$

$$\begin{aligned}
 A_{eff} &= P^0 * (\Delta A) * I^0 * C^0 \\
 &+ \frac{1}{2}(\Delta A) * [(\Delta P) * I^0 * C^0 + P^0 * (\Delta I) * C^0 + P^0 * I^0 * (\Delta C)] \\
 &+ \frac{1}{3}(\Delta A) * [(\Delta P) * (\Delta I) * C^0 + P^0 * (\Delta I) * (\Delta C) + (\Delta P) * I^0 * (\Delta C)] \\
 &+ \frac{1}{4}(\Delta P) * (\Delta A) * (\Delta I) * (\Delta C)
 \end{aligned}$$

$$\begin{aligned}
 I_{eff} &= P^0 * A^0 * (\Delta I) * C^0 \\
 &+ \frac{1}{2}(\Delta I) * [(\Delta P) * A^0 * C^0 + P^0 * (\Delta A) * C^0 + P^0 * A^0 * (\Delta C)] \\
 &+ \frac{1}{3}(\Delta I) * [(\Delta P) * (\Delta A) * C^0 + P^0 * (\Delta A) * (\Delta C) + (\Delta P) * A^0 * (\Delta C)] \\
 &+ \frac{1}{4}(\Delta P) * (\Delta A) * (\Delta I) * (\Delta C)
 \end{aligned}$$

$$\begin{aligned}
 C_{eff} &= P^0 * A^0 * I^0 * (\Delta C) \\
 &+ \frac{1}{2}(\Delta C) * [(\Delta P) * A^0 * I^0 + P^0 * (\Delta A) * I^0 + P^0 * A^0 * (\Delta I)] \\
 &+ \frac{1}{3}(\Delta C) * [(\Delta P) * (\Delta A) * I^0 + P^0 * (\Delta A) * (\Delta I) + (\Delta P) * A^0 * (\Delta I)] \\
 &+ \frac{1}{4}(\Delta P) * (\Delta A) * (\Delta I) * (\Delta C)
 \end{aligned}$$

This yields the decomposition: $\Delta CO_2 = P_{eff} + A_{eff} + I_{eff} + C_{eff}$

CO₂ — Trends in Entwicklungs- und Transformationsländern

Zusammenfassung

Entwicklungs- und Transformationsländer werden in Zukunft zunehmend zu globalen Treibhausgasemissionen beitragen. Allerdings bestehen große Unsicherheiten bezüglich der künftigen Entwicklungspfade dieser Länder. Der Beitrag befaßt sich mit der Entwicklung der CO₂-Emissionen in 14 Entwicklungs- und Transformationsländern. Es wird untersucht, inwieweit vier primäre Faktoren – Bevölkerungswachstum, Wirtschaftswachstum, Energieintensität und CO₂-Intensität – zur Entwicklung der CO₂-Emissionen beitragen, und die Hauptursachen für Differenzen zwischen historischen und prognostizierten Veränderungen jedes Faktors sowohl für die einzelnen Länder als auch im Ländervergleich diskutiert. Die Analyse führt zu dem Ergebnis, daß für den Anstieg der CO₂-Emissionen unterschiedliche Faktoren verantwortlich waren. Für die Zukunft ist jedoch zu erwarten, daß der Faktor Wirtschaftswachstum den weitaus größten Einfluß hat. Zugleich zeigt die Analyse, daß ein künftig höheres Wachstum des Pro-Kopf-Einkommens mit einer sinkenden Energieintensität einhergeht. Auch die anderen Faktoren dürften aber weiterhin einen wichtigen Einfluß ausüben. Eine optimale CO₂-Verminderungsstrategie muß daher alle Faktoren berücksichtigen.