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Population Growth and Global Carbon Dioxide Emissions

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Abstract: Previous studies on the determinants of carbon dioxide emissions have primarily focused on the role of affluence. The impact of population growth on carbon dioxide emissions has received less attention. This paper takes a step forward providing such empirical evidence, using a data set of 93 countries for the period of 1975-1996. The paper has following findings. (1) Population growth has been one of the major driving forces behind increasing carbon dioxide emissions worldwide over the last two decades. It is estimated that half of increase in emissions by 2025 will be contributed by future population growth alone. (2) Rising income levels have been associated with a monotonically upward shift in emissions.

The findings, interpretations, and conclusions are entirely those of the author. They do not necessarily represent the views of the World Bank, its Executive Directors, or the countries they represent. I thank Bob Cull, Phillip Keefer, Steve Knack, Brian O'Neill, and William Martin for very helpful comments. Author's email address: ashi@worldbank.org.

1. Issue

The last two decades have witnessed an unprecedented global warming. This has brought about great concerns over its causes and consequences. Scientists claimed that the increasing carbon dioxide emissions (CO_2) produced a massive build-up of greenhouse gas, which gave rise to recent warm temperatures (IPCC 1995; Watson et al. 1996). International negotiations have been underway to try to reach consensus in curbing the rapid growth of carbon dioxide emissions worldwide. A historic agreement was reached in Kyoto in 1997, which required its 38 developed countries of Annex 1 signatories to reduce their annual carbon emissions to an average of 5.2 percent below 1990 levels for the years 2008-12 (United Nations 1997).

In discussing the determinants of global CO_2 emissions, the conventional view holds that the rapid growth of CO_2 emissions is primarily due to increasing energy consumption as affluence grows. The impact of population growth on global CO_2 emissions has not received enough attention. Recent studies suggest that population growth has been one of the major factors in causing carbon emissions in both developed and developing countries (Bongarrts 1992; Dietz and Rosa 1994; Engelman 1994, 1998; O'Neill et al 2001; Smil 1990). However, there has not been ample empirical evidence to support this claim.

This paper's aim is to examine the impact of population growth on carbon dioxide emissions by using a panel data of 93 countries during 1975-1995 period. Specifically, I quantify the impacts of changes in population, income level, and energy efficiency of economic production on emissions in one single model. The data suggest the following conclusions. (1) One percent of population growth is associated with a 1.28 percentage increase in emissions on average. (2) The impact of population pressure on emissions has been more pronounced in developing countries than developed countries. (3) It is estimated that global emissions will reach as high as 13.72 gigatons in 2025 under the business-as-usual assumptions (this implies that the annual population growth rate will be under the UN medium growth scenario, and the annual real GDP per capita growth rate will be 1.9%). This magnitude more than doubles the emissions level of 1990, and half of the gains will be attributed to the future population growth alone. (4) Rising income levels have been associated with a monotonically upward shift in emissions.

This paper is organized as follows. In the following section, brief literature is reviewed on the relationship between population and carbon dioxide emissions; then the model specifications, data sources and variables are discussed. They are followed by the major findings. Finally, the paper concludes with some thoughts relevant to policy implications.

2. Analytical Framework

The role of population pressure on environmental quality can be traced back to the early debate on the relationship between population and natural resources. Malthus (1798 [1970]) was concerned with increasing population growth, which put pressure on limited source of land. Because of a lower marginal product of labor, the potential growth in food supply could not keep up with that of the population. He predicted that if mankind did not exercise preventive checks, population growth would be curtailed by welfare checks (poverty, disease, famine and war). Boserup (1981) held the opposite view, which argues that high population densities were a prerequisite for technological innovation in agriculture. The technological innovation made possible the increased yields and more efficient distribution of food. It could then enable the natural environment to support a large population at the same level of welfare.

Although both authors were not specifically concerned with the environment other than the resource for food production, their positions have been well taken in recent environmental debates. On the one hand, some scholars have demonstrated that the exploitation of natural, mineral and energy resources, and the ability of the environment to absorb wastes generated by mankind's activities were not keeping pace with population growth (Commoner 1971; Cropper and Griffiths 1994; Demeny 1991; Myers 1997). Others, on the other hand, have argued that the larger the population the more vigorous the development of science and technology, and the better mankind's ability to provide technological solution to environmental problems (Simon 1981).

The impact of population growth on environment quality is obvious. Each person in a population makes some demand on the energy for the essentials of life—food, water, clothing, shelter, and so on. If all else is equal, the greater the number of people, the greater the demands on energy. Birdsall (1992) specified two mechanisms through which population growth could contribute to greenhouse gas emissions. First, a larger population could result in increased demand for energy for power, industry, and transportation, hence the increasing fossil fuel emissions. Second, population growth could contribute to greenhouse gas emissions through its effect on deforestation. The destruction of the forests, changes in land use, and combustion of fuel wood could significantly contribute to greenhouse gas emissions.

The impact of population change on environmental stress was posited by Ehrlich (1968) and Holder and Ehrlich (1974) in the form of an equation relating environmental impact to the production of population size, affluence, and environmental impact per unit of economic activity known as " IPAT". Since this equation was proposed, there have been many criticisms (Bernstam 1991; Dietz and Rosa 1994). The key problem with this equation is that the relationship is definitional, and does not provide a stochastic model for testing hypothesis about the human driving forces of environmental changes. Nevertheless, IPAT is useful framework for assessing the anthropogenic environmental change, particularly the impacts of population, affluence, and technology on the environmental change.

Indeed, there have been attempts to assess the role of population on carbon dioxide emissions in light of this framework. For example, in a recent influential study, Engleman (1994) plotted the long-term growth trends of global industrial emissions of carbon dioxide and population, and found that since 1970 both emissions and population have grown at similar rates. This made him hypothesize that population growth could have driven global emissions upward. A study done by the Royal Society of London and the U.S. National Academy of Sciences (1992) also claimed that the population growth was a major threat to human well-being. But there is little empirical evidence to support their claim.

More recent studies have been conducted toward disciplining IPAT framework with a stochastic model. These studies, however, usually regress CO_2 emissions per capita on affluence (GDP per capita) and other predictors, and hence do not explicitly consider population as a predictor in the model (Grossman and Krueger 1995; Holtz-Eakin and Seldern 1995; Seldern and Song 1994; Shafik and Bandypoadhyay 1992).

The exception is the work done by Dietz and Rosa (1997), that regresses the total emissions on population size, in addition to GDP per capita. Using 1989 data of 111 countries, they found that one percentage point of growth in population could yield a 1.15 percent increase in carbon dioxide emissions. However, their study does not explicitly include technology as a predictor in the model, and, since the data they used are cross-sectional in nature, their study does not address the issue of whether the impact of population growth on emissions could vary across countries with different levels of economic development.

Thus, two questions remain to be addressed fully and empirically: (1) does population pressure have a net impact on carbon dioxide emissions holding constant the affluence and technology? and (2) has population pressure exhibited a greater impact in developing countries than in developed countries?

3. Empirical implementation

To estimate the role of population pressure on carbon dioxide emissions, I follow the Dietz and Rosa's stochastic model (1997), which takes the following form:

$$\ln I_{it} = a + b_1(\ln P_{it}) + b_2(\ln A_{it}) + b_3(\ln T_{it}) + e_{it} \qquad (1)$$

where P stands for population size, and A stands for affluence, and T stands for technology, or specifically, the energy efficiency of economic activities. The i denotes to country and t denotes to the year, and e is the error term. The dependent variable (I) is carbon dioxide emissions.

The above model has imposed a linear relationship between affluence and emissions. Other studies however found an inverted U-shaped relationship between affluence and emissions, where emissions initially worsen but ultimately improve with income.[1] To check whether the "Environmental Kuznets Curve" exists, I try another specification with a polynomial term of affluence in the model, which takes this form:

$$\ln I_{it} = a + b_1(\ln P_{it}) + b_2(\ln A_{it}) + b_3(\ln A_{it})^2 + b_4(\ln T_{it}) + e_{it} \qquad (2)$$

Model estimations could incur heterogeneity bias—the confounding effect of unmeasured country-specific variables since our data set is pooled time-series of cross-sections ones. It is likely that there are country-specific factors that might affect carbon dioxide emissions. For instance, the geographic location of countries may well be correlated with the level of carbon dioxide emissions. Many of the wealthier countries are located in the northern part of the globe where relatively more heating is needed. Similarly, there are other factors shared by all countries in a given period that may vary across time. For example, the changes in emissions were affected by world energy prices and macroeconomic fluctuations. The ordinary least squares (OLS) estimation that ignores these problems could be biased and inefficient (Hsian 1986).

To address these problems, I use a fixed-effects model by creating dummies for countries and years to represent country-specific and year-specific intercepts. The fixed-effects and random-effects models are two commonly used estimation methods designed to correct for unmeasured factors. Rather than treating country-specific effects as fixed effects to be estimated as in the fixed-effects model, random-effects model treats them as a random component of the error term, and this country-specific component of the error variance needs to be estimated. In the random-effects model, the country-specific error

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[1] `Please see a summary paper by Stern (1998) and studies by de Bruyn et al (1998) and Rothman (1998).

component is assumed to be uncorrelated with the other predictors in the model; whereas in the fixed-effect model the country-specific effects can be correlated with other predictors in the fixed-effect model. Thus, the fixed-effect model offers us with a more conservative way for model estimations. In addition, as the data are unbalanced, it could further add a new layer of difficulty in the random effects model (Greene 1993, p.634). Thus, the fixed-effect model is chosen. In using the fixed-effects model, assumption is made that parameters are homogeneous across years. Thus the model takes following form:

$$\ln I_{it} = a + b_1(\ln P_{it}) + b_2(\ln A_{it}) + b_3(\ln T_{it}) + c_i + t_t + e_{it} \qquad (3)$$

When time series data are used, the error terms could not be independent across time, and are an autoregressive process. To correct for serially correlated disturbances, adjustment is made for autocorrelation using maximum likelihood method (Greene 1993).

4. Sample Data

I am able to construct an unbalanced data set of 93 countries for the period 1975-1996, with a sample of 1999 observations[2]. The country list is in appendix 1. The data are unbalanced due to the fact that several countries lack information on GDP per capita and energy efficiency during the period of 1975-1979. These countries are Angola, Albania, Bulgaria, Bahrain, Ethiopia, Mozambique, Poland, and Vietnam. Oman does not have this information in 1996.

Among the 93 countries, 26 are low-income countries, 24 lower middle income countries, 14 upper middle income countries, and 29 high-income countries. The

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[2] I also estimated models with a balanced data, which included 84 countries spanning from 1975 to 1996, and yielded about the same findings. Findings are available upon request.

grouping of countries into four income levels is in line with the World Bank's classification (1997). The countries excluded are mostly the transitional economies where data on CO_2 emissions are only available since 1992. Nevertheless, the sample yields a good coverage of global emissions. The emissions from the sample data account for 92 percent of global emissions during period of 1975-1991 and 82 percent during period of 1992-1996. Data used in this study are all from the World Bank's statistical information management & analysis (SIMA) database (World Bank 2000b).

5. Variables

Yearly carbon dioxide emissions data are originally from Carbon Dioxide Information Analysis Center (World Bank 1997). It includes the emissions from industrial processes, stemming from the burning of fossil fuels and the manufacture of cement. In conformance with other studies (Holtz-Eakin and Selden 1995; IPCC 1992), I divide carbon dioxide emissions data by 3.664 to convert into carbon. The conversion ratio is an unit of carbon to 3.664 units of CO_2 emissions (Engleman 1998).

Affluence is captured by real GDP per capita in constant price (1995 U.S dollar). Energy efficiency of economic activities is captured by a ratio of real GDP in 1995 US dollar to commercial energy use. Thus, it measures the amount of GDP each unit of commercial energy use could produce. The higher the GDP per unit of commercial energy use, the more energy efficient of economic activity, and the less the environmental damage. The commercial energy use data were compiled by the World Bank, which used information from the International Energy Agency and United Nations' Energy Statistical Yearbook (World Bank 1997). All forms of commercial energy excluding firewood and other traditional fuels are converted into oil equivalents.

Yearly population figures are based on the estimation of national censuses. Pre-census and post-census estimates are the interpolations or projections made by the World Bank. For developing countries that lack recent census-based population data, yearly population figures are the estimates provided by national statistical offices or the United Nations Population Division (World Bank 1997). Other control variables such as trade as % of GDP and service as % of GDP are all from SIMA database of the World Bank. Table 1 gives the definitions of all variables.

6.1 Descriptive results

Figure 1 shows the global annual statistics on carbon dioxide emissions and emissions for a sample of 93 countries included in this study. There is an overall upward trend in global emissions during 1975-1996 period although there was a dip in the early 80's, which was due to the economic recession (Engleman 1994). For the sample of 93 countries, the emissions increased 80 percent during 1975-1996 period.

Figure 2 shows the annual CO_2 emissions by four income groups. Clearly in absolute terms, the high-income countries consume more than half of total emissions, and annual emissions still grew steadily over the last two decades. However, it is also noticed that emissions grew more rapidly in low-income countries, and the total emissions increased 205 percent during 1975-1996 period, the fastest in terms of percentage increase. It is followed by upper middle income countries, which grew 105 percent during the same period.

The diverging growths in emissions across four income groups have changed their shares in global emissions. Figure 3 shows the relative share contributed by each of four-income groups in total emissions over last two decades. Clearly the share contributed by the high-income countries is declining, while the share contributed by low-income countries is increasing. In 1975 the share of emissions contributed by low-income countries was only 13.4 percent, but by 1996 its share increased to 25.3 percent. In contrast, the share contributed by high-income countries declined from 69.7 percent in 1975 to 54.9 percent in 1996. The shares of upper middle and lower middle groups edged up slightly, only 2% and 1% respectively during this period.

Figure 4 and 5 present the changes of affluence and population by four income groups during the 1975-1996 period. Figure 4 shows that there is substantial growth in GDP per capita in high income countries, with 50 percent increase in average during this period, while the growth in upper middle and lower middle are moderate, with 18 percent and 30 percent increase respectively. However, the growth rates in GDP per capita in low-income countries are quite flat.

In contrast, population growth has been more pronounced in developing countries than developed countries. In Figure 5, the annual population size for four-income groups is shown. The growth is more pronounced in low, lower middle and upper middle income countries than in high-income countries. For each o f these three income groups, population increased 50 percent during this period, while for high-income group, the growth is only 16 percent.

These descriptive analyses tend to suggest that the substantial increase in emissions could correlate for the last two decades with population growth as well as with growth in affluence although correlation could be different across four income groups. The zero-order correlation of variables in Table 2 tentatively supports this assertion: both population (r=0.51) and GDP per capita (r=0.21) are positively correlated with carbon dioxide emissions. In next section, we further examine their complex relationships in the following regression models.

6.2 Regression Results

The role of population on emissions

Column 1 of Table 3 is the baseline model, with GDP per capita, population, and energy efficiency as the predictors, and total emissions as the dependent variable. Both the dependent variable and predictors are all in natural logarithm form. The model provides a good fit, with Akaike's information criterion statistic (AIC) equals –1118 relative to 1881 degree of freedom. The Durbin-watson (DW) statistic is in the neighborhood of 2, suggesting an absence of serial correlation of error terms (Greene 1993). A positive association between population growth and emissions is confirmed; a one-percent increase in population raised the CO_2 emissions by 1.28 percent. In addition, a positive relationship between affluence and emissions is also confirmed; a one-percentage increase in GDP per capita increased the CO_2 emissions by 1 percent. In contrast, an increase in energy efficiency could lead to a reduction of emissions: a one-percent increase in energy efficiency reduced the emissions by 0.22 percent. The first-order autocorrelation coefficient (AR1) is represented by rho.[3]

The role of affluence on emissions

Recent studies have suggested an inverted U-shaped relationship between affluence and emissions, known as the "Environmental Kuznets Curve" where the emissions initially worsen but ultimately improve with income (de Bruyn et al 1998; Hettige et al 1998; Rothman 1998; Stern 1998). To see if there is an inverse-U shape relationship between affluence and emissions, specification 2 adds the squared term of GDP per capita to specification 1. The positive coefficient for GDP per capita variable suggests that estimated emissions initially rise with per capita GDP, and it eventually falls (as the quadratic term is negative). However, the estimated turning point occurs at a very high out-of-sample income level. In other words, within the sample data only a monotonically upward trend in emissions with increasing income levels is discovered.

To check the robustness of out-of-sample income turning point, I present another specification in the column 3 where the emissions per capita are used as a dependent variable instead of the total emissions. This specification is similar to the log-linear specification that Holtz-Eakin and Selden (1995) have used in estimating the presence of "Environmental Kuznets Curve". Model using emissions per capita as dependent

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[3] To present evidences of appropriateness in using a model adjusting for autocorrelation, the first column of Apprendix 2 shows the results of OLS estimation. The Durbin-watson (DW) statistic is below 1, indicating a presence of serial correlation. In column 2, the adjustment for first-order autocorrelation is made using the maximum likelihood method. The DW statistic now in the neighborhood of 2, indicating an absence of serial correlation. The model using maximum likelihood method to adjust for autocorrelation has significantly improved upon OLS estimation, as indicated by a sharp decrease in AIC statistic (-249 vs. –1118). The OLS model appears to overestimate the population effect (coefficient=1.64), as compared with one with adjustment for first-order autocorrelation which has a population coefficient of 1.28. Column 3 and 4 further display the statistic for adjusting for higher orders autocorrelation. The T ratios suggest that models with adjustments made for both second and third order autocorrelations are not significant at $P<0.05$ level. Thus we choose the model only adjusting for first-order autocorrelation.

variable also generates an out-of-sample income turning point at 0.58 million US dollars (1995 constant price), although it is far less than the turning point at US$8 million generated by the Holtz-Eakin and Selden's study. This confirms that substantial economic growth would be required before CO_2 emissions began to decline, and the relationship between emissions and economic development is truly a linear one.

To further examine the relationship between population growth and emissions, I further introduce two more control variables, trade as percentage of GDP and service industry as percentage of GDP (column 4). The variation of emissions across the countries could be affected by fuel import and export. Of course it is better to use fuel import and export figures in the equation, but I would lose a lot of countries in the sample. Thus trade as percentage of GDP is used as a proxy to capture the possible linkage. The variation of emissions across countries could also be affected by the structural changes in the economy. The GDP per capital variable probably could not fully capture the variation in structural changes, and thus I further introduce a variable, service industry as a percentage of GDP. Model 4 further confirms a positive and significant association between changes in population and changes in emissions. Specifically, one percent increase in population raised the emissions by 1.21 percent, which is slightly lower that that of baseline model. Thus, the impact of population growth on emissions is found to be robust.

In addition, it is interesting to notice that when these two structural variables are controlled, the impact of energy efficiency on emissions is more pronounced. A one percentage increase in energy efficiency could reduce the emissions by almost a half a percentage point. Finally, the impact of trade and service variables are all in the right sign: the trade variable is positively associated with emissions, while the service variable is negatively associated with emissions.

The impact of population varies with the levels of affluence

To test the hypothesis that population pressure has exhibited different impacts on emissions across countries with different levels of affluence, I create an interaction term, which is shown in column 5 of Table 3. This model is hierarchical to the baseline model (column 1), and these two models are nested. The model fits the data well, which is indicated by a further significant reduction of AIC statistic as compared with that of baseline model (-1187 verse -1118), relative to the change of one degree of freedom. The negative coefficient for the interaction term suggests that the marginal effect of population on emissions diminishes as income level goes up. For example, for a country with GDP per capita at the level of $1,000, a one percent increase in population raises the emissions by 1.34 percent (1.66+6.908*-0.047). While for a country with GDP per capita at the level of $16,000, a one percent growth in population increases the emissions by 1.21 percent (1.66 +9.68*-0.047). In other word, the impact of population on emissions has been more pronounced in lower income countries than in higher income countries.

To see more clearly, I split the sample of countries into four income groups, low-income countries, lower middle income countries, upper middle income countries, and high-income countries. The results are shown in column 1 through 4 in Table 4. Findings confirm that the impact of population pressure on emissions has exhibited differently among different levels of affluence. In low-income countries, for example, a one- percent increase in population raised the emissions by 1.85 percent. And in the lower middle income countries, a one percent increase in population raised emissions by 1.66 percent, while in high income countries, a one percent increase in population raised the emissions by only half a percent.

The other appealing finding is the differentiating effects of energy efficiency on emissions in countries of various affluence levels. The role of energy efficiency on emissions has been the greatest in the low-income countries. A one percent increase in energy efficiency could decrease the emissions by almost a one percent, which is in sharp contrast to the lower middle income countries where a one percent increase in energy efficiency decrease the emissions by only about half a percent. For upper middle and high-income countries, energy efficiency could only reduce the emissions by a little over 0.20 percent. Furthermore, affluence has exercised the greatest impact on emissions in low-income countries; a one-percent growth in GDP per capita could bring about a 1.55 percent increase in emissions. It is the least in upper middle income countries where a one-percent growth in real GDP per capita increases the emissions by 0.66 percent.

7. Beyond Kyoto

Table 5 presents a set of global CO_2 emissions projections for 2000-2025 under three scenarios of population growth undertaken by the United Nations: low-variant, medium-variant, and high-variant (United Nations 1998). The projections also make an assumption of 1.9 % annual growth rate of real GDP per capita (World Bank 2000a). Under the medium-variant growth scenario, CO_2 emissions will reach 13.72 GtC in 2025.

It is a 129 percent increase over the level of 1990.[4] Table 5, which is also shown in figure 6, further gives the upper and lower bounds of future emissions under the high and low variant population projections. Under the high-variant population growth scenario and 1.9 percent annual growth in GDP per capita, the global CO^2 emissions could reach 14.53 GtC, which represents a 142 percent increase over 1990 level. However, under the low-variant scenario, the global emissions will reach only 12.92 GtC, a 115 percent increase over the level of 1990. In contrast, the last row of Table 5 makes another projection which does not take into account the impact of future population growth. It shows that emissions will reach only 9.99 GtC in 2025. In other words, out of a total of 7.72 GtC increase in emissions during 1990-2025 period, net impact due to future population growth (UN population medium growth variant) will be 3.73 GtC, which is 48.3% of total increase in future emissions. Thus, population factor will account for roughly half of the total gains in future emissions.

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[4] This result is close to the one estimated by Schmalensee et al (1998). Their 8-segment model projects the emissions in 2025 to be about 120-125 percentage higher than that of the 1990 level. To further compare the results with other projections, I further present both global emissions projection made by IPCC (1992) and this study, along with assumptions in Appendix 3. The IPCC's moderate-growth scenario A and high-growth scenario E make about the same assumptions on future population growth (1.35%), which is about the same as ours with the medium-variant scenario. However, the scenario A makes a lower annual GDP per capita growth rate assumption (1.51%) than that used in this study (1.9%), and the scenario E makes a higher annual GDP per capita growth rate assumption (2.2 %) than that used in this study. Our projection on carbon emissions in 2025 (13.720 GtC with no assumptions on the growth of energy efficiency) reasonably falls between IPCC's moderate-growth scenario A and high-growth scenarios E, which project 12.2 CO2 GtC and 15.1 CO2 GtC in 2025 respectively. Thus, our projection is also quite compatible with IPCC's .

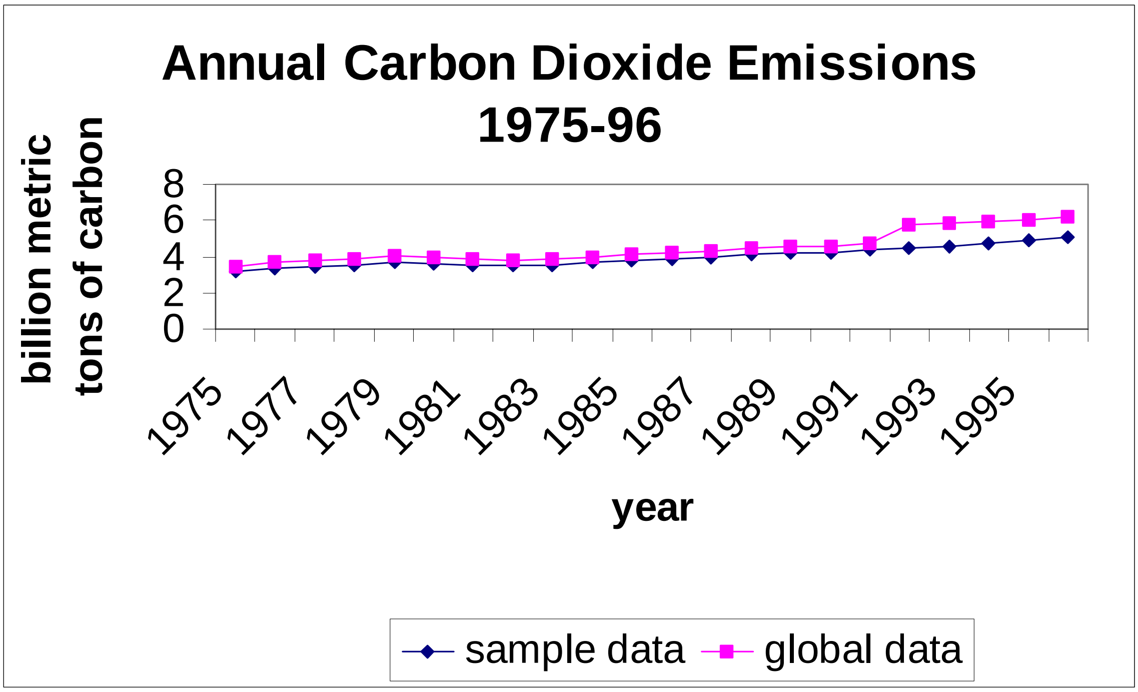
8. Conclusion

The rapid increase of carbon dioxide emissions has caused many concerns among policy makers. In discussing ways to curb CO_2 emissions, most attention has thus far focused on the role of affluence on carbon dioxide emissions. The role of population growth on emissions has been largely neglected. This paper takes a step toward assessing the impact of population growth on emissions.

The major findings of this paper lend support to the assertion that population growth was one of the major driving forces behind increasing carbon dioxide emissions worldwide over the last two decades. It is particularly true in developing countries where the impact of population on emissions has been more pronounced. On average, it is found that a 1% increase in population is associated with a 1.28% increase in carbon dioxide emissions. With such magnitude, global emissions are likely to grow substantially over the next decades. Thus, the international negotiation and cooperation on curbing the rapid growth of carbon dioxide emissions should take into consideration the dynamics of future population growth. Policy-makers should seek a shift from the current medium-variant population growth path to a more desirable low-variant population path. It is particularly true for low income countries where the population impact on emission is the greatest. This shift should include ways to improve girls' education. Studies suggest that increasing girls' education has led to a smaller family size by raising the age at onset of childbearing, and by utilizing voluntary family planning programs available to them so as to achieve their reproductive preferences (Bongarrts 1994; Bongaarts et al 1997).

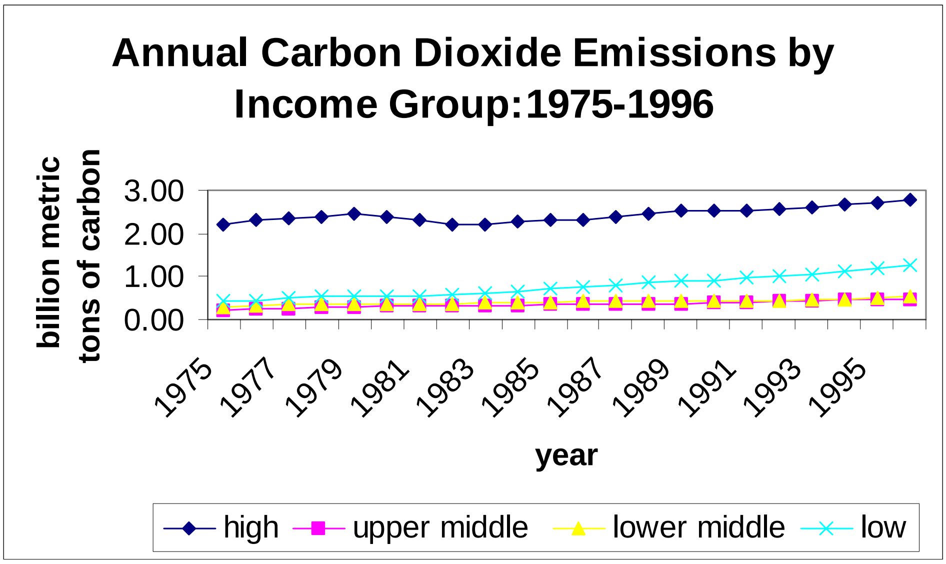
The reduction of global emissions will become a more challenging task as most developing countries will be experiencing rapid economic growth in the next decades. Rising income levels, as revealed in this study, are associated with a monotonically upward trend in emissions. Thus, another potential policy intervention on the reduction of emissions could also be in the area of increasing the energy efficiency of economic production both in developed and developing countries. As revealed in this study, an increase in energy efficiency is associated with lower emissions; it is particularly true in developing countries where the increase in energy efficiency is associated with a greater reduction of emissions. Without these policy considerations on future population growth and on the role of energy efficiency, economic growth alone could be leading to a further worsening of global carbon dioxide emissions.

Figure.1 Global Annual Carbon Dioxide Emissions: 1975-1996



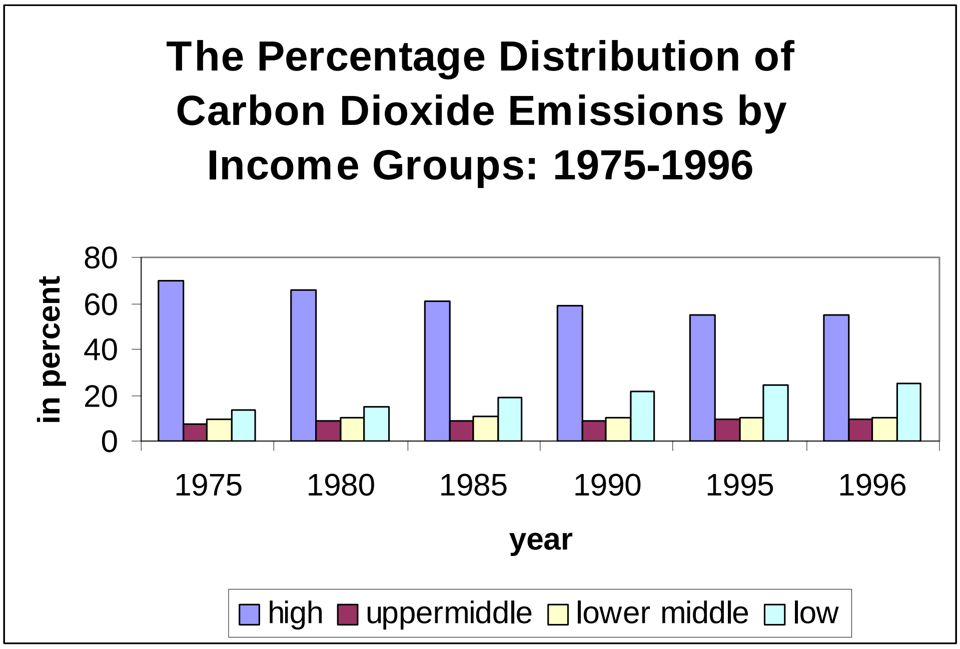
Note: Calculations on sample data are based on 93 countries. Calculations on global data are based on 174 countries for the period of 1975-1991, and on 193 countries for the period of 1992-1996.
Sources: World Bank SIMA databases 2000b.

Figure 2. Global Annual Carbon Dioxide Emissions by Income Group: 1975-1996



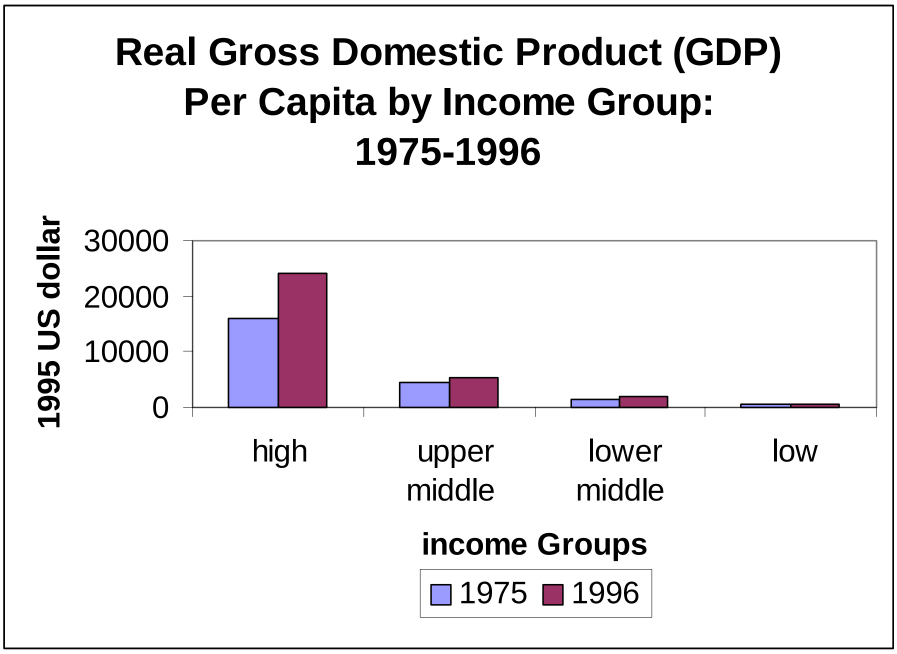
Sources: World Bank SIMA databases 2000b.

Figure 3. The Percentage Change in Carbon Dioxide Emissions by Countries of Four Income Groups:1975-1996



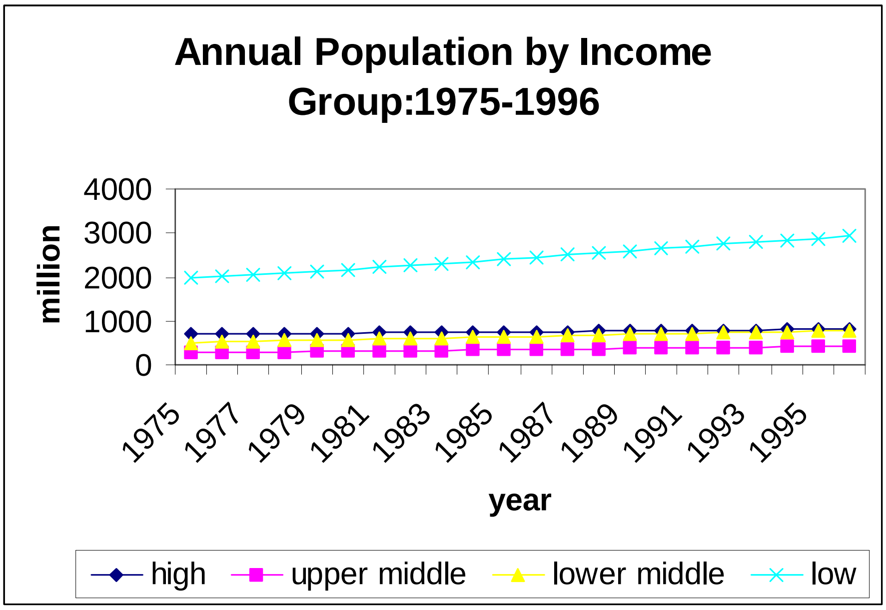
Note: Calculations on carbon dioxide emission are based on a sample of 93 countries.
Sources: World Bank SIMA databases 2000b.

Figure 4. The Growth of Affluence by Income Group: 1975-1996



Sources: World Bank SIMA databases 2000b.

Figure 5. Annual Population Growth by Income Group: 1975-1996



Source: World Bank SIMA databases 2000b.

Table 1. The Definition and Measurement of Variables Used in the Study: 1975-1996

Variable	Definition	measurement
Carbon dioxide emissions	emissions from industrial processes stemming from the burning of fossil fuels and the manufacture of cement.	metric ton
GDP per capita	constant 1995 US dollar	dollar
Population size	total population	number
Energy efficiency	the amount of real GDP (at 1995 US dollar) per kilogram of oil equivalent of commercial energy use produces	dollar
Trade (as % of GDP)	trade is the sum of export and imports of goods and services	percentage
Service (as % of GDP)	services refer to economic output of intangible commodities that may be produced, transferred and consumed	percentage
Total sample size	1999	
Number of countries	93	

Table 2 Correlation of Variables Used in the Study: 1975-1996

Variable	(1)	(2)	(3)	mean	std. dev	min	max
(1)				42.72	148	0.01	1,447
(2)	0.21 (0.001)			7,630	9,861	84.72	45,951
(3)	0.51 (0.001)	-0.10 (0.001)		45.01	138	0.16	1,215
(4)	0.02 (0.296)	0.71 (0.001)	-0.14 (0.001)	3.05	2.53	0.200	25.67

P values are in the parentheses
(1) CO_2 emissions in 1,000,000.
(2) GDP per capita.
(3) Population in 1,000,000.
(4) Energy efficiency.

Table 3. Unstandardized Coefficients from the Fixed-Effects Regression of the CO_2 Emissions: the Roles of Population, Affluence, and Energy Efficiency: 1975-1996

Variable	1	2	3	4	5
(absolute t values in parentheses)					
Dependent variable	**Total emissions**	**Total emissions**	**Emissions per capita**	**Total emissions**	**Total emissions**
Intercept	-11.78*** (5.85)	-11.84*** (5.93)	-0.928*** (6.58)	-10.76*** (4.90)	-19.96*** (5.98)
GDP per capita	1.00*** (17.83)	1.66**** (7.07)	1.71*** (11.79)	1.06*** (18.36)	1.69*** (5.45)
GDP per capita2	--	-0.04** (2.90)	-0.064** (7.03)	--	--
Population	1.28*** (10.73)	1.13*** (8.73)	--	1.21*** (9.25)	1.66*** (8.55)
Energy efficiency	-0.22*** (4.90)	-0.22*** (5.12)	--	-0.46*** (7.74)	-0.25 (5.12)
Trade (% of GDP)	--	--	--	0.08** (2.36)	--
Service (% of GDP)	--	--	--	-0.19*** (3.24)	--
<u>Interaction term</u>					
Population and GDP pc	--	--	--	--	-0.047** (2.52)
Rho	-0.69*** (37.86)	-0.68*** (37.40)	--	-0.61*** (29.59)	-0.67*** (35.55)
Income turning point (in 1995 US dollar)	--	out-of-sample	out-of-sample	--	--
<u>fitness statistics</u>					
Durbin-Watson	2.17	2.16	--	2.15	2.17
AIC	-1118	-1125	--	-929	-1187
Degree of freedom	1881	1880	--	1650	1880
Adjusted R square			0.979		
Number of countries	93	93	93	90[a]	93

All models include country and year fixed effects, and all variables are in Ln forms.

The error terms are adjusted for first-order autocorrelation, except model 3, using maximum likelihood methods. The autocorrelation coefficients (AR1) are represented by rho.

a. Bahrain, Israel, and Switzerland are excluded because of missing data on trade and service variables.

***P<0.01

**P<0.05

*P<0.10

Table 4. Unstandardized Regression Coefficients from the Fixed-Effects Regression of the CO_2 Emissions: the Role of Population, Affluence, and Energy Efficiency for Low, Low Middle, Upper Middle, and High Income Countries:1975-1996

Variable	low income countries	low middle income countries	upper middle income countries	high income countries
	(absolute t values in parentheses)			
Intercept	-24.47**	-20.52***	-4.13	-3.20
	(2.34)	(5.73)	(0.79)	(0.82)
GDP per capita	1.55***	1.16***	0.66***	1.07***
	(9.21)	(16.80)	(5.94)	(9.77)
Population	1.85***	1.66***	0.96***	0.64***
	(2.81)	(7.96)	(3.08)	(2.97)
Energy efficiency	-0.93***	-0.55***	-0.25***	-0.21***
	(4.71)	(8.60)	(3.17)	(5.24)
Rho	-0.49***	-0.72***	-0.92***	-0.95***
	(12.00)	(20.82)	(34.60)	(68.34)
fitness statistics				
Durbin-Watson	2.13	2.164	1.89	1.84
AIC	213	-944	-488	-1005
Degree of freedom	490	469	263	584
Number of countries	26	24	14	29

All models include country and year fixed effects, and all variables are in ln forms.

The error terms are adjusted for first-order autocorrelation, using maximum likelihood methods. Its coefficients (AR1) are represented by rho**.**

***P<0.01

**P<0.05

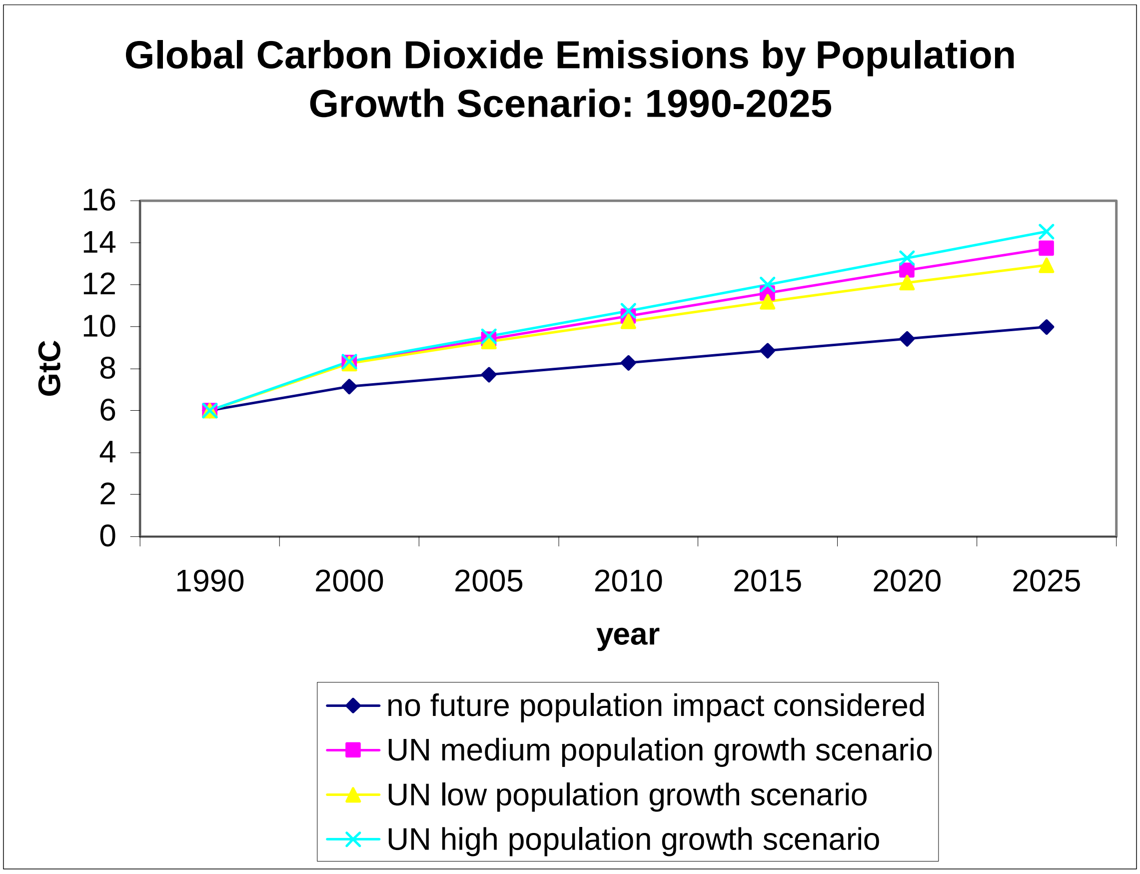
*P<0.10

Table 5. Global Carbon Dioxide Emissions by Low-Medium-High Variants Population Growth Scenario:2000-2025

projection	Year 2000	2005	2010	2015	2020	2025
Medium-variant pop growth (billion)	6.055	6.429	6.795	7.154	7.502	7.824
CO_2 emissions (Gigatons)	8.290	9.405	10.509	11.603	12.680	13.720
Low-variant pop growth (billion)	6.028	6.343	6.621	6.872	7.095	7.275
CO_2 emissions (Gigatons)	8.251	9.280	10.255	11.191	12.087	12.919
High-variant pop growth (billion)	6.082	6.516	6.966	7.430	7.903	8.379
CO_2 emissions (Gigatons)	8.329	9.532	10.758	12.005	13.265	14.529
No population impact taken into consideration CO_2 emissions (Gigatons)	7.14	7.71	8.28	8.85	9.42	9.99

Note: This projection uses 1990 as the base year. The total population in 1990 were 5.266 billions, which are taken from United Nations (1998). The total emissions in 1990 were 6 GtC, which are taken from the IPCC (1992). Population projections for 2000-2025 are taken from population projections of United Nations (1998). The assumption is made on GDP per capita growth of 1.9 percent per year (World Bank 2000a).

Figure 6. Global Carbon Dioxide Emissions Using Three UN Population Projections: 1990-2025.



Sources: See table 5.

Appendix 1 List of 93 countries in the sample:1975-1996

low income country (26)
ALBANIA, ANGOLA, BENIN, BANGLADESH, COTE D'IVOIRE, CAMEROON, CHINA, CONGO, ETHIOPIA, GHAN, HONDURAS, HAITI, INDIA, KENYA, MOZAMBIQUE, NIGERIA, NICARAGUA, NEPAL, PAKISTAN, SRI LANKA, SUDAN, SENEGAL, VIETNAM, ZAIRE, ZAMBIA, ZIMBABWE.

Low middle income country (24)
ALGERIA, BULGARIA, BOLIVIA, COLOBIA, COSTA RICA, DOMINICAN REPUBLIC, ECUADOR, EGYPT, GUATEMALA, INDONESIA, IRAN, JAMAICA, MOROCCO, PANAMA, PERU, PHILIPPINES, POLAND, PARAGUAY, ROMANIA, EL SALVADOR, SYRIAN ARAB REPUBLIC, THAILAND, TUNISIA, TURKEY,

Upper middle income country (14)
ARGENTINA, BAHRAIN, BRAZIL, CHILE, GABON, HUNGARY, SOUTH AFRICA, VENEZUELA, MEXICO, MALAYSIA, OMAN, SAUDI ARABIA, TRINIDAD AND TOBAGO, URUGUAY,

High income country (29)
UNITED ARAB EMIRATES, AUSTRALIA, AUSTRIA, BELGIUM, BRUNEI, CANADA, SWITZERLAND, DENMARK, SPAIN, FINLAND, FRANCE, UNITED KINGDOM, GREECE, IRELAND,
ICELAND, ISREAL, ITALY, JAPAN, LUXEMBOURG, KOREA, NETHERLANDS,
NORWAY, NEW ZEALAND, PORTUGAL, SINGAPORE, SWEDEN, UNITED STATES, SYPRUS, HONGKONG

Appendix 2. The Fixed-Effects Regression of the CO_2 Emissions on Population, Affluence, and Energy Efficiency: 1975-1996

		Adjusting for autocorrelations[a]		
Statistics	OLS	AR(1)	AR(2)	AR(3)
DW	0.90	2.17	2.16	2.21
AIC	-249	-1118	-1116	-1144
df	1882	1881	1880	1879
<u>absolute T value</u>				
AR(1)		28.08	22.08	22.13
AR(2)			2.82ne	3.14[ne]
AR(3)				1.37[ne]
Population coefficient[b]	1.64	1.28	1.28	1.28

All models include country and year fixed effects. The dependent variable is the total emissions, and the predictors are population, GDP per capita, and energy efficiency of economic production. All variables are in Ln form.

a. The maximum likelihood methods are used.

b. The other two variables' coefficients are not shown, which are the GDP per capita, and energy efficiency of economic production.

ne. Not significant at P<0.05 level.

Appendix 3. Summary of Global CO_2 Emissions Projections for Year 2025 by IPCC and by this Study

Average annual growth rate assumption	IPCC scenario[1]					our projections with		
	A	C	D	E	F	medium pop. variant	low pop. variant	high pop. variant
Annual population growth (%)	1.35	1.05	1.05	1.35	1.68	1.388	1.090	1.689
Annual GDP pc growth(%)	1.51	0.85	1.66	2.20	1.31	1.9	1.9	1.9
						with no assumption on energy efficiency growth		
Co2 (GtC)	12.2	8.8	9.3	15.1	14.4	13.720	12.919	14.529
						with 1 percent annual growth on energy efficiency		
						13.258	12.457	14.067

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1. IPCC (1992).

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