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The role of population growth in global warming

by

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1. Introduction

The ultimate objective of the Framework Convention on Climate Change (FCCC) signed in Rio in June 1992 is the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.' (Article 2 of the Convention).

The Framework Convention on Climate Change (FCCC) also states in its Article 3: 'The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities.'

This principle of differentiated responsibilities raises the question of the role of population growth in global warming since population and environmental impacts are often linked. This paper reviews the main theories doing so, and the different ways of quantifying the responsibilities, and it ends with a set of scenarios, a tool common to demographers and climatologists to assess the role of one factor. But before these sections, a brief introduction to the global warming issue is given, as this topic is rather new for demographers.

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2. The global warming issue

The climatic system (atmosphere, oceans, glaciers, continents surface and biosphere) receives its energy from the sun and re-emits infrared radiation towards space. The atmosphere chemical composition influences the way these radiation fluxes are absorbed by the atmosphere. If the atmosphere becomes less transparent to exiting infrared radiation, more heat accumulates in the system, and the climate warms in a way similar to a greenhouse. Certain gases, called 'greenhouse gases' have this property of being less transparent to infrared radiation than to incoming solar energy. Fortunately, some greenhouse effect does exist in our atmosphere, because otherwise, the earth surface average global temperature would be close to -18°C instead of the present 15°C, and life would probably be very different. Therefore, the problem we are dealing with is not the existing greenhouse effect, but its *intensification* by human-related greenhouse gas emissions. The greenhouse gas emissions due to human activities are likely to warm the earth's climate significantly, and to affect the habitability of the planet. This section presents this climatic background and reviews the following topics: climate changes forecasts; impacts on various sectors of developing and developed countries; key characteristics of the main greenhouse gases.

Given the importance of the potential effects of these changes, the United Nations have created in 1988 the 'Intergovernmental Panel on Climate Change'. The IPCC was charged with assessing the scientific information that is related to the various components of the climate change issue and formulating realistic response strategies for its management (Houghton et al., 1990). The high degree of consensus amongst authors and reviewers makes the report an authoritative statement of the views of the international scientific community. The IPCC published an update to its first report in June 1992 (Houghton et al., 1992). The main conclusions of these reports are summarized below.

2.1. Climatic change

The IPCC is certain of the following (Houghton et al., 1990, 1992):

- There is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be.
- Emissions resulting from human activities substantially increase the atmospheric concentrations of the greenhouse gases: carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs) and nitrous oxide (N_2O). These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface.

The IPCC calculates with confidence that:

- Some gases are potentially more effective than others at changing climate, and their relative effectiveness can be estimated. Carbon dioxide has been responsible for over half the enhanced greenhouse effect in the past.
- Atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and CFCs) adjust only slowly to changes in emissions. Continued emissions of these

gases at present rates would commit us to increased concentrations for centuries ahead.[3]

- The long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's levels; methane would require a 15-20% reduction.

Based on current model results, the IPCC predicts:

- Under the IPCC Business-as-Usual scenario for emissions of greenhouse gases, the rate of increase of global mean temperature during the next century will be about 0.3 °C per decade (with an uncertainty range of 0.2 to 0.5 °C per decade); this is more than ever seen over the past 10 000 years. This will result in a likely increase in global mean temperature of about 3 °C before the end of the next century.[4]
- The land surfaces will warm more rapidly than the ocean, and high northern latitudes warm more than the global mean in winter.
- Regional climate changes will be different from the global average change, although the confidence in the prediction of the detail of regional changes is low.
- Under the IPCC Business-as-Usual emissions scenario, there will be a global mean sea level rise of about 6 cm per decade over the next century (with an uncertainty range of 3-10 cm per decade), mainly due to thermal expansion of the oceans and the melting of some land ice. The predicted mean rise is about 65 cm by the end of the next century.

The IPCC judgement is that:

- Global mean surface air temperature has increased by 0.3 °C to 0.6 °C over the last 100 years. Global mean temperatures were anomalously high in the 1980s, and 1990 and 1991 were the warmest years on record.
- The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability; alternatively, this variability and other human factors could have offset a still larger human-induced greenhouse warming. A significant new finding is that the cooling effect of particles resulting from fossil fuel emissions may have offset a significant part of the greenhouse warming during the past several decades. The unequivocal detection of the enhanced greenhouse effect from observations is not likely before a decade or more.
- Ecosystems affect climate, and will be affected by a changing climate and by increasing carbon dioxide concentrations. Rapid changes in climate will change the

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[3] The reason for this phenomenon is the long atmospheric residence time of these gases (see Table 1 below). An analogy can be made with population dynamics: changes in fertility do not affect immediately the population size. Indeed, the atmospheric concentration of greenhouse gases may be seen as a population, the 'births' being the emissions, the 'deaths' being their removal (e.g., for CO_2, by absorption in oceans or trees) or their chemical transformation (e.g., for methane, by oxidation into CO_2).

[4] This warming of 3°C should be compared to the change in global temperature between the peak of the last glaciation, 20 000 years ago, and the pre-industrial period: reconstructions by geological methods have shown that global climate was then colder by 3 to 5°C. This apparently small temperature change was sufficient to produce large ecological disturbances, including 2 km thick ice-sheets which covered most of North America and Europe.

composition of ecosystems; some species will benefit while others will be unable to migrate or adapt fast enough and may become extinct.

2.2. Impacts on developed and developing countries

Estimates of the physical and biological effects of climate change are difficult to make because confidence in regional estimates of critical climatic factors is low. This is particularly true of precipitation and soil moisture. Despite the above uncertainties, the IPCC published also an assessment of climate change impacts (Tegart et al., 1990). Their main conclusions are summarized below, and they show that global warming may have serious consequences for both more developed countries (MDC) and less developed countries (LDC).

Hydrology and water resources
Here, the IPCC concludes that 'relatively small climate changes can cause large water resource problems in many areas, especially in arid and semi-arid regions and those humid areas where demand or scarcity has led to water scarcity. Little is known about regional details of greenhouse gas-induced hydrometeorological change. Many areas will have increased precipitation, soil moisture and water storage [...] [while] water availability will decrease in other areas, a most important factor for already marginal situations, such as the Sahelian zone in Africa. Change in the drought risk represents potentially the most serious impact of climate change on agriculture at both regional and global levels.'

Agriculture and forestry
The IPCC concluded that there is sufficient evidence from a variety of different studies 'to indicate that changes of climate would have an important effect on agriculture and livestock. [...] There may be severe effects in some regions, particularly decline in production in regions of high present-day vulnerability. These include Brazil, Peru, the Sahel region, Southeast Asia, the Asian region of [former] USSR and China. There is a possibility that potential productivity of high and mid latitudes may increase because of a prolonged growing season, but it is not likely to open up large new areas for production and it will be mainly confined to the Northern Hemisphere. Patterns of agricultural trade could be altered by decreased cereal production in some of the current high-production areas, such as Western Europe, southern US, part of South America and western Australia. On the other hand, cereal production could increase in Northern Europe.' The IPCC concludes that 'on balance, [...] food production at the global level can be maintained at essentially the same level as would have occurred without climate change; however the cost of achieving this is unclear'. The IPCC adds that 'Nonetheless, climate change may intensify difficulties in coping with rapid population growth.'

The rotation period of forests is long and current forests will mature and decline in a climate to which they are decreasingly suited. Large forest losses could occur. 'The most sensitive areas will be where species are close to their biological limits in terms of temperature and moisture. This is likely to be, for example, in semi-arid areas.'

Natural terrestrial ecosystems
Here, the IPCC concludes that 'projected changes in temperature and precipitation suggest that climatic zones could shift several hundred kilometres towards the poles

over the next fifty years. Flora and fauna would lag behind these climatic shifts, [...] and find themselves in a different climatic regime. These regimes may be more or less hospitable and, therefore, could increase productivity for some species and decrease that of others. [..] Increased incidence of disturbances such as pest outbreaks and fire are likely to occur in some areas [...]. The socioeconomic consequences of these impacts will be significant, especially for those regions of the globe where societies and related economies are dependent on natural terrestrial ecosystems for their welfare.'

Human settlements: energy, transport, and industrial sectors
'The most vulnerable settlements are those especially exposed to natural hazards, e.g. coastal or river flooding, severe droughts, landslides, severe windstorms, and tropical cyclones. The most vulnerable populations are in developing countries, in the lower income groups, residents of coastal lowlands and islands, populations in semi-arid grasslands, and the urban poor in squatter settlements, slums and shanty towns, especially in megacities. Major health impacts are possible, especially in large urban areas, owing to changes in availability of water and food and increased health problems due to heat stress and spreading of infections.'

'Global warming can be expected to affect the availability of water resources and biomass, both major resources of energy in many developing countries. In developed countries some of the greatest impacts on the energy, transport and industrial sectors may be determined by policy responses to climate change such as fuel regulations, emission fees or policies promoting greater use of mass transit. In developing countries, climate-related changes in the availability and price of production resources such as energy, water, food, and fibre may affect the competitive position of many industries.'

2.3. The greenhouse gases

Eventhough the dry atmosphere is primarily made of nitrogen (N_2), oxygen (O_2), and argon (Ar), which together constitute more than 99.9 % of its total mass, the climatic perturbations we are dealing with come from gases that represent the one per thousand remainder. The change in atmospheric concentration (i.e., proportion of the total atmospheric volume) of a given gas depends on the size of its sources (or total quantities emitted per year) and the size of its 'sinks' (or total quantities destroyed or absorbed per year). The concentration of a gas will only increase if the sources are larger than the sinks. A useful quantity is the 'residence time', or the average time that a gas molecule spends in the atmospheric 'reservoir' between entering and leaving it by migration or destruction. Table 1 shows past and present concentrations, and rates of increase of the main climatically-active gases resulting from human activities. Water vapour is excluded from this list eventhough it is causing about two thirds of the natural greenhouse effect, because the anthropic sources are negligible compared to the natural ones (climate models take into account the greenhouse effect of water vapour).

The IPCC has calculated that present CO_2 emissions contribute for more than 60 % to the total increase in the greenhouse effect over a 100 year period (Shine et al., 1990). So, it is important to know the CO_2 sources and sinks. CO_2 is released everytime fuel is burnt to obtain energy. For the same quantity of energy, coal is the most climatically-damaging fuel, before oil and gas, in that order. Land use change and deforestation also contributes to CO_2 emissions because vegetation releases CO_2 (which had been absorbed by the process of photosynthesis when growing) when it is burnt or left decaying. Cement production releases CO_2 through a chemical reaction, and this represents about 2% of total anthropogenic emissions. The main sinks which absorb CO_2 are the ocean, where it get dissolved, and the biosphere, which needs the carbon element to build organic matter. During the last decade, the fraction of CO_2 emissions that remained in the atmosphere is 46 ± 7%, the rest being absorbed by these sinks (Watson et al., 1992).

Table 1. Key characteristics of main anthropogenic climatically-active gases

Gas	Atmospheric concentration (pre-industrial)	Atmospheric concentration (present)	Net annual increase in atmosphere (%, million tonnes)	Residence time (years)
CO_2 (carbon dioxide)	280 ppmv	355 ppmv	0.5% (14000 Mt)	120 (50-200)
CH_4 (methane)	0.79 ppmv	1.72 ppmv	0.6% (32 Mt)	11
CFC11	0	0.26 ppbv	3% (0.3 Mt)	55
CFC12	0	0.45 ppbv	4% (0.4 Mt)	116
CFC113	0	0.06 ppbv	10% (0.2 Mt)	110
HCFC22	0	0.11 ppbv	5% (0.1 Mt)	16
N_2O (nitrous oxide)	0.29 ppmv	0.31 ppmv	0.2-0.3% (3.8 Mt)	132

Source of data: Houghton et al. (1990); Watson et al. (1990, 1992).

Note: 1ppmv = 1 part per million in volume = 0.0001%; 1ppbv = 1 part per billion in volume = 0.0000001%. The net annual increase in the atmosphere is the quantity of greenhouse gas that is added each year to the atmosphere. It is less than the emissions for gases such as CO_2 or CH_4 which are partially absorbed in sinks.

IPCC estimates the global fossil fuel emissions in 1989 and 1990 at 6.0 ± 0.5 GtC (Gigatonnes of carbon in the form of CO_2)[5] or 22 ± 1.8 $GtCO_2$ (Watson et al., 1992). The direct net flux of CO_2 from land-use changes (primarily deforestation) is estimated by the IPCC to be 1.6 ± 1.0 GtC/year (5.9 ± 3.7 $GtCO_2$/year), representing 10 to 30% of total anthropogenic emissions during the 1980s.

3. Linking population, climate, and environmental issues

Before the emergence of the discussion on the role of population growth in causing climate change there were very few studies on the links between climate and population. As noted by Glantz (1990), this theme has been looked at with suspicion by sociologists, especially since the study by Huntington, who in 1915, defended the idea that there is a 'natural' cleavage between the value that populations in the temperate climatic zones give to work and the one attributed in the tropics. Huntington's argument can be summarized as follows (Glantz, 1990): tropical climates lack the marked seasonal changes of the temperate zones that serve to stimulate the energies of populations. Inhabitants of the tropics, according to Huntington, have been dealt with an oppressive climate (hot and dry or hot and wet) and that was their fate.

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[5] Numbers given in tonnes of carbon in the form of CO_2 (tC) need to be multiplied by 3.7 to obtain numbers in tonnes of CO_2 (tCO_2). Many non-climatologists confuse the two ways of accounting emissions.

He contended that '[a] certain type of climate, now found mainly in Britain, France, and neighbouring parts of Europe, and in the Eastern United States is favourable to high level of civilization' (quoted in Glantz, 1990).

Most scientists judged this reasoning was racist, and the theme was not studied anymore. One should note that a 'Third World' version of this doctrine was presented by the Indian Bandyopadhyaya (1983). He defends the idea that if imperialism is the principal historic cause of underdevelopment in the South, tropical climate is the principal natural cause of this underdevelopment. He interprets the effort by rich countries to maintain climate stability and the international campaigns for environment protection as having for unique goal the preservation of the developed countries predominance and their climatic advantage. He concluded that a climate change (e.g., a global warming) could benefit Third World countries in the tropics and would reduce the development gap between North and South (Glantz, 1990).

Maybe this relatively weak scientific background to the links between climate and population explains why the new debate on the role of population growth in global warming was largely related to another discussion: the links between population and resources (mainly food) as this topic is studied since centuries.

Adequating population and food has been a concern for a long time shared by Confucius (551-479 B.C.) and Plato (427-437 B.C.), among others. Malthus, at the end of the 18th century, is probably the best known advocate of a limitation of population growth to match the limited means of subsistence. In his 'Essay', he recommended later marriage and chastity in marriage. During the 20th century, the relationships between population and resources have mainly been studied either by economists or by biologists. A good synthesis of these two different schools of thought (the economists and the biologists) is given by Keyfitz (1991), while Davis (1990) shows very well that concepts from biology, such as the carrying capacity, may not be imported as such in the study of human populations. Another review of theoretical and methodological issues is provided by Agrasot et al. (1991).

In 1972, the Club of Rome broadened the population-resources debate by including pollution along with land, food, industrialization, and non-renewable resources in a computer model of the world economy. The Club of Rome drew the public attention to natural resources depletion, to the effects of pollution, and to the limits of fossil fuel reserves (Meadows et al., 1972). The principal conclusions of their report, 'The Limits to Growth', was that if the trends in economic growth, pollution, and population were not stopped at some point, some kind of physical catastrophes would stop them (Ehrlich et al., 1977, p730).

Different interpretations of the links between population and environment are reviewed by the Overseas Development Administration of the United Kingdom Government (1992), which namely addresses the issue of family planning. They conclude: 'the more the scope for an induced reduction in population growth is seen to be real and significant -- for example by meeting an unmet demand for family planning -- the more this encourages the view that population is a direct causal factor which should be manipulated. On the other hand, the more the fertility decisions are seen to be a function of a complex of structural socio-economic factors, the less it can be seen as a simple lever to be used, and therefore the less population growth can be seen as an independent cause' (p. 10). [...] 'Indeed, there are risks attached in tying the rationale for family planning too closely to poorly understood relationship between population growth and environmental degradation. The links are too complex and uncertain, and risks of overemphasis too great, for environment to be highlighted as a major reinforcing rationale for family planning. In these circumstances it may be better to recognize that slowing population growth does not constitute a short-term solution to environmental degradation, and that working with the multiplicity of positive linkages between measures which benefit women and environmental management represent the constructive way forward.' (p. 21).

4..Quantifying the links between population and climate change

Quantifying the links between population and climate change is a way of assessing the role of population growth in global warming. Several attempts have been made: some are simpler, others are more elaborate.

4.1. Two simple ways

A first simple way starts from the geographical origin of the greenhouse gases. This has been done for example by Krause et al. (1989) and Warrick and Rahman (1992) for Third-World and non-Third-World CO_2 emissions from both fossil fuel consumption and land use change (deforestation). Cumulating CO_2 emissions since 1765, Warrick and Rahman show that the more developed countries are responsible for 84% of CO_2 emissions from fossil fuels, and for 78% from deforestation (see Figures 1 and 2). Taking into account the combined effect of all greenhouse gases, they also conclude that the developing world is responsible for 27% of the enhanced greenhouse effect.

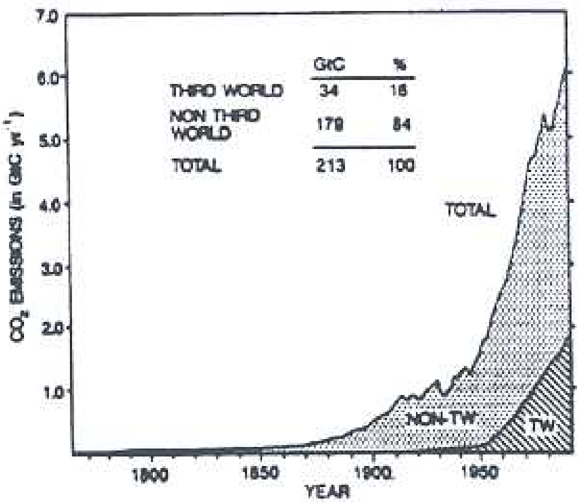
Figure 2 on deforestation clearly shows that the LDCs are doing since a few decades what MDCs did during the 19th century and the first half of this century.[6] But allotting the CO_2 emissions to the country where the emissions (or decrease in sink capacity) take place raises a problem if that country is not the one of final consumption. For example, tropical timber is exported to MDCs to produce paper, window frames, or chopsticks.

Another simple way of linking population and climate is to compute per capita CO_2 emissions. So did, e.g., Marland and Boden (1991), World Resources Institute (1992), and Green (1992). For example, Green (1992) gives the CO_2 emissions per capita from

[6] French demographer H. Le Bras (1992, p67) echoes this on an ethical ground: 'Forests losses are caused by populations who begin to occupy their space. We understand that the persons from the developed countries want to save for themselves the large tropical spaces, the virgin forests, and the wild animals herds. But it may be asked by which right the people who have killed their own bison, lynx, and Pyrenean bear, and who have burnt their primary forests during the past centuries, would forbid other people to kill their elephants, lions, and gorillas, and to burn their forests.'

fossil fuel burning (both commercial and residential), gas flaring, and cement manufacturing. These estimates do not include deforestation and use of traditional energy. Only countries with more than 1 million inhabitants in 1992 are considered. The five top countries are the United Arab Emirates (32.9 tCO_2/capita in 1989), USA (19.7), Canada (17.3), Kuwait (15.8), and Australia (15.5). Contrary to the Warrick and Rahman (1992) approach, these statistics do not provide an historical point of view as they usually focus on one year.

Figure 1. Comparison of fossil fuel-derived carbon dioxide emissions from Third World ('TW') and other ('non-TW') countries since 1765. On a cumulative basis, the non-TW countries have accounted for more than four-fifths of total emissions (from Warrick and Rahman, 1992).



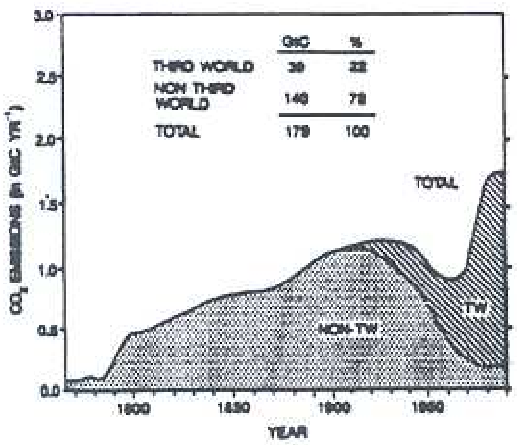


Figure 2. Comparison of carbon dioxide emissions from land use changes (deforestation) since 1765, as derived from an inverse carbon cycle model. Emissions are divided between Third World ('TW') and other ('non-TW') countries. On a cumulative basis, the total carbon emission from deforestation nearly matches that from fossil fuel burning. These results suggest that the non-TW countries have been responsible for about three-quarters of the cumulative deforestation-related carbon emissions (from Warrick and Rahman, 1992).

4.2. Other per capita indexes

Carbon dioxide is only one of the various greenhouse gases emitted by human activities, and an index has been used by the IPCC (Shine et al., 1990) to reduce the warming effect of a kg of each of these other greenhouse gases to that of a kg of CO_2. For each gas, this index, called the 'Greenhouse Warming Potential' (GWP) (explained below) can be multiplied by a country's emissions to obtain equivalent CO_2 emissions. The sum of these 'equivalent CO_2' emissions can be compared with total emissions of other countries, or divided by the population of that country to obtain per capita greenhouse emissions. It provides another measure, more elaborate than the CO_2 emissions per capita, to relate population and global warming.

Following Shine et al. (1990), who built their GWP concept on the work of Lashof and Ahuja (1990), the GWP of a particular gas is an index which takes into account both the average residence time of this gas in the atmosphere and the cumulative radiative effect over a specific time horizon of a given increase in the concentration of this gas. The GWP is usually expressed in relation to CO_2, which has a GWP equal to 1 by definition. The IPCC has computed the GWPs for a variety of trace gases over different time horizons.[7]

The World Resources Institute (1992) has multiplied the IPCC (Shine et al., 1990) GWPs by the 1989 countries' emissions of CO_2 due to fossil fuel burning and land use changes (including deforestation), methane, and CFCs to compute national ranks and percent shares of the global warming potential attributable to each country.[8] The five top countries are the USA (17.8% of world equivalent CO_2 emissions in 1989), former USSR (13.6%), China (9.1%), Japan (4.7%), and India (4.1%). Using the same data, the WRI also provides a measure of per capita equivalent CO_2 emissions. This measure is the ratio of a country's per capita emissions to the world median per capita figure, which is 2.96 tonnes of CO_2 heating equivalent per person for 1989 (WRI, 1992). The five top countries with more than one million inhabitants are the following: United Arab Emirates (14.5 times the world median), Côte d'Ivoire (9.8), USA (8.8), Australia (8.2), and Canada (7.8).

It should be remarked that both the method for computing GWPs and the data used by the WRI have been criticized by Agarwal and Narain (1991) as a basis for attributing responsibility for global warming. Besides fundamental criticisms on the method (see section 4.3), they cast doubt on the quality of data used for deforestation, which would give, according to Agarwal and Narain, an undue responsibility to developing countries such as Brazil or India.

Other criticisms of the methods based on the GWP have been made, e.g., by IPCC (Isaksen et al., 1992) and WRI (1992). The two following points may be mentioned in this respect. The first one is that the GWP of each gas is uncertain. There are two main reasons for this. First, the GWP of each gas depends very much on its residence time in the atmosphere, and this is known with a large uncertainty range, such as 50-200 years for CO_2. Secondly, the indirect effects (due to chemical reactions affecting the production or destruction of other greenhouse gases) are not well known.[9] The IPCC

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7 The GWP associated with the direct radiative effects over a 100-year horizon (without including the 'indirect' radiative effects due to the products of chemical transformation) are the following for 1 kg of each gas: CO_2: 1 (by definition), CH_4: 11, CFC11: 3400, CFC12: 7100, CFC113: 4500, HCFC22: 1600, N_2O: 270 (Watson et al., 1992).

8 The World Resources Institute also uses an index called the Greenhouse Forcing Contribution (GFC) that is roughly equivalent but not identical to the GWP used by IPCC; in particular, the IPCC method weights methane emissions slightly higher and CFC emissions lower than does the WRI method (WRI, 1992).

9 The values of "indirect" GWPs are not given in the latest IPCC report (Isaksen et al., 1992). The IPCC even warns against using the preliminary values published in their first report, and only provides the sign of the indirect components of GWPs (CO_2: none, CH_4: positive, CFCs and HCFCs: negative, N_2O: uncertain). However, it must be remarked that no indirect component

itself says: 'great care must be exercised in applying GWPs in the policy arena' (Isaksen et al., 1992); they should only be used as orders of magnitude.

The second point relates to the choice of the period over which the effect of a given gas is considered in the computation of the GWP, since this choice is arbitrary. The IPCC (Shine et al., 1990) uses 100 years in most computations, but also gives values of GWP over 20 and 500-year periods. A shorter period gives more weight on gases with short residence time (e.g., methane), while longer integration periods emphasizes the role of long-lived greenhouse gases such as carbon dioxide or CFCs.

Finally, it must also be noted that the quantities of gas emitted by each country are not well known, specially when taking into account non-fossil fuel emissions (e.g., deforestation, methane releases from livestock).

Indeed, there is no 'objective' way yet to measure a country contribution to global warming.

4.3. A Third World point of view: Agarwal and Narain

The method used by WRI was strongly criticized by two Indian scientists, Agarwal and Narain (1991), who said about the report: 'its main intention seems to be to blame developing countries for global warming and perpetuate the current global inequality in the use of the earth's environment and its resources.' (p. 1)

Besides criticisms about the data used by the WRI for deforestation rates or methane emissions from rice cultivation, they raise questions such as 'can we really equate the carbon dioxide contribution of gas guzzling automobiles in Europe and North America or, for that matter, anywhere in the Third World with the methane emissions of draught cattle and rice fields of subsistence farmers in West Bengal or Thailand?'. But Agarwal and Narain mostly question the way 'the earth's ability to clean up the two greenhouses gases of carbon dioxide and methane -- a global common of extreme importance -- has been unfairly allocated [by WRI] to different countries.'

Agarwal and Narain (1991) observe that the methodology used by WRI amounts to allocating the bigger share of the sink to the bigger polluters. They propose instead to allocate the natural sinks for CO_2 and methane to each nation on a population basis, and to calculate each country's excess emissions of each gas -- if any -- beyond what its share of the global sink can absorb. The net contribution of each country to global warming is then the amount by which its total greenhouse emissions exceeds its share of the sink. No permissible share is assumed to exist for CFCs, so that CFC emissions are added to the net emissions of CO_2 and methane. In addition, they suggest that unused permissible emissions of countries with low emissions may then be sold to high-level greenhouse gas polluters. The new ranking obtained on the basis of those net emissions increases significantly the share of industrialized countries in global

of GWP is given by IPCC for CO_2, and that the overall relative effect of present carbon dioxide emissions is not likely to be any smaller than the 61% over 100 years computed by the IPCC (Shine et al., 1990) in its first report.

warming responsibility, and removes China and India from the list of top ten net total emitters.

The key issue in Agarwal and Narain argumentation is the usage of a per capita 'right to pollute' based on the present size of the natural sinks, but these are not well known. Their method can also be criticized because the rate at which sinks can absorb anthropogenic emissions are to a large extent proportional to the emissions themselves, so that a larger polluter causes a larger sink to absorb its pollution.

4.4. The Ehrlich-Holdren equation

Another way of quantifying the links between environmental issues and population size is illustrated by the following equation, originally published by Ehrlich and Holdren (1971): $I = P\ F$, where I is a negative impact on the environment, P the population size, and F is a function which measures the per capita impact. That equation was subsequently rewritten as (Ehrlich and Ehrlich, 1990, p. 58): $I = P\ A\ T$, where I is a negative impact on the environment, P the population size, A stands for affluence or the per capita consumption, and T is 'an index of the environmental disruptiveness of the technologies that provide the goods consumed.' The last factor can also be viewed as the 'environmental impact per quantity of consumption' (Ehrlich and Ehrlich, 1990, p. 58). Although the I=PAT equation relates CO_2 emissions to three factors, population is often seen as the main one. It may be because population statistics are more readily available to climatologists and ecologists than data on comfort levels or economics, or because many MDCs writers believe that it is more important or easier to control LDCs population growth than consumption patterns in their own countries.

According to the Ehrlichs, 'The I=PAT equation is a key to understanding the role of population growth in the environmental crisis. It tells us why, for example, rich nations have such serious population problems (because the A and T multipliers for each person are so large). That is why it is so important that those nations begin shrinking the size of their population by lowering birthrates until they are below death rates. It also tells us why a little development in poor countries like China can have an enormous impact on the planet (because the P multiplier on the A and T factors are so large).'

'Note that the total impact of a society can be lowered by decreasing any of these three factors, as long as the others are not increased so as to offset the reduced factor. In the case of the attack on the ozone layer by chlorofluorocarbons (CFCs), the impact eventually could be made negligible by operating on the technology factor alone -- that is, by banning the use of the offending CFCs -- which might result in a slight decrease in affluence if substitutes were more expensive or less convenient. But the injection of the major greenhouse gases carbon dioxide (CO_2) and methane into the atmosphere, which threatens to change the climate and, among other things, wreck agricultural production, is not so easily corrected. The atmospheric concentrations of these gases are tightly tied to population size. Consequently, there is no practical way to achieve the necessary reduction in greenhouse emissions without population control' (Ehrlich and Ehrlich, 1990, p. 58-59).

However, this 'consequence' cannot be justified: statistical association does not necessarily mean a causation. Indeed, just because population and carbon dioxide emissions grew over the same period does not imply that there is any simple causal link between the two.

This logical error comes from the problem of aggregation. The I = PAT equation can certainly yield useful indications on the roots of environmental degradation, but only if applied to a specific homogeneous region or country. If it is applied to the world as a whole, average values will hide the deviations from the mean and the variations of the distributions. Since the fraction of the world population which grows at the fastest rate is also the one with the lowest per capita emissions, using average population growth rate and average per capita emissions will overestimate world emissions. Section 4.5 gives more details on this aggregation problem. But unfortunately, Ehrlichs' work contains many incorrect aggregations. Ehrlich and Ehrlich (1990, p. 17) claim for example: 'continued population growth and the drive for development in already badly overpopulated poor nations will make it *exceedingly* difficult to slow the greenhouse warming – and impossible to stop or to reverse it -- in this generation at least.' The United Nations Population Fund (UNFPA) echoes this fear and also aggregates the responsibilities of both the rich and poor countries when writing in the '1992 State of the World Population': 'long-term sustainability demands that ways are found to minimize human impacts on the environment and on such creeping dangers as climate change. One way will be to minimize additions to human numbers.' (UNFPA, 1992, p. 22). But the UNFPA publication does not report on the other ways...

Another faulty aggregation made by the Ehrlichs is again taken as granted and cited in full in a recent UNFPA-published book (UNFPA, 1991, p. 17): the Ehrlichs (1990, p. 59) say: 'to illustrate how this interaction [between reduction in greenhouse emissions and population control] works, suppose that, by dint of great effort, humanity managed to reduce the average per-capita consumption of resources on the planet (A in the I=PAT equation) by 5 percent and improved its technologies (T) so they did 5 percent less damage, on the average. This would reduce the total impact (I) of humanity by roughly 10 percent.' This calculation is meaningful only if one assumes the distribution of technology and per capita consumption to be uniformly distributed among every humans, which is not presently the case. But the Ehrlichs continue with: 'unless population growth (P) were restrained, however, its growth would bring the total impact back to the previous level in less than six years.' Since the main part of the population growth occurs in developing countries, it is incorrect to multiply this increasing population by a decreasing consumption and an improving technology that are both supposedly occurring in a developed country in this example. A similar faulty aggregation is made in 'Earth in the Balance', the book written by US Vice-President Gore (1992, p. 309-310).

A further problem is that the I=PAT equation is ignoring international trade by allotting the consumption to the country in which it takes place. Ideally, a country's CO_2 emission should take into account the total emissions associated 'from cradle to grave' with the goods consumed in that country. Pollutant emission can indeed take place at the time of production of a given good, when it is transported, consumed or used, or at the time of disposal. Inputs needed for the production of goods are themselves associated with pollution at different stages; this pollution must also be considered when evaluating the total emissions associated with a product. Different goods will have different patterns of emissions. For example, cars are relatively much more polluting through usage that through production, but it is the reverse for steel, one of its components. Steel production indeed releases much CO_2, so that a country which imports large quantities of steel will have a lower level of CO_2 emission than if it had produced this steel locally. A correction using the 'cradle to grave' concept in the Ehrlich-Holdren equation would not affect sectors such as domestic heating or transportation inside the country, since emissions in these cases are directly related to local usage, but it would affect emissions related to imported products like steel. Ignoring international trade in applications of the I=PAT equation biases the evaluation of responsibility for polluting emissions.

4.5. Developments of the Ehrlich-Holdren equation: the aggregation problem

The Ehrlich-Holdren equation has been applied or developed by several scientists in order to quantify the links between population growth and global warming. By doing so, they still raise the aggregation problem that we have already mentioned in the above section. We will review the following authors: Harrison, Bongaarts, and Lutz.

In what he calls 'the cigarette packet method' Harrison (1991) simplifies the Ehrlich-Holdren equation by deducting the rate of population growth from the growth rate of the pollutant (e.g. CO_2) to obtain the increase in the rate of emissions per capita. He assumes that these are due to changes in consumption and in technology. For the period between 1950 and 1985 he claims that 'simple arithmetic tells us that population growth accounts for 62 per cent of the increase in CO_2 emissions, while per capita use and technology account for 38 per cent together.' (p. 4). Obviously, this is too simple an arithmetic and it raises the same problem of aggregation as in the Ehrlich-Holdren equation. Myers does the same calculation and the same error in UNFPA (1991, p. 25).

To the contrary, Bongaarts (1992) warns against the problem by writing: 'it should be emphasized that these estimates [of the role of population growth in future global warming] are rather crude and should be used with caution because the assumption of independence between population growth and per capita CO_2 production is at best a rough approximation of reality' (p. 308-309). This warning is relevant even if the author performs separate calculations for MDCs and LDCs, with different CO_2 emission rates, which makes a lot of sense. In his effort to estimate the role of population growth in future global warming (until 2100), Bongaarts defines the specific contribution of population growth 'as the proportional reduction in the average annual CO_2 emission growth rate that would occur if population size is kept constant after 1985 and if the projected future trend in the per capita emission rate remains unaffected' (p. 308). By doing so, he finds that 'the role of population growth as a determinant of the projected rise in CO_2 emissions appears to be substantial. It accounts for 35 percent of the global increase and for 48 percent of the growth in LDCs between 1985 and 2100' (p. 309). In the same paper, Bongaarts also develops an interesting model to evaluate the relative contributions of the developed and developing countries to climate stabilization.

The problem of aggregation is best addressed by Lutz (1992) who entitles a section of his paper: 'the message depends on the level of aggregation'. Lutz clearly shows that 'the only solution would be to go down to a level of aggregation where the population is sufficiently homogeneous' (p. 6) so that there is no more correlation between per capita carbon emissions and the rate of that population growth.

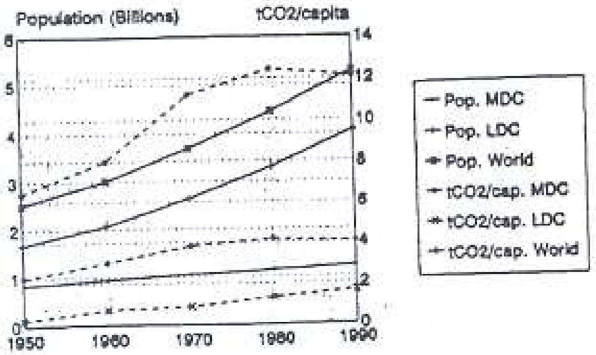

Figure 3. Evolution of population (continuous lines) and CO_2 emissions per capita (dashed lines) in MDCs and in LDCs from 1950 to 1990 (based on data from Marland and Boden, 1991).

As a preliminary step in this direction, Lutz splits the total world population into four groups (across all nations) that have supposedly the same demographic patterns and the same CO_2 emissions. Applying this method, he shows that 'the extension of the UN medium variant population projection now results only in a 20% increase of total carbon emissions over the next 60 years assuming constant per capita emissions. This is much less than the 86% increase that results from treating the whole world as one homogeneous region and from the 40% increase that results from a distinction between the North and the South.' (p. 6). Lutz concludes that 'most of the calculations given so far on the effect of population growth on CO_2 emissions are of rather limited use because they tend to refer to only one specific level of aggregation.' (p. 8). With this striking result, Lutz clearly states that any calculation based on the Ehrlichs formula I=PAT or on any extension of it must be performed at the lowest level of aggregation possible to avoid correlations between the factors of the equation.

5. The role of population growth in past CO_2 emissions

To try to quantify the role of population growth in past CO_2 emissions, we now present the results of a set of scenarios that show how important the world CO_2 emissions from fossil fuel and cement would have been had the population and/or the CO_2 per capita followed different paths of evolution during the period 1950-1990. We also make several standardizations (as usual in demography: see Wunsch and Termote, 1978) to examine what would have happened if the LDCs had had the CO_2 per capita of the MDCs, and conversely.

The observed emissions used as a basis for the simulations come from Marland and Boden (1991). Table 2 shows the evolution of the CO_2 per capita emissions for nine regions[10] of the world between 1950 and 1990. The variability is striking between and within the two broader groups, MDCs and LDCs. For example, North America emissions of CO_2 per capita are 3.5 times higher than the Western Europe value in 1950, and 2.4 times higher in 1990. In the LDCs, the average African emitted 3.2 times as much CO_2 than an inhabitant of Centrally Planned Asia (essentially China) in 1950,

[10] Marland and Boden (1991) subdivided the world into the following nine regions: North America (USA and Canada), Western Europe, Eastern Europe (including former Soviet Union), Centrally Planned Asia (including People's Republic of China, Viet Nam, North Korea, and Mongolia), Far East (including India, South Korea, Indonesia, Taiwan, Thailand, Pakistan, Malaysia, the Philippines,...), Oceania (mostly: Japan, Australia, and New Zealand), Developing America (the American continent less USA and Canada), Middle East (Saoudi Arabia, Iran, Turkey, ...), and Africa.

but only 0.5 as much in 1990. Another feature of Table 2 is a slight decline of CO_2 emissions per capita after 1970 (actually 1973) in North America and Western Europe. Figure 3 displays the evolution of population and CO_2 emissions in MDCs and in LDCs during the same period. As already seen above both phenomena have a cumulative impact on the future.

Table 2. Annual $^tCO_2$/capita emissions for the nine regions considered in section 5.

	1950	1960	1970	1980	1990
North America	16.315	15.746	20.362	20.041	18.979
Western Europe	4.640	6.029	8.188	8.688	7.798
Eastern Europe	3.986	6.937	9.652	12.460	12.568
Oceania	1.754	3.073	7.331	8.334	9.082
More Developed	6.417	8.021	11.189	12.397	12.092
South/Central America	0.995	1.413	1.836	2.438	2.219
Far East	0.160	0.260	0.424	0.675	0.970
Africa	0.430	0.565	0.832	1.084	1.057
Middle East	0.310	1.190	2.669	3.722	4.188
Centrally Planned	0.136	1.187	1.007	1.559	2.215
Less Developed	0.275	0.767	0.912	1.335	1.637
World	2.313	3.045	3.838	4.174	4.033

Source: Marland and Boden (1991).

Table 3 presents the results for nine scenarios. Although the results are summed up for the MDCs and LDCs, the simulations were performed separately for the nine regions shown in Table 2 with their corresponding population figures and CO_2 emissions per capita. This desaggregation into nine regions is more accurate than performing the calculations for two groups only (MDCs and LDCs) but is yet probably too crude to fully avoid the heterogeneity within the nine regions. For each scenario Table 3 also compares the simulated total CO_2 emission to the observed value for the corresponding year and the difference is indicated in per cent. It thus gives the influence of the factor(s) considered in that scenario. Admittedly, these simulations also neglect a number of factors, including emissions from deforestation (for which data are more uncertain) and emissions of other greenhouse gases, with their various residence times. But these simulations only intend to stimulate more detailed studies made with more elaborate tools.

The first set of scenarios deals with the effect of population growth alone. Scenario 1 tests the effect on the CO_2 emissions of an hypothetical stationarity of the LDCs populations at their 1950 level, with the observed evolution of the CO_2 per capita emissions in the different regions: the result would have been 18% less world emissions than the real figure for 1990. Conversely if the MDCs populations had not grown since 1950, the difference would have been higher: -23%, as shown by scenario 2. Of course these two gains would be added to each other had both the LDCs and MDCs populations been blocked at their 1950 levels (scenario 3). Thus for the period 1950-1990, the MDCs population growth played a greater role in the increase of the world CO_2 emissions than the LDCs population growth did, because the CO_2 emissions per capita multiplier is so large in MDCs.

Table 3. The role of population growth in past CO_2 emissions: scenarios. For each scenario and for each year, CO_2 emissions from fossil fuel and cement are given in million tonnes of CO_2 ($MtCO_2$) for the more developed countries (MDC), the less developed countries (LDC), and the world total (TOT). The calculations have been made with nine separate regions. The last line (D%) shows the relative change in world emissions compared to the observed data for the same year.

	Year	1950 $MtCO_2$	1960 $MtCO_2$	1970 $MtCO_2$	1980 $MtCO_2$	1990 $MtCO_2$
Observed data	MDC	5358	7604	11781	14152	14665
	LDC	462	1589	2411	4415	6676
Source: Marland and Boden (1991)	TOT	5821	9193	14192	18567	21341
1. Pop. MDC = real data	MDC	5358	7604	11781	14152	14665
Pop. LDC = 1950 value	LDC	462	1301	1517	2223	2786
CO_2/cap MDC = real data	TOT	5821	8905	13297	16375	17452
CO_2/cap LDC = real data	D%	0	-3.1	-6.3	-11.8	-18.2
2. Pop. MDC = 1950 value	MDC	5358	6608	9171	10123	9778
Pop. LDC = real data	LDC	462	1589	2411	4415	6676
CO_2/cap MDC = real data	TOT	5821	8197	11582	14538	16454
CO_2/cap LDC = real data	D%	0	-10.8	-18.4	-21.7	-22.9
3. Pop. MDC = 1950 value	MDC	5358	6608	9171	10123	9778
Pop. LDC = 1950 value	LDC	462	1301	1517	2223	2786
CO_2/cap MDC = real data	TOT	5821	7909	10687	12346	12565
CO_2/cap LDC = real data	D%	0	-14.0	-24.7	-33.5	-41.1
4. Pop. MDC = real data	MDC	5358	6195	6944	7586	8149
Pop. LDC = real data	LDC	462	1589	2411	4415	6676
CO_2/cap MDC = 1950 value	TOT	5821	7785	9355	12001	14825
CO_2/cap LDC = real data	D%	0	-15.3	-34.1	-35.4	-30.5
5. Pop. MDC = real data	MDC	5358	6195	6944	7586	8149
Pop. LDC = real data	LDC	462	584	754	957	1200
CO_2/cap MDC = 1950 value	TOT	5821	6780	7698	8543	9349
CO_2/cap LDC = 1950 value	D%	0	-26.3	-45.8	-54.0	-56.2
6. Pop. MDC = real data	MDC	5358	7604	11781	14152	14665
Pop. LDC = 1950 value	LDC	10789	13486	18812	20843	20330
CO_2/cap MDC = real data	TOT	16147	21090	30592	34994	34995
CO_2/cap LDC = MDC values	D%	177.4	129.4	115.6	88.5	64.0
7. Pop. MDC = 1950 value	MDC	5358	6608	9171	10123	9778
Pop. LDC = 1950 value	LDC	10789	13486	18812	20843	20330
CO_2/cap MDC = real data	TOT	16147	20094	27983	30966	30109
CO_2/cap LDC = MDC values	D%	177.4	118.6	97.2	66.8	41.1
8. Pop. MDC = real data	MDC	230	727	960	1524	1985
Pop. LDC = real data	LDC	462	1589	2411	4415	6676
CO_2/cap MDC = LDC values	TOT	692	2316	3371	5939	8661
CO_2/cap LDC = real data	D%	-88.1	-74.8	-76.2	-68.0	-59.4
9. Pop. MDC = 1950 value	MDC	230	641	761	1115	1367
Pop. LDC = 1950 value	LDC	462	1301	1517	2223	2786
CO_2/cap MDC = LDC values	TOT	692	1942	2278	3338	4153
CO_2/cap LDC = real data	D%	-88.1	-78.9	-83.9	-82.0	-80.5

The second set of scenarios addresses the effect of CO_2 per capita. If we block the CO_2 per capita in the MDCs at their 1950 values and have the MDCs and LDCs populations grow as they really did, the world emissions would have been significantly less than observed: -15% in 1960, -30% or more since 1970 (scenario 4). Between 1980 and 1990, the decrease in the gain (from -35.4% to -30.5%) is associated with the slight diminution of the MDCs CO_2 per capita during the 1980s and with the decreasing weight of MDCs emissions in the world total for that scenario. The comparison between scenarios 4 and 3 indicates that the effect of the populations growth in both MDCs and LDCs could have been offset until 1980 by the sole blocking of MDCs CO_2 per capita rates to their 1950 values. Scenario 5 differs from scenario 4 by adding the blocking of CO_2 per capita values in LDCs at their 1950 levels. A comparison with scenario 3 shows that an hypothetical freeze of world CO_2 per capita emissions at their 1950 values would have reduced world emissions in 1990 by a significantly larger amount (-56% in 1990) than a freeze in world population would have (-41% in 1990). Bringing now together scenarios 4 and 5 leads to the following reductions of world CO_2 emissions if the sole LDCs CO_2 per capita had been locked at their 1950 levels: -11% in 1960, -11.7% in 1970, -18.6% in 1980, and -25.7% in 1990.

The last four simulations combine hypotheses on both population growth and CO_2 emissions evolution, and they also include an 'exchange' of CO_2 rates between LDCs and MDCs. In scenario 6, LDCs are given MDCs CO_2 per capita emissions and LDCs populations are constrained to their 1950 levels (as in scenario 1). This would have led to a tremendous increase in the world CO_2 emissions. Since in reality, the relative difference between MDC and LDC CO_2 per capita emissions has decreased over time, the large difference between scenario 6 results and the observed emissions decreases between 1950 and 1990. It is still very high in 1990: +64%. Scenario 7 adds to these hypotheses the zero-growth of the MDCs populations, whose net effect has already been discussed with scenario 2. The resulting changes in world emissions are the sum of those in scenarios 6 and 2.

Finally, LDCs CO_2 per capita mean values are attributed to MDCs, and scenario 8 shows the net effect of this hypothesis: world CO_2 emissions would have been significantly lower (-88% in 1950, -76% in 1970, and -59% in 1990). Scenario 9 multiplies these reduced CO_2 per capita rates by the 1950 MDCs populations and adds for the LDCs a non-growing population hypothesis to simulate the strongest decrease of world total emissions of these scenarios: around -80% CO_2 emissions in 1960, with a mere stability since then until 1990.

The scenarios results tend to show that, for industrial CO_2 emissions between 1950 and 1990, past population increases in developing countries have contributed much less to CO_2 increases than either increases in consumption in MDCs or population growth in MDCs did (scenario 1 compared to scenarios 4 and 2, respectively). They also show (or remind) that (past and) present emissions per capita in developed countries are not extendable to the rest of the world, even if populations had been blocked at the 1950 level (scenarios 6 and 7), since they dramatically increase already excessive emissions. Scenarios 9 and 8 give the lowest total emissions, but imply the extension of LDCs consumption patterns to MDCs as well, with or without population control. These last two scenarios look probably very extreme to MDCs readers, but they illustrate in a striking manner the very small CO_2 emissions per capita associated with the way of life of LDCs inhabitants. Since changes in consumption patterns are affected by a weaker structural inertia than population is, it may be argued (see Meadows et al., 1992) that it would be more rapidly effective to put the emphasis on changing the energy and resource consumption patterns, specially in rich countries. By doing so, the growth of the world CO_2 emissions could be braked while waiting for the outcome of the reduction of population growth. Such reduction may indeed be necessary, not as much because of past responsibilities of population growth in global warming, as shown by Table 3, but to allow a sustainable development.

6. Conclusion

A significant warming of the average surface temperature of the Earth is likely to take place in the next century because of the release of greenhouse gases caused by human activities. If these emissions continue unabated, the warming would be between 2 and 5 degrees Celsius on the average by the end of the next century. This would represent a fast and large change: it may be compared to the warming observed between the peak of the last glaciation (20 000 years ago) and the pre-industrial period, as this warming was about 3 to 5 degrees.

This warming will have a large impact on the habitability of our planet: sea level will rise, changes in precipitation patterns will affect agriculture and ecosystems, heat waves and tropical storms will be more frequent. To allow a 'sustainable climate' (Gouzée and van Ypersele, 1992), i.e., a climate that does not change faster than the speed at which the economy, natural and agricultural ecosystems can adapt naturally, the concentration of greenhouse gases in the atmosphere must be stabilized as soon as possible, which implies a global reduction of emissions. To achieve this, the Rio Convention introduced the principle of 'differentiated responsibilities' among countries.

Three different types of responsibilities are often distinguished: population, consumption, and technology, following the well-known Ehrlichs equation.

These three factors are included in the notion of a 'planetary bargain' that the American climatologist Stephen Schneider (1989, p. 269) proposed in 'The Genesis Strategy': for him, 'developed countries would control their disproportionate use of natural resources and provide capital and technology to help developing countries improve their economic base. At the same time, the less developed countries would be expected to reduce population growth rates markedly and raise their standards of living.' A similar idea is developed by the French demographer Jacquard (1991).

The principle of 'differentiated responsibilities' also has methodological consequences. As clearly demonstrated by Lutz (1992), the I=PAT equation is only valid if it is applied to a specific, homogeneous region. Using this equation for inhomogeneous regions that are aggregated, or to the world as a whole, leads to significant errors in quantifying the importance of each factor in the I=PAT equation. Unfortunately, these errors are encountered even in UNFPA publications.

To quantify the role of population and CO_2 emissions per capita (the two factors that are in the simplest form of the Ehrlich-Holdren equation) in producing world CO_2 emissions, we have applied this equation to nine rather homogeneous regions of the world. Using observed population and CO_2 emission statistics for the 1950-1990 period, we have built different scenarios using a standardization method, as commonly made in demography. These scenarios have shown that the increase in MDC CO_2 emission per capita had a significantly larger effect on world total emissions increases than LDC population growth did. It was also shown that MDC population growth had a larger effect than LDC population growth. Extending MDC CO_2/capita emission to LDCs with their population stabilized at their 1950 value leads to emissions that are about three times larger than the ones observed in 1950, two times larger than the 1970 emissions, and 64% higher than the 1990 level. These numbers illustrate in a striking manner the concept of 'differentiated responsibilities' introduced in the Rio Convention.

Finally, this paper has shown that demographers may bring some contributions to the debate on the role of population in global warming (and possibly in other environmental issues). The first one is related to the aggregation problem: demographers are used to multiply the relevant rate to the corresponding population at risk and this practice should prevent them to make erroneous aggregations. They also know the standardization methods that may produce interesting scenarios. Another point is the analogy between the inertia of the demographic system (caused by the multiplying effect that a young population has on the long range) and the inertia of the climatic system (mainly due to the long residence time of several greenhouse gases and the long time needed to heat the upper ocean). Finally, demographers do more and more recognize the complexity of the relationships between demographic, social, economic, and environmental factors. As Tabah (1992, pp. 293-4) says: 'the demographic equality [the eventual convergence of fertility rates in MDCs and LDCs] would imply either that people will become equal in terms of economic and social conditions, or that differences in economic, social and even cultural conditions will no longer have any effect on either fertility or mortality.' Of course, this holds true at a policy level, and precludes any one-dimensional approach to the population-environment issue.

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