# Have increases in population, affluence and technology worsened human and environmental well-being?

*Indur M. Goklany*[1]

## 1. Introduction

Concerns about population growth historically revolved around the notion that there may be insufficient arable land, minerals or energy to meet the needs of an exponentially increasing population. Today they are compounded by fears that as wealth increases, so would consumption of natural resources, and that new technologies would enable further exploitation of these resources. Absent empirical information, it can be plausibly argued that together these factors conspire to increase environmental impacts with potentially disastrous effects on human welfare.

The general skepticism of population growth, economic development, and technology exhibited by many, if not most, environmentalists and Neo-Malthusians — henceforth Neo-Malthusians — is captured by the equation, I = PAT, where I is a measure of environmental impact, P is the population, A stands for affluence — a surrogate for per capita production or per capita consumption, often measured in terms of the gross domestic product (GDP) per capita — and T, denoting technology, is a measure of the impact per unit of production or consumption (e.g., Commoner 1972; Ehrlich and Holdren 1971; Ehrlich and Goulder 2007) . [Technology, as used here, includes both hardware (e.g., scrubbers, catalytic convertors and carbon adsorption systems) and software technologies (e.g., policies, management techniques, computer programs to track or model environmental quality, and emissions trading) (Ausubel 1991; Goklany 1995).]

According to the IPAT equation, if all else remains the same, an increase in population, affluence or technology would each act as multipliers for environmental impact (Commoner 1972; Ehrlich and Holdren 1971; Ehrlich and Ehrlich 1991; Ehrlich 2008). And as that impact increases, human well-being would necessarily deteriorate.

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[1] Address: Office of Policy Analysis, US Department of the Interior, 1849 C Street, NW, Washington, DC, USA 20240. E-mail: igoklany@cox.net. The views expressed in this paper are the author's and not the US government's.

While noting that the IPAT equation is a simplified representation and sometimes acknowledging that the terms on the right hand side are not independent of each other, its formulators have nevertheless used it to support their contention that the human enterprise as currently constituted is unsustainable in the long run, unless the population shrinks, we diminish, if not reverse, "overconsumption" or economic development particularly in the United States, and apply the precautionary principle to new technologies, which in their view essentially embodies a presumption against further technological change unless the technology involved is proven safe and clean (Ehrlich and Holdren 1971; Ehrlich and Ehrlich 1991; Myers 1997; Raffensperger and Tickner 1999).

Despite recognizing that "benign" technology could reduce some impacts, many Neo-Malthusians argue, to quote Jared Diamond (2005: 504), it's a mistake to believe that "[t]echnology will solve our problems." In fact, goes this argument, "All of our current problems are unintended negative consequences of our existing technology. The rapid advances in technology during the 20th century have been creating difficult new problems faster than they have been solving old problems..." Diamond (2005: 505). Ehrlich and co-workers argue that for most important activities, new technology would bring diminishing returns because as the best resources are used up (e.g. minerals, fossil fuels and farm land), society would increasingly have to turn to marginal or less desirable resources to satisfy demand which would increase energy use and pollution (Ehrlich and Holdren 1971; Ehrlich et al. 1999).

There are alternate views of the role of technological change and economic growth regarding human and environmental well-being. Ausubel and other systems-oriented industrial ecologists believe that additional technological change has to be part of the solution in order to reduce the environmental impact of the processes designed to meet human needs (Ausubel 1998; Ryan 1999). However, even these ardent advocates of technology view economic growth as a multiplier of impacts, rather than a contributor to the solution (Ausubel 1998; Landes 1998).

Another view is that as a country develops economically, its environment initially deteriorates and then begins to improve, that is, a plot of environmental impact versus economic development on the horizontal axis would be shaped like an inverted-U, a shape similar to one discovered by Simon Kuznets, the Nobel-prize winning economist, for income inequality. Accordingly, this view is often labeled as the environmental Kuznets curve (EKC) hypothesis (Shafik 1994; Grossman and Krueger 1995).

In the “environmental transition” hypothesis, Goklany (1995, 1998; 2007a) has generalized the EKC hypothesis to attempt to account for both economic development and technological change. Under this hypothesis, initially societies opt for economic and technological development over environmental quality because it allows them to escape from poverty and improve their quality of life by making food, education, health, homes, comfort, leisure and material goods more affordable. But over time society perceives that environmental deterioration, notwithstanding economic development, compromises that quality of life and it starts to address its environmental problems. Being wealthier and having access to greater human capital, it’s now in a better position to afford and employ cleaner technologies. Consequently, environmental deterioration can, first, be halted and, then, reversed. Under this hypothesis, technological change and economic growth may initially be the causes of environmental impacts, but eventually they can combine to effect an “environmental transition” — after which they become a necessary part of the solution to environmental problems. Such a transition, if it occurs at all, would be evident as a peak in a stylized curve of environmental impact versus time, assuming that both economic development and technology advance with time. This assumption, while true in general since Malthus’ time, hasn’t always been so, nor is there a guarantee that it will hold for all places at all times in the future.

In the following, I’ll examine whether long term empirical data support the Neo-Malthusian notion that as populations increase, become wealthier, and technology advances, we’ll run out of resources, and environmental quality and human well-being will deteriorate. I’ll inspect trends that typically span several decades, because short term trends can be misleading. My examination, which will be illustrative rather than exhaustive, will focus mainly on the US because its long term data is available relatively readily and because it has traveled farthest on the path of economic development. Global data will be used where available. I’ll also look at data from some developing countries, mainly India and/or China, to contrast their experience with that of the US.

With respect to the environment, my selection of indicators to examine is guided largely by the World Health Organization’s (2002) analysis of the contribution of various food, nutritional and environmental risk factors to the global mortality and disease burden. That analysis estimates that of those risk factors, hunger and malnutrition are the largest contributors to the mortality and disease burden, followed by water related diseases, indoor air pollution, and urban outdoor air pollution. I’ll also look at indicators related to climate change, not because it’s among the highest contributors — it ranks below the top ten — but because of the current interest in all matters related to global warming (Goklany 2007a: 355-356).

Note that long term data are unlikely to be homogeneous, and are plagued with numerous uncertainties which increase the further one goes back in time or during periods of unrest, wars and social tensions. Therefore, they are best used to draw qualitative rather than quantitative conclusions. Also, unless noted otherwise, GDP in this paper is provided in terms of constant 1990 International dollars (adjusted for purchasing power parity, PPP), per Maddison (2003) and GGDC (2008). Finally, I will draw liberally from Goklany (2007a).

But first let's briefly examine trends in population growth over the last few decades. .

## 2. Trends in Population Growth and Total Fertility Rates

The original Neo-Malthusians premise was that population would grow exponentially. Indeed until the latter decades of the 20th century, these concerns seemed well founded, as technological change increased the rate of population growth by reducing mortality rates. Despite that, the rate of population increase has slowed in recent decades. Instead of adding 10.6 percent to the world's population every 5 years (from 1965-1970), currently we are adding 6.0 percent (UNPD 2007). Accordingly, recent population projections show that population should peak during this century, perhaps at 8.85 billion around the 2080s, with a 90 percent probability that it will not exceed 11.5 billion in 2100 (Lutz et al. 2007).

Nevertheless, while most experts currently discount the possibility of exponential population increase, the notion lingers on in the popular mind (see, e.g. Dot Earth 2008). This tends to color discussions on environmental matters. In any case, Neo-Malthusians insist that even current population levels may be catastrophic for humanity, with some suggesting that the earth's sustainable limit may be anywhere between 0.5 to 2 billion may be (Dahl 2005).

The onset of the decline in growth rate was more or less concurrent with mortality rate declines in general, and preceded the appearance of AIDS. The proximate cause is obviously a decline in total fertility rate (TFR), that is, the number of children borne by a woman, which seems to have occurred worldwide, but to a differing extent in each country and culture. What are the underlying causes of the decline in TFR?

Figure 1, based on cross country data from the World Bank (2005), shows that TFR generally declines independently with the level of economic development (as measured by GDP per capita) and with time (which is a surrogate for technological change).[2] Goklany (2007a, 2007b) argues that this isn't merely cause-and-effect, equally important is that conditions that favor economic and technological development and, significantly, the desire for such development, also help reduce TFR.

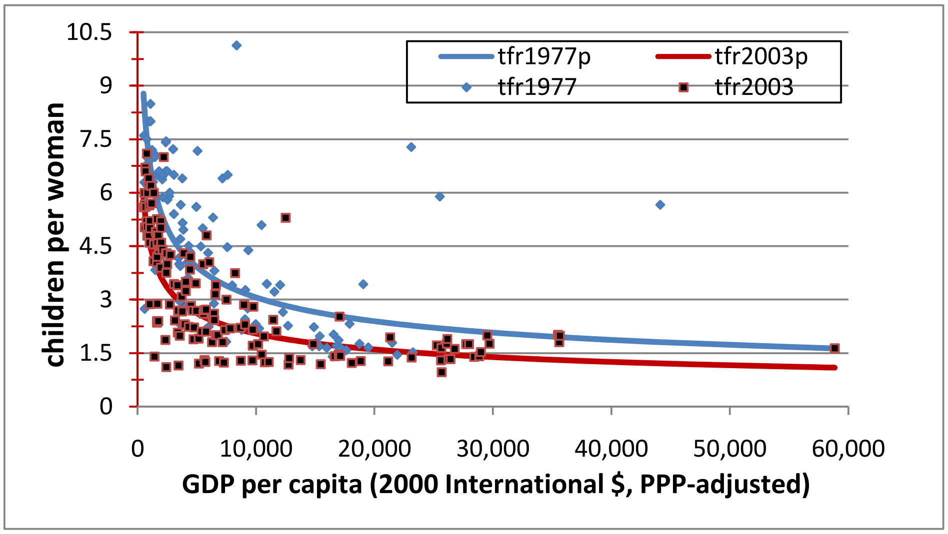

**Figure 1: Total fertility rate (TFR) vs. per capita income, 1977-2003.** Source: Goklany (2007a).

First, since lower poverty — the not-so-surprising consequence of economic growth — means lower infant mortality rates and higher survival rates, it reduces pressures for more births. This is particularly important because in poorer countries children are about the only form of social security, which is one reason why they have the highest TFRs. Moreover, richer societies are more likely to be able to afford broader based social security programs which can reduce the pressure for more children. Third, lower poverty levels also mean greater access to technology, which reduces the value of child labor whether on the farm or in urban areas.. Fourth, richer societies offer greater educational and economic opportunities for women, which also increases the opportunity costs of their child bearing and child rearing years. Sixth, the time and cost to educating children to be competitive and productive in a richer and more technologically advanced society encourages small family sizes.

Apart from economic and technological development itself, factors that contribute to economic

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[2] Goklany (2007b) shows that a similar relationship holds for cross country TFR data for 1960 and 2000 using GDP in constant dollars per market exchange rates (MXR), whereas Figure 1 uses PPP-adjusted GDP.

growth and the desire for greater wealth can help create conditions that tend to lower TFR. In particular, literacy and the amount of education, especially of women, helps propagate good habits of diet, nutrition, sanitation and safe drinking water. This improves health and reduces mortality, in general, and infant and maternal mortality, in particular. As noted, this reduces pressures to maximize birth and enables families to "plan" their sizes. At the same time, improved health leads to greater wealth (or economic growth).

Finally, many couples — arguably swayed by commercials and lifestyles depicted by a ubiquitous, globalized and globalizing visual mass media — defer child birth in favor of current consumption (Goklany 2007a).

Consequently, TFR has dropped progressively with both economic development and time. Thus, in the IPAT equation, P is not independent of A and T, and sooner or later, the richer the nation the lower its population growth rate, which might lead to a cleaner environment (Goklany 1995, 1998).

Therefore, while economic development and technological change might initially increase the rate of population growth by reducing mortality rates, in the long run, they moderate population growth by helping directly or indirectly create the conditions for many families to voluntarily opt for fewer children (and lower TFR).

## 3. Trends in Human Well-being

Although global population is no longer growing exponentially, it has quadrupled since 1900. Concurrently, affluence (or GDP per capita) has sextupled, global economic product (a measure of aggregate consumption) has increased 23-fold and carbon dioxide has increased over 15-fold (Maddison 2003; GGDC 2008; World Bank 2008a; Marland et al. 2007.[3] But contrary to Neo-Malthusian fears, human well-being, measured by any objective indicator, has never been higher.

Food supplies, Malthus' original concern, are up worldwide. Global food supplies per capita increased from 2,254 Cals/day in 1961 to 2,810 in 2003 (FAOSTAT 2008). This helped reduce hunger and malnutrition worldwide. The proportion of the population in the developing world,

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[3] Time series from these sources were linearly extrapolated to 2008.

suffering from chronic hunger declined from 37 percent to 17 percent between 1969-71 and 2001-2003 despite an 87 percent population increase (Goklany 2007a; FAO 2006).

The reduction in hunger and malnutrition, along with improvements in basic hygiene, improved access to safer water and sanitation, broad adoption of vaccinations, antibiotics, pasteurization and other public health measures, helped reduce mortality and increase life expectancies. These improvements first became evident in today's developed countries in the mid- to late-1800s and started to spread in earnest to developing countries from the 1950s. Their infant mortality rate was 180 in the early 1950s; today it is 57. Consequently, global life expectancy, perhaps the single most important measure of human well-being, increased from 31 years in 1900 to 47 years in the early 1950s to 67 years today (Goklany 2007a).

Globally, average annual incomes tripled since 1950. As a result, the proportion of the world's population outside of high-income OECD countries living in absolute poverty, traditionally based on average consumption of less than $1 per day in 1985 International dollars (adjusted for purchasing power parity), which had been at 84 percent in 1820, has been halved since 1981, from 40 percent to 20 percent (Goklany 2007a; WRI 2008; World Bank 2007).

Equally important, the world is more literate and better educated. Child labor in low income countries declined from 30 to 18 percent between 1960 and 2003. People are freer politically, economically and socially to pursue their well-being as they see fit. More people choose their own rulers, and have freedom of expression. They are more likely to live under rule of law, and less likely to be arbitrarily deprived of life, limb and property. Social and professional mobility has never been greater. It's easier to transcend the bonds of caste, place, gender, and other accidents of birth in the lottery of life. People work fewer hours, and have more money and better health to enjoy their leisure time (Goklany 2007a).

Figure 2 summarizes the US experience over the 20th century with respect to growth of population, affluence, material, fossil fuel energy and chemical consumption, and life expectancy. It indicates that population has multiplied 3.7-fold; income, 6.9-fold; carbon dioxide emissions, 8.5-fold; material use, 26.5-fold; and organic chemical use, 101-fold. Yet its life expectancy increased from 47 years to 77 years and infant mortality (not shown) declined from over 100 per 1,000 live births to 7 per 1,000.

It is also important to note that not only are people living longer, they are living healthier. The disability rate for seniors declined 28 percent between 1982 and 2004/2005 and, despite better diagnostic tools, major diseases (e.g., cancer, and heart and respiratory diseases) occur 8–11 years later now than a century ago (Fogel 2003,; Manton et al. 2006).

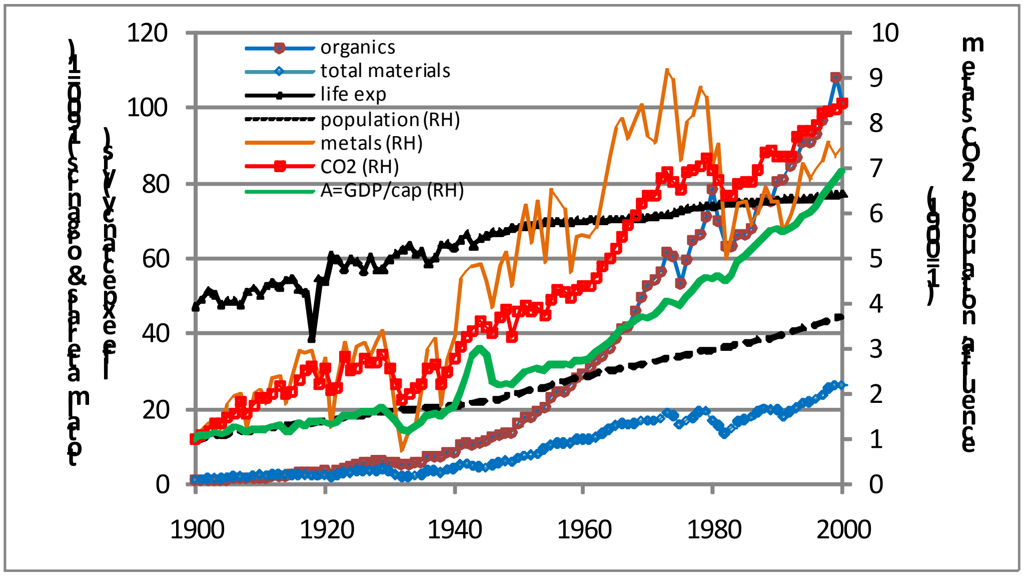

**Figure 2: US material, chemical and energy use, population and affluence compared to life expectancy, 1900-2000.** Adapted from Goklany (2007a), based on Matos (2005), Marland et al. (2005), Maddison (2003).

If similar figures could be constructed for other countries, most would indicate qualitatively similar trends, especially after 1950, except possibly, for the erstwhile members of the Soviet Union and Sub-Saharan Africa. In the latter two cases, life expectancy, which had increased following World War II, declined after the late 1980s to the early 2000s, possibly due poor economic performance compounded, especially in Sub-Saharan Africa, by AIDS, resurgence of malaria, and tuberculosis due mainly to poor governance, breakdown of public health services and other manmade causes. However, there are signs of a turnaround, perhaps related to increased economic growth since the early 2000s, which could, of course, be a temporary blip (Goklany 2007a; World Bank 2008a).

Notably, in most areas of the world, the health adjusted life expectancy (HALE), that is, life expectancy adjusted downward for the severity and length of time spent by the average individual in a less-than-healthy condition, is higher today than the unadjusted life expectancy of times past. HALE for the China and India in 2002, for instance, were 64.1 and 53.5 years, which exceeded their unadjusted life expectancy of 63.2 and 50.7 years in 1970-1975 (WRI 2008).

Figure 3, based on cross country data, indicates that contrary to Neo-Malthusian fears, both life expectancy and infant mortality improve with the level of affluence (economic development) and time, a surrogate for technological change (Goklany 2007a). Other indicators of human well-being that improve independently with affluence and time are access to safe water and sanitation (see below), literacy, level of education, food supplies per capita, and the prevalence of malnutrition (Goklany 2007a, 2007b).

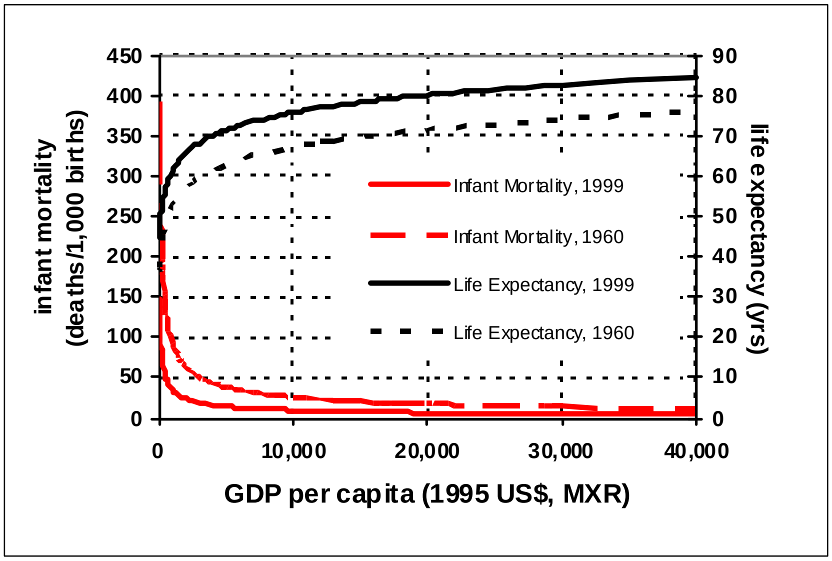

**Figure 3: Life expectancy & infant mortality as a function of economic development and secular technological change, 1960-1999).** Note: MXR = market exchange rates. Source: Goklany (2007a), based on World Bank (2001).

## 4. Trends in Environmental Well-being

In this section I will examine long term trends in various key environmental indicators to establish whether they are consistent with Neo-Malthusian or other views regarding the effect of economic growth and technological change on the environment. I will use the IPAT equation to determine how well changes in impacts (I) track with changes in population (P), affluence (A), and technology (T).

Estimating Technological Change. In applying the IPAT equation, affluence will be measured by GDP per capita or, if that's unavailable, gross national product (GNP) per capita. For the U.S. the difference between these two measures in any year is slight — on average, within 0.54 percent (with a range from +1.21 to -0.05 percent) for 1929-1997 (Goklany 2007a).

Since A is represented by GDP per capita, the IPAT equation may be rewritten as:

$$I \equiv \text{population} \times (\text{GDP/population}) \times T \qquad \ldots \qquad (1)$$

Since total consumption — the product of P and A — is equivalent to GDP, the technology-factor (T) can be estimated using:

$$T = I/\text{GDP} \qquad \ldots \qquad (2)$$

Thus, T is equivalent to impact per unit of GDP. Notably, a decline in T would reduce I and denotes an improvement in technology.

The technological change ($\Delta T$) from an initial time ($t_i$) to final time ($t_f$) can then be estimated by:

$$\Delta T = \Delta(I/\text{GDP}) \qquad \ldots \qquad (3)$$

If population, affluence, their product (GDP), and the technology-factor are all normalized to unity at $t_i$, then

$$\Delta T = (I_f/\text{GDP}_f) - 1, \qquad \ldots \qquad (4)$$

where subscript f denotes the value at the end of the period.

Where emissions (E) are used to characterize the environmental impact, technological change is the change in emissions per GDP, that is,

$$\Delta T = \Delta(\text{emissions/GDP}) = (E_f/\text{GDP}_f) - 1 \qquad \ldots \qquad (5)$$

I will, except where noted, use Equation 4 (or 5) to estimate technological change, and whether that has made matters better or, consistent with the Neo-Malthusian view, worse over the period of analysis. For some indicators, e.g., mortality from extreme weather events (a purported indicator of global warming) or water related diseases, I'll substitute $P_f$ for $\text{GDP}_f$ ($= P_f \times A_f$) in the above equations on the basis that, *ceteris paribus*, as a first order approximation, mortality increases linearly with P but is relatively insensitive to affluence.

### *4.1 Cropland or Habitat Conversion*

Because cropland is critical for producing the food and nutrition necessary to ward off hunger and malnutrition — still among the largest contributors to global mortality — the first Malthusian concern was that humanity may run out of cropland. Now the concern is that there may be too much of it. In fact, the single largest threat to ecosystems and biodiversity is the diversion of habitat to agricultural uses, particularly cropland.

Figure 4 shows trends for the US from 1910 to 2006 in the amount of cropland planted, population (P), affluence (A), GDP (= P x A), as well as two measures of technology, namely, T (calculated as I/GDP) and T' (calculated as I/P). All variables are normalized to 1910.

This figure shows that despite a more-than-tripling of the population and a 19-fold increase in consumption (GDP), cropland was unchanged at 330 million acres. That is, the impact has not increased, contrary to naïve interpretations of the IPAT equation. This is because the decline in the T-factor has compensated for these increases. T' was at 0.31 in 2006 relative to 1910, i.e., technology reduced the impact by 69 percent.

Arguably, however, it's more appropriate to use GDP (= P x A) to estimate technology because affluence increases the demand for meat and milk, and the propensity for wastage. Using this measure, T (= I/GDP) stands at 0.05 in 2006 relative to 1910, that is technology reduced impact by 95 percent. Perhaps, the correct measure would be to use the product of population and the logarithm of affluence. Regardless, T and T' bracket the range for technology.

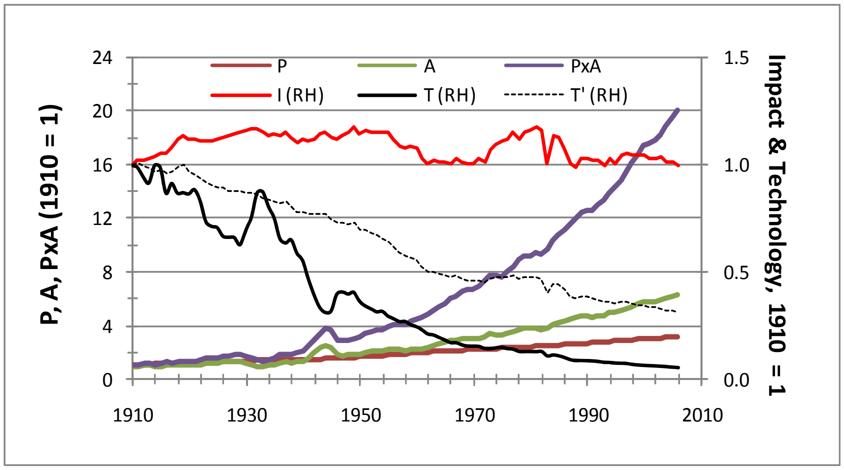

**Figure 4: IPAT for US cropland, 1910-2006.** Sources: GDP and population data are from Maddison (2003), GGDC (2008), World Bank (2008a); cropland data is from ERS (2008).

Note that cropland was higher (387 million acres) in both 1949 and 1981 than in 1910 and 2006, and that cropland would currently have been lower but for subsidies which have negated the full extent of improvements that technological change might have achieved. Moreover, some of the increase in yield that has helped halt land conversion could be due to higher carbon dioxide concentrations.

Figure 5, which shows global trends in cropland from 1700 to 2005, also offers no support for the proposition that increases in population and affluence necessarily increase impacts. In fact, this figure indicates that technological change since 1961 "saved" about 1,300 million hectares from conversion to cropland and that, like in the US, cropland may be peaking globally (that is, going through an environmental transition; Goklany 2007a). Whether it actually stabilizes and/or declines consistent with the environmental transition hypothesis depends on the availability, and barriers to, technological change. In this regard, European attitudes toward genetically modified crops, and the diffusion of those attitudes to developing countries, particularly in Africa, retards technological change and are counterproductive, as are subsidies in developed countries which keep more land under cultivation (Goklany 2007a).

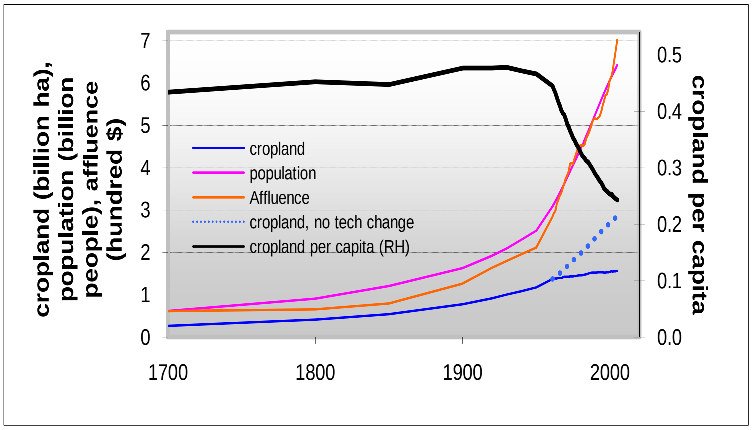

**Figure 5: Global cropland, population, affluence, and cropland per capita, 1700-2005.** Note that the difference between the dotted and solid blue lines equals the amount of habitat "saved" from conversion had technology been frozen at 1961 levels**.** Sources: Goklany (2007a), Maddison (2003), GGDC (2008), FAOSTAT (2008); World Bank (2008a).

### *4.2 Water-related Impacts*

Water has traditionally been high in the list of environmental priorities because of the potential of death and disease from water related diseases. Figure 6 shows that from 1900-1970, US death rates due to various water-related diseases — dysentery, typhoid, paratyphoid, other gastrointestinal disease, and malaria —declined by 99.6 to 100.0 percent (USBC, various years).

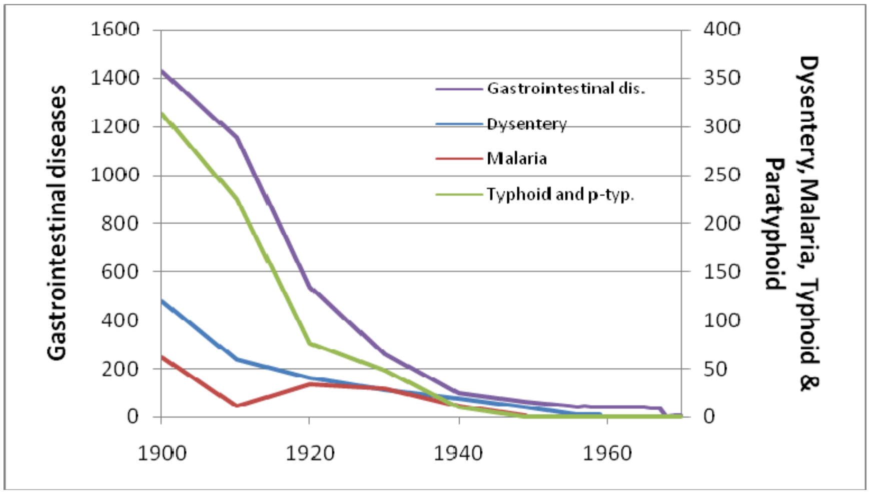

**Figure 6: Death rates for various water related diseases, 1900-1970.** Source: Goklany (2007a), based on USBC (various years, 1975).

These reductions, which preceded the 1972 Clean Water Act, can be attributed to, among other things, greater knowledge of better hygiene, greater access to safe water and sanitation, and new and more effective therapies.

Analysis of cross country data indicates that access to both safe water and sanitation generally increases with economic development and time (Goklany 2007a, 2007b). Because of higher levels of economic development and technological diffusion, such access, although not yet universal, has never been higher. Between 1990 and the early 2000s, for example, the proportion of the population with access to safe water increased from 70 to 84 percent in South Asia and 49 to 53 percent in Sub-Saharan Africa, while with regard to sanitation, it increased from 16 to 35 percent in South Asia, and 32 to 36 percent in Sub-Saharan Africa (World Bank 2008b).

### *4.3 Traditional Air Pollution*

Concern over traditional air pollutants — soot, other forms of particulate matter, sulfur dioxide, carbon monoxide and, in some places, ozone — was instrumental in raising environmental consciousness in the US and today's richer countries. Long term data indicates that air quality for these traditional pollutants has generally improved, particularly for the pollutants — and in the areas — that were of the greatest public health concern (Goklany 2007a). For these countries, long term air quality trends show pronounced peaks that are generally consistent with the environmental transition hypothesis rather than with Neo-Malthusian theories that affluence and technological change make matters worse.

With respect to the US, probably a harbinger for other countries, the earliest environmental transitions apparently occurred for indoor air quality (by the 1940s), followed later by improvements in outdoor air quality. This is especially significant because the vast majority of people spend the majority of their time indoors, generally at home. Therefore indoor exposure is perhaps the single most critical determinant of the potential public health impact of air pollution. Remarkably, improvements in indoor air quality, which were enabled by improvements in technology and greater affluence, occurred voluntarily as households moved away from solid fuels such as coal and wood to cleaner energy sources within the home — oil, gas, electricity.

With respect to US national outdoor air quality as well, the transitions seem to have occurred earlier for pollutants and locations that were of the earliest and greatest concern. They occurred first for total suspended particulate matter (around 1957), followed by sulfur dioxide (early-to-mid 1960s), carbon monoxide (mid-to-late 1960s), lead (mid-to-late 1970s), ozone (mid-to-late1970s nationally but mid-1950s in California, where it was a major early concern), and finally nitrogen oxides (in the late-1970s). Somewhat counter-intuitively, many of these transitions also preceded the Clean Air Act Amendments of 1970.

For the traditional air pollutants, US trends in emissions, an indicator of lower significance to public health and welfare than either indoor or outdoor air quality, indicate that they too have gone through their environmental transitions.

Notably, air quality in the currently industrializing (or developing) countries is substantially worse than in developed countries. Beijing, Mexico City, New Delhi and Cairo, for instance, are among the most polluted in the world. Nevertheless, developing countries seem to have learnt from the experience of developed countries. In fact, in many respects, they are ahead of industrialized countries at the same level of economic development. For example, the US first introduced unleaded gasoline in 1975 when its GDP per capita was $16,300, whereas India and China instituted some controls for lead-in-gasoline by 1997, when their GDPs per capita were $1,600 and $3,000, respectively (Maddison 2003; Goklany 2007a). By 2006, only about 25 countries out of about 200 were using leaded gasoline (Dumitrescu 2005) although the global GDP per capita was about $7,300. This, of course, is due to the diffusion of knowledge and technology from industrialized to developing countries.

Analysis of air pollution trends from 1993-2004 in twenty Asian cities — Bangkok, Beijing, Busan, Colombo, Dhaka, Delhi, Hanoi, Ho Chi Minh, Hong Kong, Jakarta, Kathmandu, Kolkata, Mumbai, Manila, Seoul, Shanghai, Singapore, Surabaya, Taipei and Tokyo — showed that, in general, TSP and PM-10 decreased from 1993 to 2004, although ambient levels were above limits set by the World Health Organization (Figure 7; CAI-Asia 2006). [Sixteen of the 20 cities are in developing Asia.] For $SO_2$, levels had been improved to within WHO guidelines. For $NO_2$, the levels had been stabilized around WHO guidelines. These results are consistent with Hao and Wang's (2005) analysis indicating that despite substantial emission increases, average concentrations in Chinese cities for total suspended particulates, PM-10, and $SO_2$ declined by 25, 10 and 44 percent, respectively, between 1990 and 2002. In other words, some areas in Asia have apparently gone through their environmental transitions for a variety of air pollutants, and at lower levels of economic development than in the US.

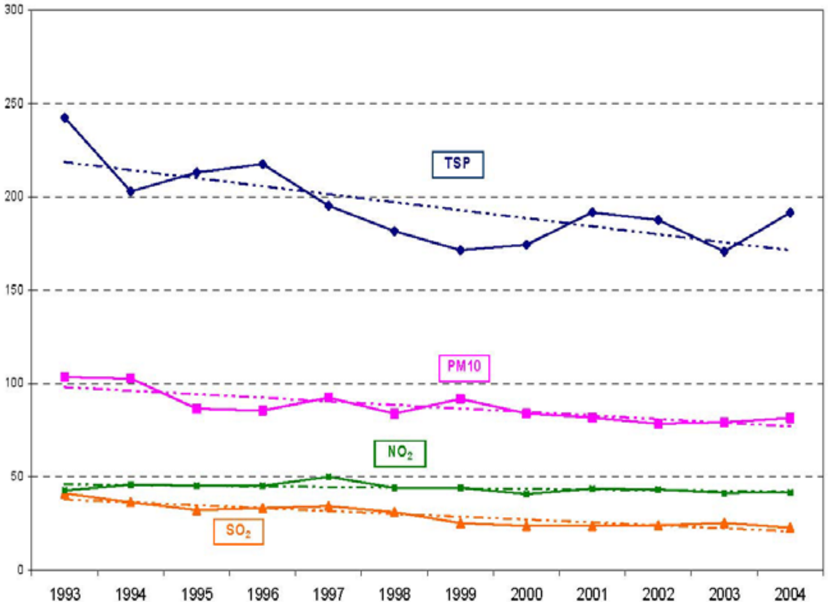

**Figure 7: Air Quality trends in 20 major Asian Cities, 1993-2004.** Source: CAI-Asia (2006).

There have been improvements in Latin America as well. Figure 8 shows improvements in Mexico City, legendary for its air pollution, from 1986-2006 (Molina et al. 2008). Similarly, PM-10 concentrations in Brazil's industrial region of Cubatao — among the world's fastest growing industrial areas — declined from 180 to about 80 micrograms per cubic meter from 1984-1998 (Wheeler 2001). Fine particulate matter (PM-2.5) concentrations dropped 52 percent in Santiago, Chile between 1989 and 2001 (Koutrakis et al. 2005).

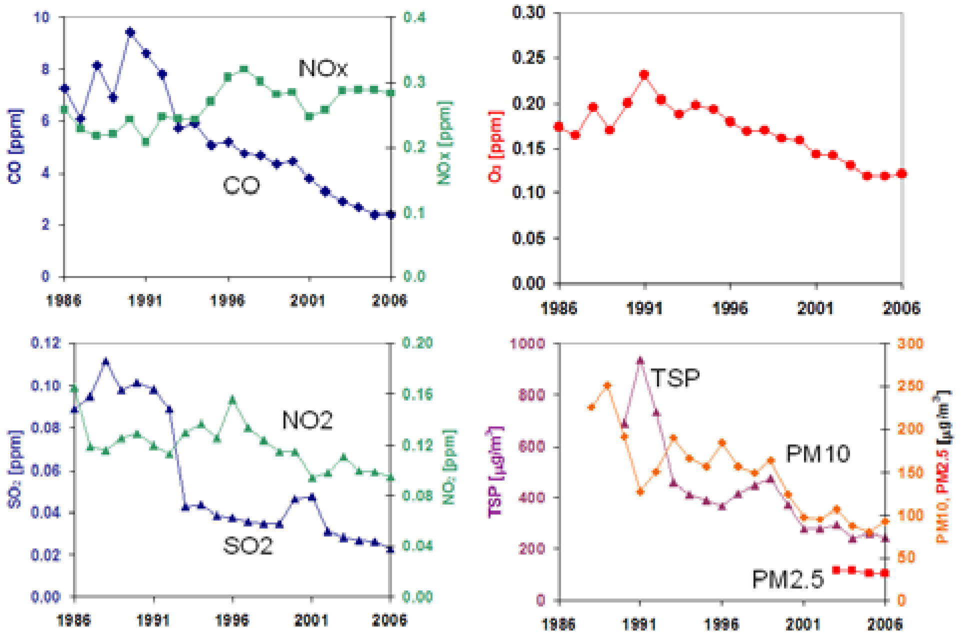

**Figure 8: Air quality trends in the Mexico City Metropolitan Area, 1986-2006.** Source: Molina et al. (2008).

The major air pollution problems in developing countries are, however, indoors. Half of the world's population continues to use solid fuels such as coal, dung and wood. The World Health Organization*'s Global Burden of Disease 2000 (Version 2)* study estimates that in 2000 air pollution was responsible for 2.4 million premature deaths (or 4.3 percent of all deaths), two-thirds of which were attributed to indoor pollution from particulate matter in developing countries from cooking and heating with coal, dung and wood and the remainder to outdoor air pollution (WHO 2002a, 2002b; Bruce et al. 2000) . On the basis of disability-adjusted life years (DALYs), a measure which discounts every year of life lived under a disability by the severity of that disability, indoor air pollution accounts for 2.7 percent of annual lost DALYs worldwide, and outdoor air for 0.5 percent.

Economic growth, by giving the inhabitants of developing countries the means to switch out of dirty solid fuels and into cleaner, but no-longer-exotic, technologies such as natural gas, oil or even electricity, would help reduce the disease burden in these countries significantly, essentially allowing today's developing countries to follow the same path so successfully taken by the rich nations in reducing population exposure to air pollutants.

### *4.4 Global Warming*

Carbon Dioxide. Unlike the other environmental indicators examined thus far, carbon dioxide has only recently been elevated in the popular mind as a significant environmental problem. Arguably, this elevation did not occur until around the late 1990s with the passage of the Kyoto Protocol or even the first decade of the 21st century, with the publication of the IPCC's Third and Fourth Assessment Reports. Even now, some would dispute this characterization, while others would dispute its importance (e.g., Lomborg 2004; Goklany 2005). Efforts to reduce $CO_2$, therefore, are still immature. This task is further complicated by the socioeconomic consequences of reducing $CO_2$ emissions (Nordhaus 2008) and the fact that it will necessarily take time, technology and capital to modify existing energy infrastructure. Accordingly, it is no surprise that empirical trends do not indicate that $CO_2$ has peaked, although as shown below, various areas have peaks in emissions per GDP (or the carbon intensity), which is a *leading* environmental indicator (because absent a long term sustained reduction in it, a growing economy will be unable to bring about a transition with respect to total emissions; Goklany 2007a).

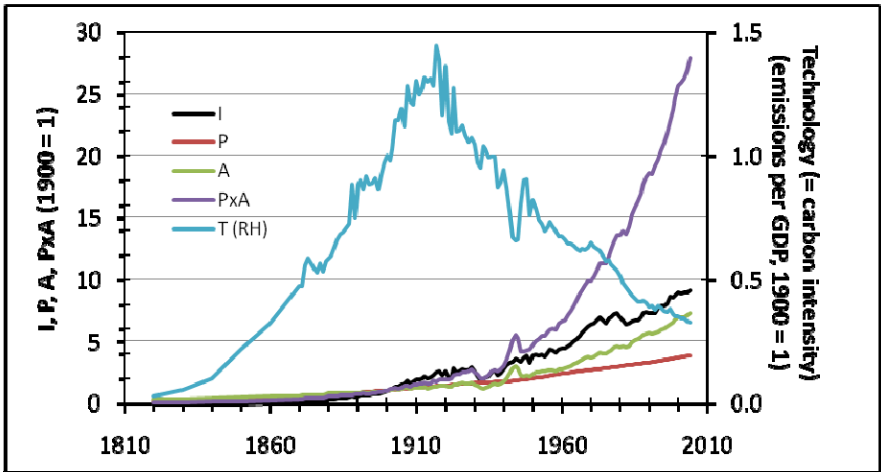

**Figure 9: IPAT trends for CO2, US, 1820-2004.** Sources: Marland et al. (2007), Maddison (2003), GGDC (2008).

Figures 9 and 10 show US and global trends from 1820 to 2004 in each of the terms of the IPAT equation and PxA (=GDP), all normalized to 1900. I (i.e., $CO_2$ emissions), P, A, and PxA are plotted on the left hand axis, and technology (=I/PxA) on the right hand axis.

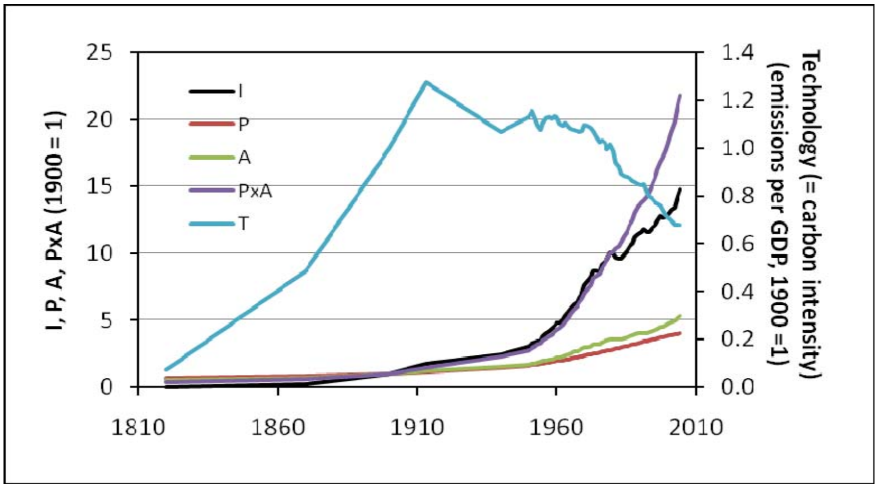

**Figure 10: Global, 1820-2004.** Sources: Marland et al. (2007), Maddison (2003), GGDC (2008), World Bank (2008a).

They show that for the US, despite a 27-fold increase in consumption (i.e., GDP) since 1900, $CO_2$ emissions increased 8-fold. This translates into a 67 percent reduction in impact per unit of consumption (i.e, the T-factor, which is also the carbon intensity of the economy) during this period, or a 1.1 percent reduction per year in the carbon intensity between 1900 and 2004. Since 1950, however, US carbon intensity has declined at an annual rate of 1.7 percent. Arguably, $CO_2$ emissions might have been lower, but for the hurdles faced by nuclear power.

Globally, consumption increased 21-fold since 1900, while $CO_2$ increased 13-fold because technology reduced the impact cumulatively by 32 percent or 0.4 percent per year. Both US and global carbon intensity increased until the early decades of the 20th century. Since 1950, global carbon intensity has declined at the rate of 0.9 percent per year.

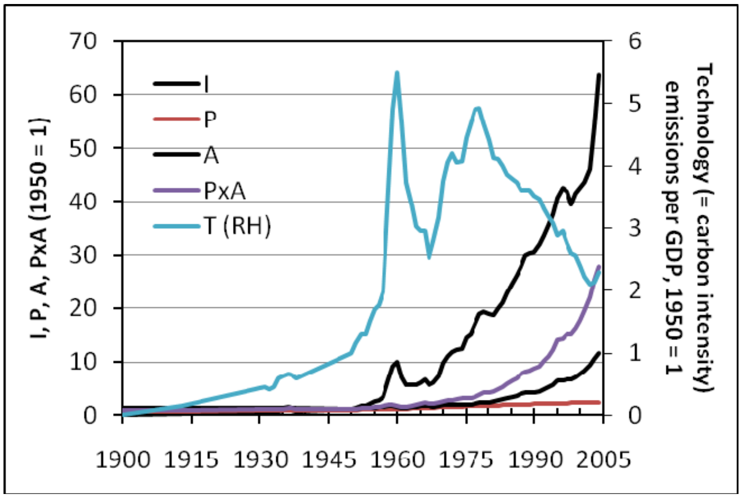

**Figure 11: China, 1900-2004.** Sources: Marland et al. (2007), Maddison (2003), GGDC (2008).

Figure 11 shows the components of IPAT and PxA for China from 1900-2004, each normalized to 1950 levels. Chinese consumption increased by a factor of 27 since 1950, while $CO_2$ emissions increased by more than twice as much (a factor of 63), reflecting its rapid transition from a rural agrarian society to the world's manufactory. From 1950 to 2004, improvements in carbon intensity failed to keep pace with the cumulative consumption increase. Since 1979, the first year of China's economic reforms, carbon intensity has dropped at an annual rate of 1.3 percent, in part because of the reforms. Nevertheless, this drop isn't large enough to compensate for the tremendous increase in consumption.

Since improvements in technology mostly preceded general recognition of $CO_2$ as an environmental issue, they can mainly be attributed to "business as usual" where all economic participants seek to maximize private welfare (including profits) via minimization of costs (including energy costs).

Deaths due to Extreme Events. To the extent that extreme weather events are exacerbated by global warming, deaths due to such events could be an indicator of the impacts of global warming.

Globally, both cumulative mortality and cumulative mortality rate for all extreme weather events (namely, drought, extreme temperatures, floods, slides, waves and surges, wildfires, and wind storms) have been declining since the 1920s [Goklany (2007c), based on data from EM-DAT (2007)]). While older data are necessarily suspect, between 1900-1909 to 1997-2006, mortality apparently dropped by 80 percent and mortality rate by 95 percent, the latter at an annual rate of 4.6

percent (see Table 1). The drops after the 1920s (not shown below) are even steeper (Goklany 2007c).

| | Deaths, earliest 10-yr period | Deaths, final 10-yr period | Death rates, earliest 10-yr period (per million) | Death rates, final 10-yr period (per million) | Technological change (%), based on mortality rate | Rate of technological change (%/yr), based on mortality rate |
|---|---|---|---|---|---|---|
| **World**<br>**all extreme events**<br>**1900/09-1997/2006** | 1,280,000 | 258,000 | 78.8 | 4.17 | -94.7 | -4.6 |
| **U.S.**<br>**Hurricanes**<br>**1900/09-1997/2006** | 8,730 | 1,760 | 11.3 | 0.60 | -94.7 | -4.6 |
| **U.S.**<br>**floods**<br>**1903/12-1997/2006** | 260 | 740 | 0.31 | 0.26 | -15.8 | -0.3 |
| **U.S.**<br>**tornados**<br>**1917/26-1997/2006** | 3,160 | 620 | 2.90 | 0.22 | -92.5 | -4.1 |
| **U.S.**<br>**Lightning**<br>**1959/68-1997/2006** | 1,180 | 440 | 0.63 | 0.16 | -75.4 | -2.2 |

**Table 1: The effects of technological change on declining US and global mortality and mortality rate for extreme weather events during the 20th century**. Source: Goklany (2007c), based on EM-DAT (2007) for global mortality data; McEvedy and Jones (1978) for global population; Blake et al. (2007) for US hurricanes; NCDC (2005, 2007) and NWS (2007) for US lightning and tornados; HIC (2007) for US floods; USBC (2007 for US population. NOTE: A negative sign indicates that technological change reduces impacts.

Table 1 also shows that with regard to the US, a similar comparison of the earliest 10-year period to the latest 10-year period (1997-2006) for which data were available at the time of analysis, mortality due to hurricanes, tornados and lightning was reduced by 80, 80 and 63 percent, and mortality *rate* by an annual rate of 4.6, 4.1 and 2.2 percent per year, respectively. However, for floods, mortality increased by 85 percent, but mortality rate declined 16 percent (an annual rate of 0.3 percent).

Note that for each of each of these US indicators in Table 1, except hurricanes, mortality and mortality rates peaked during the 20th century. For hurricanes the peak occurred in 1900-1909, and was dominated by the 8,000 fatalities due to the 1900 Galveston hurricane, and there was a subsidiary peak during the last period because of the 2005 hurricane season, for which I used a death tally of 1,525 per Blake (2007).

## 5. Are Resources Becoming Scarcer?

Neo-Malthusians are also concerned that as populations increase and become more affluent, basic resources will become scarcer, and that we may even run out of some. This, of course, was the basis for the famous bet between Paul Ehrlich and Julian Simon over whether the price of a basket of commodities would increase from 1980 to 1990, which the latter won.

However, in the last decade nominal (i.e., current) prices for most commodities — food, energy, minerals and metals —have surged, largely due to increased demand in industrializing China and, to a lesser extent, India and elsewhere. In this section I will examine whether and to what extent recent increases have made these commodities less affordable. I'll focus on metals, gasoline, and food in a variety of settings.

My preferred index of affordability is the ratio of price to an individual's wages or disposable personal income — the lower the ratio the less affordable the commodity. However, where data on wages and disposable income are not available readily, I'll use GDP or GNP per capita.

Metals. Figure 12 shows trends from 1800 to 2007 in the price of thirteen metals for the US relative to wages, indexed to the 1990 level (=100). This indicates that these metals are generally higher today than in the 1990s, but not as high as they were in the 1970s and 1980s (except possibly for zinc and nickel). Perhaps more importantly, they are more affordable today than for most of history. Of course, we have no idea whether the current blips will become a long term trend or recede like previous blips in the long slide in prices-relative-to-wages.

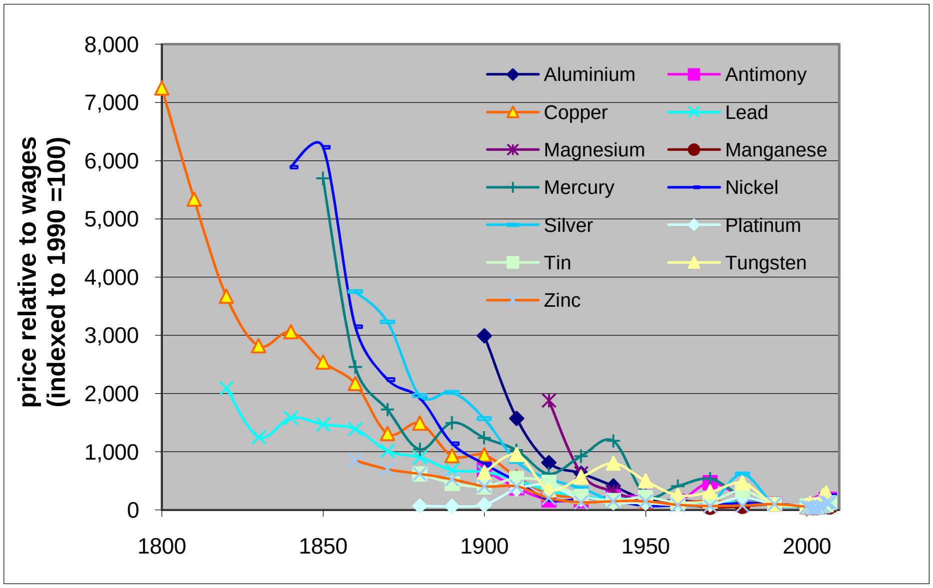

**Figure 12: Metal prices relative to wages, US, 1800-2007.** Sources: (1) Data for 1800-1990 are from Moore (1995). (2) Price data from 1990-2007 are from various issues of USGS, *Mineral Commodities Summaries* and *Minerals Year Books*, available at http://minerals.usgs.gov/minerals/pubs/commodity/, visited on July 7, 2008. (3) Wage data for 1990-2007 are from Bureau of Labor Statistics, *Establishment Data: Historical Hours and Earnings*, available at, ftp://ftp.bls.gov/pub/suppl/empsit.ceseeb2.txt, visited Jun 27, 2008.

Figure 13 shows indices for the nominal and real price of metals for 1900 to June 2008. The nominal price index is patched together from Pfaffenzeller's (2007) index for six metals (aluminum, copper, lead, silver, tin, and zinc) for 1900-2000, and World Bank's (2008c) metals and minerals price index for the remainder of the period. The real price index is derived from the nominal price index using the BEA (2008) GDP deflator for 1929-2008, and the implicit price index published in US Bureau of the Census (1975) from 1900-1929. Although the indices are patched together using different data sources, there is no escaping the surge in prices since 2001-2002. Even in real terms, the metals price index hasn't been higher since World War I. However, in terms of affordability, estimated as the real GDP per capita divided by the real price, the picture is a little different.

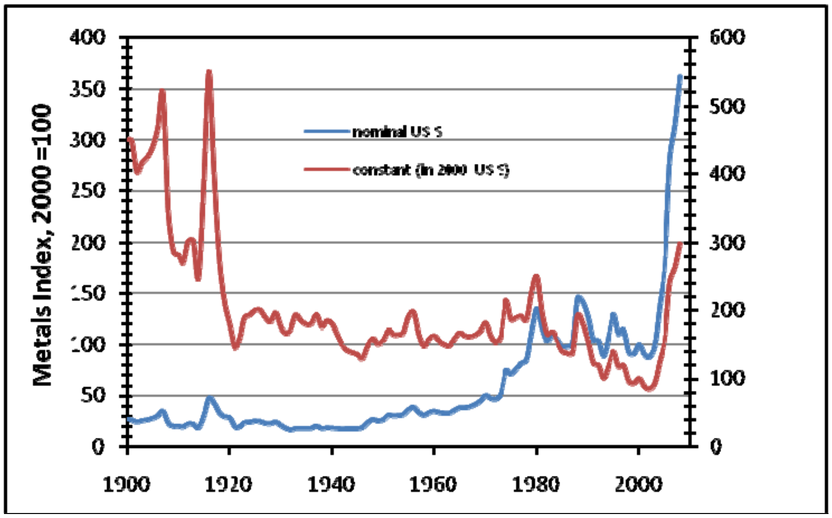

**Figure 13: Metals commodity indices, 1900-June 2008.** Sources: (1) Commodity price in nominal dollars is indexed 100 in 2000. Data are from Pfaffenzeller (2007) for 1900-2000 for metals, and from the World Bank (2008c) index for minerals and metals for 2001-June 2008, courtesy of Betty Dow, July 8, 2008. (2) Constant dollars based on GDP deflator for the US from 1929-2008 using BEA (2008), and GNP deflator from USBC (1975:.224), for 1900-1928.

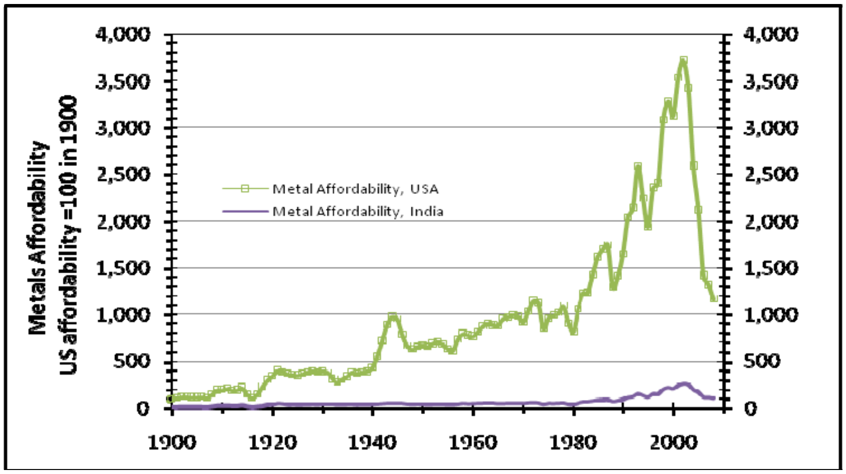

**Figure 14: Metals affordability index, India and US, 1900-June 2008.** Sources: (1) See Figure 13. (2) US and Indian GDP per capita are based on Maddison (2003) for 1900-1980, and GGDC (208) for 1981-2007. For June 2008, GDP per capita were estimated using the same growth rate as from 2006-2007.

Figure 14 shows that affordability peaked in 2002. It is presently at the 1981-1982 level for the United States, and the 1990-1991 level for India. So, despite price run ups, metals are today more affordable today than they have been historically. For the average Indian, metals are seven times more affordable today than in 1900, and for the average American, they are eleven times more affordable.

Food. Essentially similar patterns as that for metals are evident for food affordability (see Figure 15, which has been developed using the same sources and methods as that used for the previous figure.).

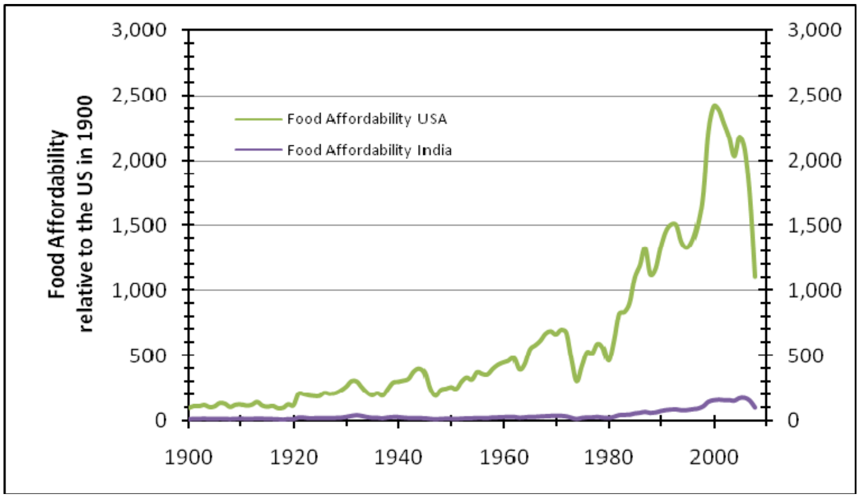

**Figure 15: Food affordability index, India and US, 1900-June 2008.** Sources: same as Figure 13.

Gasoline in the US. Figure 16 shows from 1949 to mid-2008, the nominal and real price indices for gasoline, and a gasoline affordability index for the US, the last calculated as the ratio of the average person's personal disposable income to the price of gasoline.[4] This figure, which uses a nominal price of regular gasoline of \$4.11 a gallon in mid-2008, the prevailing price at the time of writing, shows that both the real inflation-adjusted price and the nominal price are the highest they've been since at least 1949. The gasoline affordability index, currently at 1.35 indexed to the 1960 level = 1, peaked in 1998 at 3.32, and is at levels comparable to the late 1960s and early 1980s.

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[4] Figure 16 uses the price of regular leaded gasoline from 1949-1975, the arithmetical average of average of regular leaded and regular unleaded gasoline for 1976-1990, and regular unleaded for 1991-2008. For 2008, I assume a gasoline price of \$4.11 per gallon. Gasoline prices are from DOE (2008). All other economic data are from BEA (2008) — Tables 1.1.9 (for 1949-2007) and Table 2.6 (for May 2008) for the implicit price deflator for GDP, and Tables 2.1 (for 1949-2007) and Table 2.6 (for May 2008) for the real disposable income per capita.

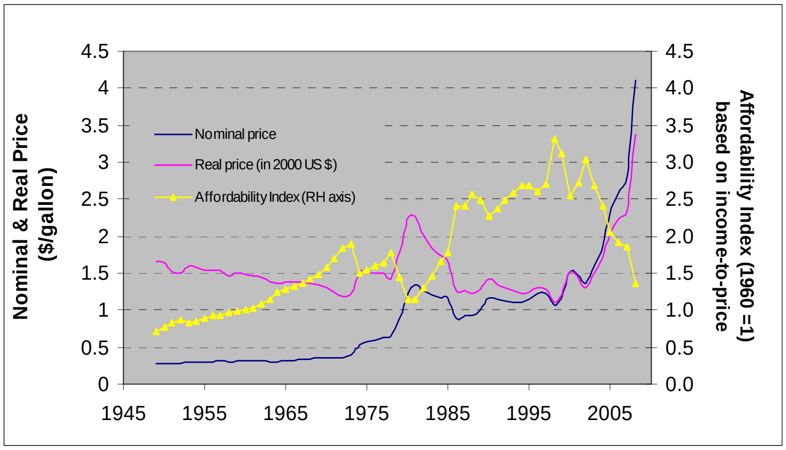

**Figure 16: Gasoline affordability index, 1949-mid 2008, (1960=1).** Sources DOE (2008), BEA (2008).

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## 6. Effects of Long Term Technological Change on Impacts

Table 2 shows for the environmental indicators and areas examined in Section 4, long term changes in environmental impact (I), population (P), affluence (A), their product (GDP = P x A), the technology factor (T), and technological change (ΔT). T and ΔT are calculated using Equations 4 or 5, except for mortality, where population is substituted for GDP.

The entries for each of the components of the IPAT equation are their values at the end of the period of analysis normalized to unity at the beginning of the period. Thus, the first row indicates that in 2006, US population was 3.22-times its 1910 level; affluence, 6.24-times; GDP, 20.08-times. Nevertheless, the environmental impact of U.S. agriculture, measured by the amount of cropland, was essentially unchanged. T, measured by cropland per GDP, was 0.05 times its 1910 level. Hence, the amount of technological change (ΔT) during the intervening period — the percent change in impact per unit of GDP — is minus 95.0 percent (in the second last column). [The *minus* sign indicates that the environmental impact per GDP *declined*, i.e., matters *improved*.] Finally, the last column provides an estimate of the annual rate of technological change, assuming exponential change (minus 3.1 percent per year).

As with all trends, results displayed in Table 2 can be sensitive to the starting and ending years used for compiling the data, particularly for episodic events, e.g., extreme weather events. To avoid bias, in these cases I used the longest readily available record.

This table indicates that since 1900 affluence has increased faster than population worldwide, and in the US, China and India.

Second, but for technological change, impacts would generally have been much higher, in many instances by an order of magnitude or more. For instance, per unit of GDP, technological change reduced the global environmental impact of agriculture by 84 percent from 1950 to 2005. In fact, it has stabilized the amount of habitat converted to cropland in the US and almost stabilized it globally (Figures 4 and 5). During the 20th century, it reduced death rates from various water related diseases in the US by 99.6-100 percent. It also reduced the cumulative global death rate from extreme weather events by 95 percent, while reducing US death rates from hurricanes, lightning, floods and tornados by 16-95 percent. Because of technology, US indoor air pollution levels are currently 96 to 99 (+) percent lower than they otherwise would be. However, while technology reduced the rate of increase, $CO_2$ emissions, nevertheless, grew substantially.

Third, improvements are apparently more pronounced for indicators most directly related to human well-being. Specifically, for each pollutant, indoor air quality improved earlier and faster than emissions, and mortality rates were reduced more than indicators whose relationship to public health is more indirect. With respect to global warming related indicators, mortality rates from total extreme weather events declined substantially, although carbon dioxide emissions increased despite reductions in the carbon intensities of economies. This is true even in India and China, where recent improvements in carbon intensities coincide with the initiation of economic liberalization, despite generous fuel subsidies to consumers.

For the environmental indicators used to characterize the impacts on land, air, and water — cropland, indoor air quality, traditional air pollutant emissions, and mortality from water-related diseases — technological change generally more than compensated for any long term increase that might have occurred in impact due to increases in either population or affluence, but not always for the combined effect of the two (i.e., P x A). The exception to this is US $NO_x$ emissions where technology compensated for population increase between 1900 and 2003, but not for affluence.

What the table doesn't show is that even where technology was unable to fully compensate for the increase in aggregate consumption — and national air emissions, including $NO_{x,}$ are cases in point — impacts at the end of the period were substantially lower than in previous decades (Goklany 2007a: 133).

In general, long term environmental trends have not conformed to the notion that, sooner or later, technology will necessarily increase environmental impacts. Moreover, if one goes sufficiently far back into the historical record, e.g., for habitat converted to cropland, air pollution emissions or water related diseases, the initial trends will show environmental deterioration, seemingly validating the Neo-Malthusian view. But over time this interpretation fails, as the environmental impact is more or less halted (e.g., cropland) or even reversed (air and water pollution) (Goklany 2007a). Such declines indicate that, in effect, sooner or later technology no longer acts as a multiplier, but as a divisor for the environmental impact.

## 7. Discussion

Long term empirical trends offer little support for Neo-Malthusian worldviews. Population has increased, but affluence and consumption have grown even faster. Yet metals, food and energy are more affordable today than they have been for much of history.

Initially environmental quality suffered, but by virtually every critical measure — hunger, malnutrition, mortality, education, income, liberty, leisure, material goods, mobility, life expectancy — human well-being advanced. In the US, for instance, this advance has been more or less continuous since the 1850s, despite the waxing and waning of a variety of environmental problems in the interim. And this is also true for the world as a whole, at least since the 1950s (Goklany 2007a).

The improvements in human well-being despite increased population suggest that affluence and, contrary to Diamond's (2005: 505) claim, technology, have solved more problems than they have created.

Historically, in the richer countries hunger and water related diseases were conquered first, then indoor air pollution, and finally outdoor air pollution. Once richer countries learned to cope with water related diseases such as cholera and dysentery (through knowledge of basic hygiene, a better understanding of the causes of these diseases, better access to safe water and sanitation, draining of swamps, and so forth), there was little *public* emphasis on other environmental problems. Despite that, *private* actions for the most part cleaned up indoor air pollution. These actions, including voluntary switching to cleaner fuels and installation of more efficient combustion appliances, were enabled by greater prosperity and technological change, and driven by each household's natural desire to advance its own quality of life.

Similar economic and behavioral forces were also at work for outdoor air pollution, and the pollution intensity of the economy declined, but not rapidly enough even though, in retrospect, many of the traditional air pollutants were in the midst of, or had even gone through, their environmental transitions (Goklany 2007a). In the US, in the wake of the prosperity of the 1960s and early 1970s and once the privations of the Great Depression and World War II had become distant, the clamor for governmental intervention grew. The resulting regulations accelerated the underlying rate of improvement driven by the imperative for economic efficiency in a relatively free market system, and was compounded by the transition from a manufacturing economy to a service and knowledge based economy. Consequently, environmental quality is much better now than in previous decades. Carbon dioxide emissions, however, continue to grow. But this is due to the fact that it's a late arrival to society's list of environmental problems — in fact, its importance, given other global problems, is still contested — and, in any case, there's been insufficient time to address it economically (Lomborg 2004; Goklany 2005, 2007a; Nordhaus 2008).

Today's developing countries have been following the path laid down by the early developers. Many of them have lower environmental quality than previously, but because of the diffusion of technology (which includes knowledge) from developed countries, they are farther along than early trailblazers like the US at the same level of economic development. For instance, in 2006 when GDP per capita for low income countries was $1,327, their life expectancy was 60.4 years, a level that the US first reached in 1921, when its GDP per capita was $5,300. Even Sub-Saharan Africa, the world's developmental laggard, is today ahead of where the US used to be! In 2006, its per capita GDP was at the same level as the US in 1820 but the US first reached Sub-Saharan Africa's current infant mortality level in 1917, and life expectancy in 1902 (estimated from World Bank 2008a, Maddison 2003, GGDC 2008; USBC 2008).

It can't be overemphasized that despite any environmental deterioration that may have occurred, human well-being of the vast majority of the world's population has been improving and is generally higher today than it's ever been, as indicated not only by life expectancy and mortality rates, but by other critical measures of well-being, including poverty, food supplies, education, child labor, and so forth (Goklany 2007a).

Why does reality not mirror Neo-Malthusian concerns?

First, much of the environmental and Neo-Malthusian narrative implicitly or explicitly equates human well-being with environmental well-being. While the latter may be a component of the former, the two aren't the same. Few outside of some in the well-developed countries would rank environmental indicators among the highest indicators of human well-being, except perhaps for access to safe water and sanitation.[5] In fact, the most critical indicators of human well-being — life expectancy, mortality rates, prevalence of hunger and malnutrition, literacy, education, child labor, or poverty —generally improved even during periods when other environmental indicators were deteriorating (e.g., Figure 2), indicating a lack of correlation between the two over the long term. In fact, long term trends are consistent with the environmental transition hypothesis in that in its early stages, economic and technological development is negatively correlated with environmental quality, whereas at high levels of development the correlation is positive (Goklany 2007a).

Second, population growth has slowed. It's no longer growing exponentially. And affluence and technology have much to do with that (Figure 1).

Neo-Malthusians also overlook the fact that affluence, technology and human well-being reinforce each other in what has been called the cycle of progress (Goklany 2007a). If existing technologies are not up to the task of reducing impacts or otherwise improving the quality of life, it's possible with wealth and human capital to improve existing technologies or create new ones that will. HIV/AIDS is a case in point.

When HIV/AIDS appeared on the scene, it was totally unanticipated. It was, for practical purposes, a death sentence for those who contracted it. It took the wealth and human capital of the most developed countries to launch a response. Out of this came an understanding of the disease and a variety of therapies were formulated. Once among the top ten killers in the US, today HIV ranks nineteenth (counting all cancers and cardiovascular diseases as single categories). From 1995 to 2004, age-adjusted death rates due to HIV declined by over 70 percent (USBC 2008). The rich countries have figured out how to cope with it, and developing countries are benefiting from the technologies that the former were able to develop because they had the necessary economic and human resources, and institutions at their disposal.

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[5] This also helps explain why these environmental problems are among the first to be solved, and why lack of such

Third, both technology and affluence are necessary because while technology provides the methods to reduce environmental problems, affluence provides the means to afford them. In fact, access to HIV therapies in many developing countries is much higher because of wealthy charities and governments of the developed countries.

Fourth, there is a secular component to technological change (see Figures 1 and 3), so that it ought to advance even if affluence doesn't, provided we are open to scientific and technological inquiry. Thus, with secular technological change and the mutually reinforcing advances in economic development, the ability to reduce untoward impacts and enhance the quality of life has also grown rapidly.

These factors acting in concert over the long haul, have enabled technology for the most part to improve faster than either population or affluence and helped keep environmental damage in check (e.g., for cropland) or even reverse it (e.g., for water pollution, and indoor and traditional outdoor air pollution), particularly in the richer countries.

Table 2 also shows that in the long run, technology has often reduced impacts by an order of magnitude or more. Thus, notwithstanding plausible arguments that technological change would eventually increase environmental impacts, historical data suggest that, in fact, technological change *ultimately* reduces impacts, provided technology is not rejected or compromised via subsidies (which usually flow from the general public to politically favored elements of society).

A corollary to this is that projections of future impacts spanning a few decades but which do not account for technological change, more likely than not, will overestimate impacts, perhaps by orders of magnitude. In fact, this is one reason why many estimates of the future impacts of climate change are suspect, because most do not account for changes in adaptive capacity either due to secular technological change or increases in economic development (IPCC 2007: Figure SPM.2; Goklany 2007d).

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access trends downwards with economic development (Shafik 2004), indicating that virtually every country has gone past its environmental transition for these indicators (Goklany 2007a).

## 8. Conclusion

Contrary to Neo-Malthusian fears, population is no longer growing exponentially. Second, from a historical perspective, food, energy and materials are more affordable today than they have been for much of human history. Third, despite unprecedented growth in population, affluence, consumption and technological change, human well-being has never been higher, and in the last century it advanced whether trends in environmental quality were up or down.

These outcomes were all possible because of greater economic and technological development, and, more importantly, the institutions that undergird such development. Together, they steadily improved human well-being over the last century. With respect to the environment, however, their record is mixed. Initially, in the rich countries, they exacerbated environmental quality, but eventually they provided the methods and means for cleaning up the environment. That is, they enabled the transition from being part of the problem to part of the solution.

Developing countries, on the other hand, have yet to make that transition for many environmental indicators in many places, although technological diffusion, combined with a little bit of affluence, has allowed them to move ahead of developed countries at equivalent levels of development.

In general, the world seems to have made the environmental transitions for access to safe water and sanitation, and lead in gasoline, and seems to be on the verge of a transition for cropland.

So much for the past and present; what about the future?

Humanity needs to improve the well-being of the billions in developing countries that still suffer from poverty and poverty-related problems such as hunger, malnutrition, contaminated water, malaria, and other diseases, while, over the next half century, also accommodating an additional 3 billion people and containing environmental impacts.

However, just as today’s population couldn’t be sustained and well-being improved with yesterday’s technology (Table 2), tomorrow’s population cannot be sustained or its well-being advanced with today’s technology. Economic and technological development have brought us this far, and they are also necessary to move us forward.

Without them, poverty, and all its consequences, cannot be reduced; the world will have to postpone the transition for cropland; more habitat will be diverted to meet human needs; and we will be in a poorer position to cope with new and unanticipated challenges that the rest of nature may throw our way, including novel or resurgent diseases (such as another AIDS, or worse) or climatic changes.

So if affluence and technology are bad, their absence will be worse for both humanity and the rest of nature.

But neither economic nor technological development is guaranteed. Many policy preferences of some environmentalists and Neo-Malthusians, founded on their skepticism of affluence and technology, would only make progress toward a better quality of life and a more sustainable environment harder. Their fears could become self-fulfilling prophecies. Inklings of this can be seen in their antipathy toward genetically modified crops which delays progress in reducing worldwide hunger and malnutrition even as it postpones an environmental transition for cropland and the development of a more environmentally benign agriculture; in the (fortunately) largely unsuccessful efforts to subordinate human well-being to environmental quality that were used to justify restrictions on the use of DDT for public health purposes; in their opposition to the development of natural resources even under strict environmental supervision, which reduces supplies and increases prices; in the hostility to energy development whether it is fossil fuels or nuclear, and which legitimizes dubious alternatives such as land and water hungry biofuels, solar farms, and dams; and at their dismay at the development of China and India as they finally raise themselves from a poverty that the richer nations escaped from a century ago (Goklany 2007a; Boqiang 2007).

## Acknowledgment

I am grateful to Nicholas Eberstadt for bringing Pfaffenzeller (2007) to my attention.

**TABLE 2: CHANGES IN POPULATION, AFFLUENCE AND TECHNOLOGY FOR VARIOUS INDICATORS**

| | | | | | | | | Technological change | |
|---|---|---|---|---|---|---|---|---|---|
| **Indicator** | **Area** | **Period** | **Population (P)** | **Affluence (A = GDP/P)** | **P x A = GDP** | **Impact (I)** | **Technology factor (T)** | **Total )T in %** | **)T, in %/year** |
| LAND (habitat converted to cropland) | | | | | | | | | |
| cropland planted | U.S. | 1910-2006 | 3.22 | 6.24 | 20.08 | 1.00 | 0.050 | -95.0 | -3.1 |
| cropland | World | 1950-2005 | 2.56 | 3.32 | 8.49 | 1.34 | 0.157 | -84.3 | -3.3 |
| cropland | India | 1961-2005 | 2.43 | 3.19 | 7.77 | 1.05 | 0.136 | -86.4 | -4.4 |
| cropland | China | 1961-2005 | 1.97 | 10.44 | 20.57 | 1.49 | 0.072 | -92.8 | -5.8 |
| WATER (deaths due to water related diseases)* | | | | | | | | | |
| Malaria | U.S. | 1900-1970 | 2.68 | | | 0.000 | 0.000 | -100 | |
| typhoid and paratyphoid | U.S. | 1900-1997 | 3.73 | | | 0.000 | 0.000 | -100 | |
| GI diseases | U.S. | 1900-1970 | 2.68 | | | 0.004 | 0.002 | -99.8 | -8.6 |
| dysentery | U.S. | 1900-1998 | 3.78 | | | 0.014 | 0.004 | -99.6 | -5.5 |
| AIR (indoor air pollution; residential emissions per occupied household) | | | | | | | | | |
| $SO_2$ | U.S. | 1940- 2002 | 2.17 | 4.07 | 8.83 | 0.02 | 0.002 | -99.8 | -9.5 |
| VOC | U.S. | 1940- 2002 | 2.17 | 4.07 | 8.83 | 0.14 | 0.015 | -98.5 | -6.5 |
| $NO_x$ | U.S. | 1940- 2002 | 2.17 | 4.07 | 8.83 | 0.39 | 0.044 | -95.6 | -4.9 |
| PM-10 | U.S. | 1940- 2002 | 2.17 | 4.07 | 8.83 | 0.05 | 0.006 | -99.4 | -8.0 |
| CO | U.S. | 1940- 2002 | 2.17 | 4.07 | 8.83 | 0.05 | 0.006 | -99.4 | -7.9 |

| Indicator | Area | Period | Population (P) | Affluence (A = GDP/P) | P x A = GDP | Impact (I) | Technology factor (T) | Technological change | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | **Total )T in %** | **)T, in %/year** |
| AIR (national annual emissions) | | | | | | | | | |
| $SO_2$ | U.S. | 1900- 2003 | 3.80 | 7.08 | 26.93 | 1.60 | 0.059 | -94.1 | -2.7 |
| VOC | U.S. | 1900- 2003 | 3.80 | 7.08 | 26.93 | 1.89 | 0.070 | -93.0 | -2.5 |
| $NO_x$ | U.S. | 1900- 2003 | 3.80 | 7.08 | 26.93 | 7.94 | 0.295 | -70.5 | -1.2 |
| PM-10 | U.S. | 1940- 2002 | 2.17 | 4.07 | 8.83 | 0.29 | 0.033 | -96.7 | -5.4 |
| CO | U.S. | 1940- 2003 | 2.17 | 4.07 | 8.83 | 1.14 | 0.127 | -87.3 | -3.2 |
| Lead | U.S. | 1970- 2000 | 1.38 | 1.89 | 2.60 | 0.02 | 0.007 | -99.3 | -15.1 |
| GLOBAL WARMING (extreme weather events, deaths, based on 10-year averages)* | | | | | | | | | |
| Deaths due to climate-related disasters | World | 1900/09-1997/2006 | 3.67 | | | 0.20 | 0.053 | -94.7 | -.4.6 |
| Deaths from hurricanes | U.S. | 1900/09-1997/2006 | 3.44 | | | 0.20 | 0.053 | -94.7 | -4.6 |
| Deaths from floods | U.S. | 1903/12-1997/2006 | 3.25 | | | 2.85 | 0.842 | -15.8 | -0.3 |
| Deaths from tornados | U.S. | 1917/26-1997/2006 | 2.65 | | | 0.02 | 0.075 | -92.5 | -4.1 |
| Deaths from lightning | U.S. | 1959/68-1997/2006 | 1.51 | | | 0.37 | 0.246 | -75.4 | -2.2 |

| | | | | | | | | Technological change | |
|---|---|---|---|---|---|---|---|---|---|
| **Indicator** | **Area** | **Period** | **Population (P)** | **Affluence (A = GDP/P)** | **P x A = GDP** | **Impact (I)** | **Technology factor (T)** | **Total )T in %** | **)T, in %/year** |
| GLOBAL WARMING (carbon dioxide emissions from combustion and industrial sources) | | | | | | | | | |
| $CO_2$ | U.S. | 1900-2004 | 3.84 | 7.28 | 27.91 | 9.12 | 0.327 | -67.3 | -1.1 |
| $CO_2$ | U.S. | 1950-2004 | 1.92 | 3.11 | 5.99 | 2.38 | 0.398 | -60.2 | -1.7 |
| $CO_2$ | World | 1900-2004 | 4.06 | 5.37 | 21.80 | 14.81 | 0.680 | -32.0 | -0.4 |
| $CO_2$ | World | 1950-2004 | 2.51 | 3.21 | 8.06 | 4.85 | 0.602 | -39.8 | -0.9 |
| $CO_2$ | China | 1950-2004 | 2.37 | 11.74 | 27.81 | 63.66 | 2.29 | **128.9** | **1.5** |
| $CO_2$ | China | Since economic liberalization<br>1979-2004 | 1.34 | 5.06 | 6.76 | 3.31 | 0.49 | -51.1 | -1.3 |
| $CO_2$ | India | 1950-2004 | 2.97 | 3.63 | 10.77 | 20.16 | 1.87 | **87.1** | **1.2** |
| $CO_2$ | India | Since economic liberalization<br>1991-2004 | 1.24 | 1.73 | 2.16 | 1.84 | 0.85 | -14.8 | -1.1 |

*Death associated with these indicators are expected to increase with population but not with affluence (except through its effect on technology, which is captured in the T-factor). Therefore, the values of A and P x A are not relevant in these cases, and )T = percent reduction in death rates over this period. Deaths due to malaria are from USBC (1954) and Newman et al. (2004).

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