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Original Contribution

Climate Change and Global Health: Quantifying a Growing Ethical Crisis

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Abstract: Climate change, as an environmental hazard operating at the global scale, poses a unique and ''involuntary exposure'' to many societies, and therefore represents possibly the largest health inequity of our time. According to statistics from the World Health Organization (WHO), regions or populations already experiencing the most increase in diseases attributable to temperature rise in the past 30 years ironically contain those populations least responsible for causing greenhouse gas warming of the planet. Average global carbon emissions approximate one metric ton per year (tC/yr) per person. In 2004, United States per capita emissions neared 6 tC/yr (with Canada and Australia not far behind), and Japan and Western European countries range from 2 to 5 tC/yr per capita. Yet developing countries' per capita emissions approximate 0.6 tC/yr, and more than 50 countries are below 0.2 tC/yr (or 30-fold less than an average American). This imbalance between populations suffering from an increase in climate-sensitive diseases versus those nations producing greenhouse gases that cause global warming can be quantified using a ''natural debt'' index, which is the cumulative depleted CO_2 emissions per capita. This is a better representation of the responsibility for current warming than a single year's emissions. By this measure, for example, the relative responsibilities of the U.S. in relation to those of India or China is nearly double that using an index of current emissions, although it does not greatly change the relationship between India and China. Rich countries like the U.S. have caused much more of today's warming than poor ones, which have not been emitting at significant levels for many years yet, no matter what current emissions indicate. Along with taking necessary measures to reduce the extent of global warming and the associated impacts, society also needs to pursue equitable solutions that first protect the most vulnerable population groups; be they defined by demographics, income, or location. For example, according to the WHO, 88% of the disease burden attributable to climate change afflicts children under age 5 (obviously an innocent and ''nonconsenting'' segment of the population), presenting another major axis of inequity. Not only is the health burden from climate change itself greatest among the world's poor, but some of the major mitigation approaches to reduce the degree of warming may produce negative side effects disproportionately among the poor, for example, competition for land from biofuels creating pressure on food prices. Of course, in today's globalized world, eventually all nations will share some risk, but underserved populations will suffer first and most strongly

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from climate change. Moreover, growing recognition that society faces a nonlinear and potentially irreversible threat has deep ethical implications about humanity's stewardship of the planet that affect both rich and poor.

Keywords: biofuels, built environment, cobenefits, CO_2 **emissions,** food security, global warming, equity, natural debt, malaria, malnutrition

Introduction: The Public Health Context: Individual Rights Versus The Public Good

Health is essential to the quality of life and is viewed by many as a fundamental human right. While self-destructive behavior such as cigarette smoking may involve an informed choice (at least today when the risks are well-known), "second-hand smoke" inhaled by nonsmokers has been viewed as a violation of the human right to health. In fact, this involuntary exposure has been the driving force behind legislation banning smoking in the workplace and other public settings. We address how climate change, as an environmental hazard operating at the global scale, poses a unique and "involuntary exposure" to many societies, and therefore represents one of the largest health inequities of our time, and, unlike some others, is threatening to increase even more.

The conflict between individual choice versus the broader public good has been a central axiom of public health concerns. Other situations from gun control to motorcycle helmet laws also exemplify this principle; in the case of the latter, helmet laws in many locations have been repealed following protests by riders who argue that to take away this freedom represents an infringement of personal rights. Overlooked, however, are statistics on the astounding cost to local society that a single head-trauma patient causes (requiring a recovery time of months or even years) following a motorcycle crash (Hundley et al., 2004).

Now consider another aspect of a motorcycle–or for this matter, car, bus, truck, coal-fired power plant, or any greenhouse emitting activity. Is the pollution emitted from the tailpipe harming other individuals apart from the rider? Certainly most nations have air quality regulations to minimize hazardous air pollution emissions, and local populations are protected in part because of these pollution standards. But what about the portion of the exhaust that contributes to greenhouse gas warming of the globe, thereby indirectly affecting remote populations around the world—populations that have hardly contributed to global warming? These nations also tend to be the poorest, the most natural-resource-dependent, and with the least capacity to adapt to the potential increased risk of diseases and other sector impacts of climate change. Herein lies the ethical dilemma of climate change and health: those most vulnerable to the health risks are also those least responsible for creating the problem. In the same vein as cigarette legislation whereby smokers are restricted from harming nonsmokers, countries burning fossil fuels and emitting greenhouse gases must consider the negative health impacts imposed on countries burning far less. In environmental legislation, this is called the "polluter pays principle."

Climate Change and Equity

Article 3 of the United Nations Framework Convention on Climate Change (UNFCCC) states that "The Parties should protect the climate system for the benefit of the present and future generations of humankind, on the basis of equity and in accordance with their common but different responsibilities in respect to capacities" (http://www.unfccc.int/files/essential_background/background_publications_html).

Baer et al. (2000) argue that greenhouse gas emissions should be based on every person's equal right to the "atmospheric commons." The concept of equal rights to a commons has been successfully implemented in the past, for example, the UN Convention on the Law of the Sea that stipulated common ownership of the deep sea and its resources for the good of humanity (Baer et al., 2000). Similar to the above public health issues around smoking or motorcycle helmets, which illustrate the tension between private versus public rights to health, a balance might be made between national interests versus global population well-being (Maylaert et al., 2004).

The imbalance of responsibility for global warming is striking when comparing across nations. Average global carbon emissions approximate one metric ton per year (tC/yr) per person. In 2004, U.S. per capita emissions neared 6 tC/yr (with Canada and Australia not far behind), and Japan and Western European countries range from 2 to 5 tC/yr per capita. Yet developing countries' per capita emissions approximate 0.6 tC/yr, and more than 50 countries are below 0.2 tC/yr (Marland et al., 2007). It is this lowest level of emissions, in fact, that the IPCC recommends reaching (or 0.3 tC/yr per capita) if society is to stabilize the atmosphere at twice preindustrial levels, assuming a leveling of world population approximating 10 billion (Houghton et al., 1996).

In viewing climate change impacts from an ethical standpoint, Schneider and Lane (2005) note three distinct areas where inequities will be most significant: (1) *intercountry* equity, (2) *intergenerational* equity, and (3) *interspecies* equity, the latter being beyond the scope of this article. A fourth area should also be considered: *intracountry* or subnational equity (Thomas and Twyman, 2005), certainly demonstrated by the 2004 Hurricane Katrina disaster when the majority of drowning deaths in New Orleans were poor or disadvantaged; a stark reminder of the wide economic gap and varied levels of vulnerability within a single country.

Schneider and Lane (2005) further classify impacts across five potential measures: (1) market system costs in dollars per ton of carbon, (2) species lost per ton carbon, (3) human lives lost in persons per ton carbon, (4) ''distributional'' effects, e.g., income differentials per ton carbon, and (5) quality of life changes, e.g, lost pristine parks per ton carbon. Our article focuses on the ''intercountry'' or international inequity related to the human health impacts of climate change, for which the World Health Organization (WHO) has begun to quantify a few specific health outcomes influenced by climatic factors, as part of its large international Comparative Risk Assessment (CRA) (Ezzati et al., 2004).

Vulnerability and The WHO Global Burden of Disease

Vulnerability is determined by the level of *exposure* to a risk factor, *sensitivity* to that risk, and *capacity to adapt to* the risk factor. Health effects of climate change are substantially diverse and regional differences in vulnerability to climate-sensitive diseases are significant, e.g., from differences in climate exposures, public infrastructure/adaptability, or baseline climate-sensitive disease rates (Gross, 2002; Patz et al., 2005). For example, regions that experience strong El Niño events (e.g., western South America, Southeast Asia, and Africa) or locations experiencing concurrent environmental degradation could modify (up or down) the strength of climate exposures (Patz and Olson, 2006). Deforestation across Indonesia or Latin America, for instance, has altered local hydrology (Foley et al., 2005), and in the face of heavy rainfall events deforested slopes can exacerbate flooding (Patz and Kovats, 2002; Ebi et al., 2007). Areas bordering loci of high disease endemicity, such as malaria in the African highlands, could be at risk if current temperatures are limiting the geographic distribution of disease. Arctic peoples such as the Inuit are already experiencing changing risks as the Arctic has been warming (Ford et al., 2006) Society's capacity to adapt to expected changes in any of these instances will partially determine vulnerabilities to climate change-induced health hazards.

Figure 1 compares cumulative CO_2 emissions for the period from 1950 to 2000 versus WHO estimates across four health outcomes: malaria, malnutrition, diarrhea, and inland flooding fatalities (McMichael et al., 2004). Those regions or populations already experiencing the most increase in diseases attributable to temperature rise in the past 30 years ironically contain those populations least responsible for causing greenhouse gas warming of the planet. For example, Africa—a continent where an estimated 70-80% of malaria occurs—has some of the lowest per capita emissions of greenhouse gases. On the other hand, at the country level, the United States has, to date, been both the world's leading contributor to greenhouse gases and the world's highest energy consumers per capita, with Canadians and Australians not far behind. Indeed, the WHO CRA shows that 99% of the disease burden from climate change has been occurring in developing countries and 88% of that in children under age 5—age being another major axis of inequity.

Disease and Economic Burdens: The Case of Malaria

Malaria is the world's most widespread and fatal vector-borne disease, killing 1-2 million persons a year, the majority of these being young children. In fact, an estimated 25% of all-cause mortality in children aged 0-4 years is directly attributed to malaria (Sachs and Malaney, 2002). Malaria transmission is highly influenced by climate and is one reason why sub-Saharan Africa is strongly affected by climate change on the WHO global burden of diseases map. One biological reason for malaria's persistence in the tropics lies with the ''base case reproduction rate'' of malaria, which is much higher in the warm and humid tropics compared to temperate regions. The climate suitability for

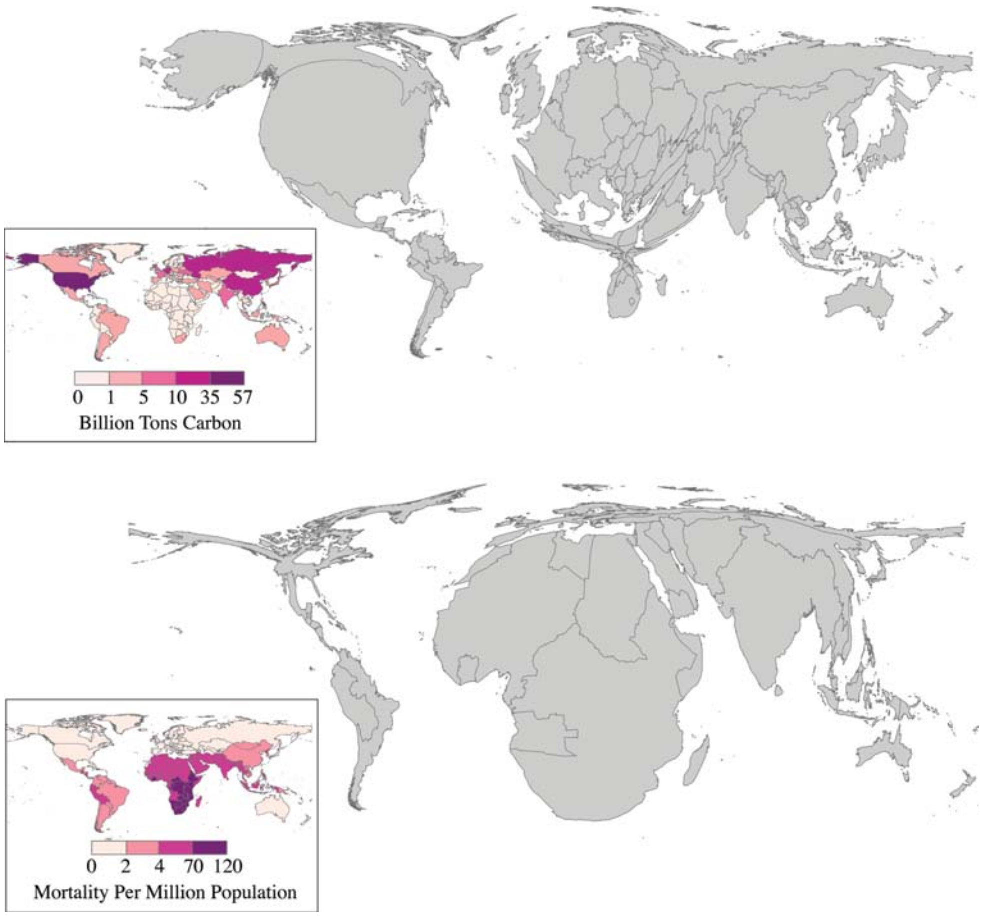

Figure 1. Comparison of undepleted cumulative carbon dioxide (CO_2) emissions (by country) for 1950 to 2000* versus the regional distribution of four climate-sensitive health effects (malaria, malnutrition, diarrhea, and inland flood-related fatalities). (**a**) CO_2 emissions data source: Marland G, Boden TA, Andres RJ (2007) Global, regional, and national fossil fuel CO_2 emissions. In: *Trends: A Compendium of Data on Global Change*, Oak Ridge, TN: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy. [*To aggregate statistics for countries that changed boundaries between 1950 and 2000, two modifications were made based on methods outlined in Smith (1991, 1996). First, for countries that became unified during the period 1950-2000, such as Germany, the sum of the carbon emissions from the separate countries before unification were added to the cumulative carbon emissions after unification. Second, for countries that separated from a union such as those in the former USSR, carbon emission that accumulated before the dissolution of the unified state were reapportioned to the member nations based on populations for the year 2000; the percent of a country's population relative to the sum of the populations of the other countries that broke from the Union determined the weight of the carbon emissions delegated to that nation. To fill gaps in the data for countries that maintained their boundary but did not collect emissions statistics for certain periods, data were extrapolated for missing years using regression methods outlined in Smith (1996).] (**b**) The Intergovernmental Panel on Climate Change (IPCC) "business as usual" greenhouse gas (GHG) emissions scenario, "IS92a," and the HadCM2 general circulation model (GCM) of the UK Hadley Centre were used to estimate climate changes relative to "baseline" 1961-1990 levels of GHGs and associated climate conditions. Existing quantitative studies of climate-health relationships were used to estimate relative changes in diarrhea, malaria, inland and coastal flooding, and malnutrition from 2000 to 2030 (McMichael et al., 2004). This is only a partial list of potential health outcomes, and there are significant uncertainties in all of the underlying models. These estimates should therefore be considered a conservative, approximate, estimate of the health burden of climate change.

malaria in the tropics has made it much more challenging to reduce regional or local disease, particularly compared with the successful eradication in many cooler temperate regions where disease transmission historically and for climate/geographic factors has been less robust.

Sachs and Malaney (2002) have shown a striking correlation between malaria and poverty. Moreover, they show that malaria-endemic countries also have a lower rate of economic growth compared with nonmalaria countries, an average growth in per capita GDP of 0.4% per year versus

2.3% per year, respectively. This is not surprising when one considers that beyond the direct health costs of disease, broader economic costs usually include work and school absenteeism, reduced tourism, and decreased foreign investment (due to reduced confidence in the health of the work force). In short, if climate change increases malaria in developing countries, development will also be impeded and the inequity of the situation expands.

One important caveat to the marked regional differences in disease risk is that globalized trade and travel can facilitate the spread of disease to distant locations. A majority of emerging diseases with the potential for global spread often start in developing tropical countries. If climate change tips the balance of disease emergence or resurgence in these regions, where there is currently inadequate disease surveillance, then both developed and developing countries may encounter an increased risk from infectious agents. Therefore, while climate change may disproportionately affect poor countries, populations in the industrialized world will also experience risk.

Natural Debt as a Conceptual Framework

We show cumulative CO_2 emissions in Figure 1 because current emissions (which are commonly used to indicate relative responsibilities by nations) are not the best indicator of actual contribution to global warming. Atmospheric warming today is the result of the greenhouse gases in the atmosphere at present, which are in turn the result of the cumulative emissions from the past minus those removed by natural processes. The problem does not stem from just the current year's emissions but rather from cumulative emissions since the start of the industrial revolution; these have been added faster than the natural assimilative capacity of the atmosphere and have resulted in the rapid buildup of greenhouse gases. The character of Earth's assimilative capacity for CO_2 emissions is complex but is known to have short- and long-term components, i.e., some is removed quickly but some remains for hundreds of years (Joos et al., 1996). Today about half of the roughly 300 Gt (gigatons) total emitted by fossil fuel combustion in human history remains in the atmosphere (Houghton, 2007).

Just as nations often borrow financial resources from the future, creating a national debt, they also essentially borrow assimilative capacity from the future by emitting pollutants faster than Earth can assimilate, creating a "natural debt" (Smith, 1991). As with national debt, a bit of natural debt is perhaps not much of a problem, but when it becomes too large, natural debt compromises the capability of future generations to take care of themselves. Thus, natural debt (cumulative depleted emissions) is probably the best simple measure of the responsibility of a region, nation, economy, or person for the current excess warming caused by human activities. By this measure, for example, in the year 2000, the average U.S. resident had about 135 metric tons of carbon in his or her name in the atmosphere from the operation of the U.S. economy over time compared with approximately 0.25 t for the average Cambodian. Other rich countries also have high natural debts: Canada, ~100; UK, ~85; Japan, ~55, but not nearly as high as the U.S. Middle-income countries generally have natural debts less than 40 t, e.g., Mexico has approximately 20 and Turkey has approximately 15. Poor countries have natural debts less than 5 t/capita.

Natural debts vary even more than current emissions because most rich countries have been emitting at high levels for many decades and thus have high natural debts. Most of the rapidly growing developing countries, however, have been emitting strongly only in relatively recent years, not long enough to build up large natural debts. Thus, for example, around 2000 the ratio of per-capita emissions between the U.S. and either China or India was almost two times greater by a measure of natural debt compared to current emissions. Most importantly, even though the gap in current emissions is closing between the older rich countries and rapidly growing economies like those in India and China, natural debts are only slowly converging. Indeed, by this more accurate indicator of responsibility for global warming, developing countries will never catch up because by the time they start to have natural debts like those in the currently developed countries they will have graduated to developed country status themselves (Green and Smith, 2002).

With such an indicator of responsibility we can examine the change in climate change health burden in a more quantitative fashion. This is shown in Figure 2, which puts climate change risk into the context of other environmental health risks, using the WHO CRA results, which is the only consistent, coherent, complete, and combined (morbidity and mortality) database available worldwide (Smith and Ezzati, 2005). This is reflected in Figure 2 where health burden is measured as DALYs (lost life years) per 1000 capita on a log scale. Consistent with the Environmental Risk Transition framework (Smith, 1990), Fig-

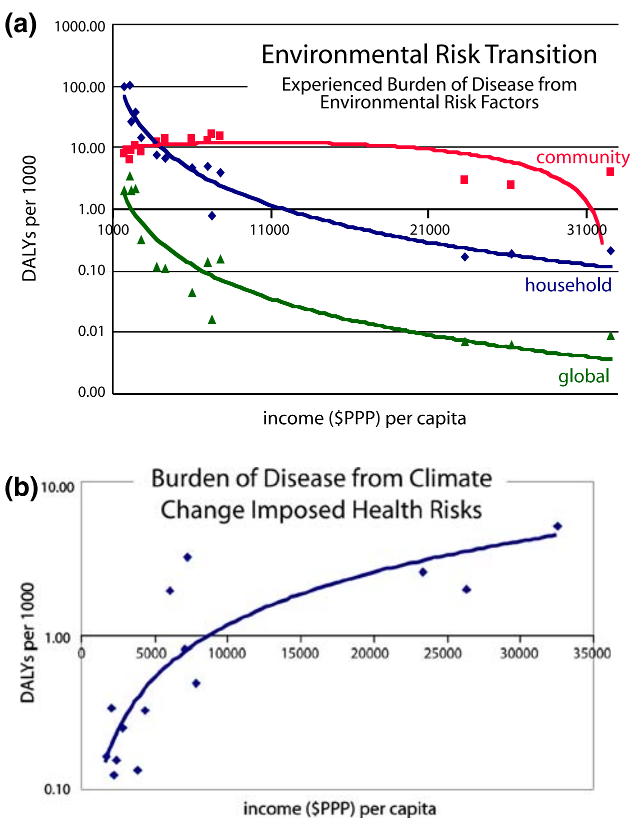

Figure 2. (**a**) Environmental risk transition with experienced burden of disease from environmental risk factors. Imposed ill health from greenhouse gas emissions by income around the year 2000. Note that household risks decline with economic development and community risks tend to at first rise and then fall. Experienced global risks fall steeply with development (from Smith and Ezzati 2005). (**b**) Burden of disease from climate change imposed health risks. Using natural debt as the indicator of responsibility, this shows the distribution of imposed global health burden from climate change according to income. It has the inverse trend of the experienced global risks in (**a**) (from Smith and Ezzati 2005 and Smith 1996).

ure 2a shows that household risks (e.g., dirty water and air) decline with income and community risks (e.g., urban air pollution, traffic, traffic accidents, occupational hazards) rise at first and then fall. Experienced global risks from climate change follow a pattern somewhat like household risks, i.e., a steep decline with development. Unlike the other two types of risk, however, those that experience global risks are in entirely different parts of the world than those that impose it. Figure 2b, therefore, shows who is actually imposing the risk, using natural debt as the indicator for the relative share of each country for the total global health risk from climate change to the year 2000. This map illustrates the inverse pattern, with poor countries imposing much less burden than rich countries (Smith and Ezzati, 2005). These figures quantify the patterns shown in the maps of Figure 1.

Note in Figure 2a that the total health burden from climate change in 2000 was much smaller than that from other environmental risks. Of course, it is not the relatively small burden attributable to climate change to date that is the major concern but that this risk is rising. The curve for global risk will be shifting upward with time, although presumably with the same general shape, i.e., with the poor at much more risk. Thus, the *avoidable* risk from climate change (what can be avoided if action is taken now) is greater than the *attributable* risk that has been expressed so far.

The natural debt calculations depicted in Figure 2b were based on only emissions of CO_2, which is the major, but not sole, greenhouse gas and is mainly the result of fossil fuel combustion. Addition of the other two major greenhouse gases quantified globally by IPCC, methane and N_2O, which are also produced by agricultural and other activities, would reduce the inequity somewhat because the differences between rich and poor nations are less. The overall pattern of global inequality would remain, however, which is that rich populations impose hundreds of times more health risk than they experience and poor countries experience far more health risk than they impose.

Approaching Future Energy Alternatives With Ethics and Open Eyes

As society begins to make necessary gains in mitigating global warming and the associated impacts, it also needs to pursue equitable solutions that first protect the most vulnerable population groups, e.g, be they defined by demographics, income, or location (Wilkinson et al., 2007a). Needed also are comprehensive assessments with broad knowledge of tradeoffs and cross-sector effects. As a first step toward optimizing solutions for climate change, *co-benefits* from energy conservation and ultimately decreased fossil fuel combustion should be recognized. The most direct and obvious cobenefit from lowering greenhouse gas emissions is the reduction in air pollution; according to the WHO, about 2.4 million premature deaths occur from indoor and outdoor air pollution annually, essentially all from combustion sources with greenhouse implications as well (WHO, 2002; Ezzati et al., 2004). If urban and household energy use were more efficient, aside from healthier air quality there are other benefits to gain as well, including improved economic and energy security.

Multiple Cobenefits from Sustainable Urban Design

Urban design throughout the world has become decoupled from public health. Sprawling suburbs, particularly in the U.S., have fostered dependence on the automobile, with subsequent negative health effects such as air pollution, the urban heat island effect, and reduced personal fitness and mental health (Frumkin et al., 2004; Wilkinson et al., 2007b). Not surprisingly, the urban poor experience a disproportionate amount of these hazardous exposures, an issue of "environmental justice" (or injustice in this case).

Great gains in health could be achieved if cities were redesigned to be more fitness promoting and, at the same time, environmentally sustainable (Patz et al., 2007). For example, according to a U.S. Department of Transportation National Household Survey, for respondents who indicated they used mass transit, the median time of walking to and from transit approached 20 minutes (Besser and Dannenberg, 2005), which is equivalent to two thirds of the minimum recommended daily exercise level. Of the ten leading causes of death in the U.S., most can be attributed in part to a sedentary lifestyle. According to the Department of Transportation, 40% of trips made by car are less than two miles (Department of Transportation, 2001), a distance easily achieved on a bicycle. Therefore, if car trips could be replaced by biking or walking, a significant "triple-win" of personal fitness, improved respiratory health from improved air quality, and reduced tons of emitted greenhouse gases could be achieved (M.L. Grabow et al., unpublished data). But disadvantaged urban groups must be included in such planning to avoid the potential for widening the already large gap in the access to healthy and desirable neighborhoods. New areas must also be designed with cultural sensitivity and diversity in mind so that marginalized segments of society can be afforded a realistic chance to new health opportunities and environmental justice issues are considered at every level.

Caution with Biofuels: "Feeding" the Combustion Engine at the Cost of Not Feeding People or Protecting Tropical Biodiversity?

The Fourth Assessment Report of the IPCC (2007) concluded that with "90 percent certainty," human activity (primarily burning fossil fuels and cutting tropical forests) is causing global warming. In the wake of this latest international assessment, political will is already shifting in recognition of the need to reduce greenhouse gases and reduce the adverse consequences of climate change. As attention on energy alternatives to fossil fuels heightens, issues of health, environment, and development must be simultaneously at the planning table. Pros and cons of nuclear power, for example, are well recognized by environmental and health scientists. But fewer cost/benefit analyses have been conducted for biofuels over the years (Berndesa et al., 2003; Hill et al., 2006).

While reducing our reliance on fossil fuel energy is immediately and obviously necessary, an unregulated biofuels boom could affect world food supplies and price (United Nations-Energy, 2007). If energy demand drives up the price of corn, for example, this can inflict undue burden on poor or malnourished populations or shift agricultural areas away from other traditional food crops. According to one estimate, for every percentage increase in the real price of staple foods, 16 million more people could become food-insecure (Boddiger, 2007). Furthermore, the amount of humanitarian food aid available for extremely impoverished countries will also be affected in the short term as food aid shipments from the U.S. are inversely correlated to commodity prices (Naylor et al., 2007).

Increased reliance on crop-derived ethanol or biodiesel also could have devastating effects on the fate of the world's tropical forests. Expansion of the leading biofuel crops is already evident in South America and insular Southeast Asia as large-scale fields of soybean and oil palm, respectively, expand in these regions leading to forest clearing, expulsion of subsistence farmers, and large emissions of carbon dioxide to the atmosphere (Fearnside and Laurance, 2003; Nepstad et al., 2006). New research shows that the vast majority of recently expanding oil palm fields have replaced closed forest in parts of Malaysia and Indonesia and that increases in soybean production in Brazil coincide with more forest conversion (H.K. Gibbs, unpublished data).

Conclusion

Growing evidence of the acute impacts of global environmental change is driving renewed consciousness among the world's peoples and nations of the need to act quickly to protect the planet's ecological and climatic systems. Without such action, millions of people in all countries are likely to face significantly greater health risks. Existing health disparities for many people already struggling with poverty, malnutrition, and the effects of natural disasters will be exacerbated by climate change. But unlike illness caused by unhealthy behaviors, a substantial proportion of the most vulnerable populations to climate change impacts are not the same people that are causing the problem. In addition, not only is the health burden from climate change itself greatest among the world's poor, but some of the major mitigation approaches to reduce the degree of warming may produce negative side effects disproportionately among the poor. Should they bear the brunt of adverse effects caused by industrialized nations? The inequity of the situation looms large and is already a major part of the international negotiations toward solutions to combat global climate change. As human health threats from climate change are now recognized as a core issue in the climate change arena, the WHO and other health agencies and organizations should be encouraged and supported in conducting full and equitable health impacts assessments on both the risks from and solutions to climate change.

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