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IS CLIMATE CHANGE THE "DEFINING CHALLENGE OF OUR AGE"?

Indur M. Goklany[1]

ABSTRACT

Climate change, some claim, is this century's most important environmental challenge. Mortality estimates for the year 2000 from the World Health Organization (WHO) indicate, however, that a dozen other risk factors contribute more to global mortality and global burden of disease. Moreover, the state-of-the-art British-sponsored fast track assessments (FTAs) of the global impacts of climate change show that through 2085-2100, climate change would contribute less to human health and environmental threats than other risk factors. Climate change is, therefore, unlikely to be the 21st century's most important environmental problem. Combining the FTA results with WHO's mortality estimates indicates that halting climate change would reduce cumulative mortality from hunger, malaria, and coastal flooding, by 4–10 percent in 2085 while the Kyoto Protocol would lower it by 0.4-1 percent. FTA results also show that reducing climate change will increase populations-at-risk from water stress and, possibly, threats to biodiversity. But adaptive measures focused specifically on reducing vulnerability to climate sensitive threats would reduce cumulative mortality by 50–75 percent at a fraction of the Kyoto Protocol's cost without adding to risks from water stress or to biodiversity. Such "focused adaptation" would, moreover, reduce major hurdles to the developing world's sustainable economic development, lack of which is the major reason for its vulnerability to climate change (and any other form of adversity). Thus, focused adaptation can combat climate change and advance global well-being, particularly of the world's most vulnerable populations, more effectively than aggressive GHG reductions. Alternatively, these benefits and more — reductions in poverty, and infant and maternal mortality by 50-75%; increased access to safe water and sanitation; and universal literacy — can be obtained by broadly advancing sustainable economic development through policies, institutions and measures (such as those that would meet the UN Millennium Development Goals) at a cost approximating that of the Kyoto Protocol. However, in order to deal with climate change beyond the 2085-2100 timeframe, the paper also recommends expanding research and development of mitigation options, reducing barriers to implementing such options, and active science and monitoring programs to provide early warning of any "dangerous" climate change impacts.

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1. INTRODUCTION

Some scientists, media, and, more importantly, eminent policy makers claim that climate change is this century's most important global environmental problem (e.g., Clinton 1999; Cordis News 2004). For example, President Sarkozy has reportedly identified climate change as one of the two most important challenges facing society in the 21st century — the other is "the conditions of the return of the religious in most of our societies" (McNicoll 2008). And U.N. Secretary General Ban Ki-moon has declared that climate change is "the defining challenge of our age" (Rosenthal 2007). Such pronouncements fuel the quest for rapid and drastic reductions in greenhouse gas (GHG) emissions and concentrations.

I will examine whether climate change is, indeed, the most pressing environmental and human health problem the world faces this century. Accordingly, I will compare through the foreseeable future the contribution of climate change against that of non-climate-change related factors to various critical climate-sensitive risks to human and environmental well-being. With respect to human well-being, I will examine mortality from hunger, malaria (which is responsible for about 75 percent of the global burden of disease from vector-borne diseases; IPCC 2001a: 463), and coastal flooding; and the population at risk for water stress. With respect to environmental well-being, I will examine the future (projected) global effect of climate change on net biome productivity, habitat lost to cropland, and the extent of coastal wetlands.

I will then compare the costs and benefits through the foreseeable future of mitigation policies that would restrict GHGs against adaptation policies that would reduce the adverse impacts of climate change.

Building on Goklany (2005, 2007a), which compared the significance of climate change relative to non-climate-change related threats based on estimates of populations at risk (PARs) for malaria, hunger, coastal flooding, this paper makes the same comparison but based on estimates of global mortality for the present (Section 3.1) and the foreseeable future (Section 3.2). Using mortality instead of PAR enables an apples-to-apples comparison, because the relationship between PAR and public health outcomes varies from threat to threat. Also, cost estimates of adaptation options have been updated from Goklany (2005) using UN Millennium Project (2005a, 2005b, 2005c) and the IPCC (2007). These updated estimates are used to compare the costs and benefits through the foreseeable future of various mitigation and adaptation options (Section 4). Based on these estimates, the paper offers policies for the adaptive management of climate change risks (Section 5), before concluding (Section 6).

2. INFORMATION SOURCES USED IN THIS PAPER

This paper draws most of its information directly or indirectly from analyses of the global impacts of climate change based on the IPCC (2000) emission scenarios whose salient characteristics are shown in Table 1, along with the corresponding IPCC labels for the scenario, estimates of atmospheric CO_2 concentrations, global temperature increases (ΔT), and sea level rise through 2085, assuming no mitigation of climate change (Arnell et al. 2004). Columns in this and most subsequent tables are arranged in the order of decreasing ΔT, i.e., A1FI (warmest) on the left to B1 (coolest) on the right.[2]

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[2] The "FI" in "A1FI" indicates that this scenario is fossil fuel intensive.

Table 1. Characteristics and Assumptions of Various Scenarios

	Scenario A1FI	A2	B2	B1
Population in 2085 (billions)	7.9	14.2	10.2	7.9
GDP growth factor, 1990-2100	525-550	243	235	328
GDP/capita in 2085, Global average	$52,600	$13,000	$20,000	$36,600
GDP/capita in 2100				
Industrialized countries	$107,300	$46,200	$54,400	$72,800
Developing countries	$66,500	$11,000	$18,000	$40,200
Technological change	Rapid	Slow	Medium	Medium
Energy use	Very high	High	Medium	Low
Energy technologies	fossil intensive	regionally diverse	"dynamics as usual"	high efficiency
Land use change	Low-medium	Medium-high	Medium	High
CO2 concentration in 2085	810	709	561	527
Global temp change (°C) in 2085	4.0	3.3	2.4	2.1
Sea level rise (cm)	34	28	25	22

Sources: Arnell (2004): Tables 1, 6, 7; and Nicholls (2004): Tables 2 and 3. GDP and GDP/capita are in 1990 U.S. dollars. Note: Global temperature change is based on the HadCM3 model.

I will assume that the foreseeable future extends to 2085-2100. This may be overly-optimistic because the emission scenarios are driven by socioeconomic assumptions and projections which, according to a paper commissioned for the Stern Review, "cannot be projected semi-realistically for more than 5–10 years at a time" (Lorenzini and Adger 2006: 74).

For information on future climate change impacts, I will use Goklany's (2007a) compilation of peer reviewed results of the Fast Track Assessments (FTAs) of the global impacts of climate change sponsored by the British Government (Parry 2004; Arnell et al 2002; Arnell 2004; Nicholls 2004; Parry and Livermore 1999). The FTAs' authors include many significant contributors to the IPCC's assessments.

The FTAs systematically overestimate climate change impacts because they do not account fully for increases in adaptive capacity resulting from higher wealth and advances in technology assumed by the IPCC scenarios that are used to drive the FTA analyses (Goklany 2005, 2007a; Tol 2005). That is, these impact assessments are internally inconsistent with the fundamental assumptions embedded in the IPCC emissions scenarios which drive estimates of future climate change that are then used to project future impacts. Nevertheless, for this study I will mostly take the FTA results at face value because the results are peer reviewed and have played an important part in the international debate on global warming having been cited extensively by the IPCC's Assessments, the UK Government-sponsored *Symposium on Avoiding Dangerous Climate Change* during the run-up to the G8's 2005 Gleneagles Summit (DEFRA 2005), and the Stern Review (2006). Also, FTA results allow us to estimate the future contribution of climate change to various critical climate-sensitive environmental and health problems.

Like the FTA, this paper doesn't consider low-probability but potentially high-consequence outcomes (e.g., shutdown of the thermohaline circulation, or melting of the Greenland and Antarctic ice sheets). They are deemed unlikely to occur during this century, if at all (IPCC 2007: 17).

I will rely on WHO (2002) for mortality data on various food, nutritional and environmental risks, many of which are climate-sensitive; IPCC (2001b) for costs of the Kyoto Protocol; and the UN Millennium Project (2005a, b, c) for costs of reducing malaria, hunger, and other risks and hurdles to sustainable development faced by developing countries, in particular.

3. IS CLIMATE CHANGE THE WORLD'S MOST IMPORTANT ENVIRONMENTAL PROBLEM?

3.1 The Present

A review paper in *Nature* attributes 166,000 deaths worldwide in 2000 to climate change (Patz et al. 2005). This estimate is based on analysis published under WHO auspices but whose authors acknowledge that

> climate change occurs against a background of substantial natural climate variability, and its health effects are confounded by simultaneous changes in many other influences on population health. . . . Empirical observation of the health consequences of long-term climate change, followed by formulation, testing and then modification of hypotheses would therefore require long time-series (probably several decades) of careful monitoring. *While this process may accord with the canons of empirical science, it would not provide the timely information needed to inform current policy decisions on GHG emission abatement, so as to offset possible health consequences in the future*. [(McMichael et al. 2004: 1546), emphasis added.]

Even if one eschews skepticism regarding this estimate (since science was sacrificed in pursuit of predetermined policy objectives), this amounts to 0.3 percent of the 55.8 million global death toll (WHO 2002). In fact, climate change is outranked by at least 10 other health risk factors related to food, nutrition, environment and occupational exposure, whether based on global mortality or global burden of disease (using disability-adjusted life years, DALYs, lost due to a given disease). See Table 2. [This table assumes 154,000 deaths attributable to climate change per WHO (2002), rather than 166,000. Whichever estimate is employed, the ranking of climate change wouldn't change.]

Table 2. Priority Ranking of Food, Nutrition and Environmental Risk Factors Based on Lost DALYs for 2000

	Ranking	Attributable mortality		DALYs Lost	
		(000)	(%)	(000)	(%)
Underweight (insufficient food)	1	3,748	6.7%	137,801	9.5%
Blood pressure (unhealthy foods)	2	7,141	12.8%	64,270	4.4%
Unsafe water, sanitation and hygiene	3	1,730	3.1%	54,158	3.7%
Malaria (see NOTE, below)		1,121	2.0%	42,080	2.9%
Cholesterol (unhealthy foods)	4	4,415	7.9%	40,437	2.8%
Indoor smoke from solid fuels	5	1,619	2.9%	38,539	2.7%
Iron deficiency (malnutrition)	6	841	1.5%	35,057	2.4%
Overweight (unhealthy or too much food)	7	2,591	4.6%	33,415	2.3%
Zinc deficiency (malnutrition)	8	789	1.4%	28,034	1.9%
Low fruit and vegetable intake	9	2,726	4.9%	26,662	1.3%
Vitamin A deficiency (malnutrition)	10	778	1.4%	26,638	1.8%
Lead exposure (environmental)	11	234	0.4%	12,926	0.9%
Urban air pollution (environmental)	12	799	1.4%	7,865	0.5%
Climate change (environmental) (See NOTE below)	13	154	0.3%	5,517	0.48%
SUBTOTAL (see NOTE, below)		**27,566**	**49.42%**	**511,319**	**35.2%**
TOTAL IN 2000 FROM ALL CAUSES		**55,776**		**1,453,617**	

NOTES: Except for malaria, the deaths (and lost DALYs) for the various risk factors listed in the table are calculated by reassigning deaths (and lost DALYs) from immediate causes of death to the above listed risk factors. Under this approach, deaths and lost DALYs due to malaria were redistributed into the totals for underweight, zinc and Vitamin A deficiencies, and climate change. Because of that, malaria is, by itself, unranked, and the SUBTOTAL does not include the numbers for malaria. By itself malaria would have been ranked at least 4th (based on lost DALY's) or 8th (based on mortality).

Source: Goklany (2007b: 355-356), derived from World Health Report 2002, Annexes 2, 3, 11, 12, 14-16.

Climate change is outranked by more mundane problems, e.g., malaria (1.12 million deaths); underweight (3.24 million deaths);[3] unsafe water, inadequate sanitation, and hygiene (1.73 million deaths); indoor air pollution from indoor heating and cooking with wood, coal, and dung (1.62 million deaths); various micronutrient deficiencies (2.4 million deaths); insufficient fruit and vegetable intake (2.7 million deaths); urban air pollution (0.8 million deaths); and lead exposure (0.23 million deaths).

Climate change is clearly not today's most important environmental or public health problem. However, would its future impacts outweigh that of other factors?

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[3] This estimate excludes an estimated 0.51 million people who died from malaria but whose deaths were attributed to underweight in the report (WHO 2002).

3.2 The Foreseeable Future

To illuminate this issue, for public health related impacts, I will use Goklany's (2007a) compilation of FTA results for global PARs in 2085 for hunger, malaria, coastal flooding, and water resources (from Parry et al. 2004; Arnell et al. 2002; Martens et al. 1999; Nicholls 2004; Arnell 2004). I will then convert the PARs for hunger, malaria [which accounts for 75 percent of the global burden of the main vector-borne diseases, IPCC (2001a: 463, Table 9-1)], and coastal flooding into annual mortality assuming that mortality scales linearly with PAR, and that mortality for these threats between 1990 and 2001 is unchanged.[4]

Because the PAR for malaria (from Arnell et al. 2002) used an older "business-as-usual" IPCC scenario (IS92a) which also assumed no mitigation whatsoever and a 1990-2085 global temperature rise of 3.2°C, additional assumptions are necessary to derive mortality for each scenario depicted in Table 1. Specifically, I will assume that for each scenario, PAR scales linearly with the global population in 2085 without climate change, *ceteris paribus*, and that the ratio of the additional PAR due to climate change to PAR absent climate change varies with the square of the ratio of the global temperature change.

The second assumption is broadly consistent with practice employed in most integrated assessment models. It may even be conservative. Nordhaus' RICE/DICE, Manne et al.'s MERGE and Tol's FUND assume that the impacts of climate change are linear or quadratic functions of global temperature increases (ΔT), whereas Hope's PAGE assumes that impact functions (I) take the form of a polynomial such that $I = \text{constant} \times T^n$, where n is an uncertain variable whose minimum, most likely and maximum values are 1, 1.3, and 3 respectively (Warren et al. 2006).

Mortality Estimates for Hunger, Malaria and Flooding

Table 3 shows results for 1990 and 2085 for mortality due to hunger, malaria, and coastal flooding without climate change, the increase in mortality due to climate change alone, and the sum of the two for each scenario. In order to simplify this table, it shows only mortality using *upper bound estimates* for increases in PAR due to climate change, that is, Table 3 exaggerates the relative importance of climate change.

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[4] This assumption is necessary because mortality data for hunger and malaria are not readily available for 1990. The number of people suffering from chronic undernourishment in the developing countries was virtually unchanged from 1990–1992 and 2000–2002 (824 million versus 815 million; FAO 2004). Malaria killed 2 million in 1993 and 1.12 million in 2001 (WHO 1995, 2002). I will use the latter figure for 1990. Finally, there were 7,100 fatalities due to floods, windstorms and waves/surges in 1990 and an average of 7,500 for 2000–2004 (excluding deaths due to the 2004 Christmas tsunami) (EM-DAT 2005). Nevertheless, Table 7 assumes 8,000 deaths in 1990 due to coastal flooding alone. Thus Table 7 underestimates the relative importance of malaria, while overestimating coastal flooding. Both assumptions inflate the importance of climate change relative to other factors. But for these assumptions, this paper's conclusions would be even stronger. See next footnote.

Table 3. Deaths in 2085 from Hunger, Malaria, and Coastal Flooding (thousands). For simplicity only upper bound estimates are shown.

	1990 Baseline	A1FI 2085	A2 2085	B2 2085	B1 2085
Population in 2085 (billions)		7.9	14.2	10.2	7.9
Global temp change (°C) in 2085		4.0	3.3	2.4	2.1
Mortality in absence of climate change					
Hunger	3,240	407	2,976	904	349
Coastal flooding	8	2	59	28	4
Malaria	1,120	1,657	2,977	2,143	1,657
(Subtotal)	*4,368*	*2,067*	*6,012*	*3,075*	*2,010*
Change in mortality due to climate change					
Hunger	0	109	-35	19	39
Coastal flooding	0	42	222	53	27
Malaria	0	95	96	44	26
(Subtotal)	*0*	*237*	*282*	*116*	*92*
Total mortality	**4,368**	**2,304**	**6,295**	**3,191**	**2,102**

Figure 1, based on Table 3, shows that *for each scenario*, climate change's contribution to the total mortality burden from malaria, hunger, and coastal flooding is small, varying from 3.6 percent under the B1 scenario to 10.3 percent under the A1FI (richest-but-warmest) scenario. Thus, halting climate change at its 1990 level would reduce the mortality burden in 2085 from these factors by no more than 10.3 percent under the warmest (A1FI) scenario, or 237,000 deaths out of a possible 2,304,000.[5]

Second, in terms of both absolute numbers and the proportion of global population (based on population estimates from Table 1), the total mortality in 2085 from the three risk factors, hunger, malaria and flooding, is highest for the poorest scenario (A2), suggesting that lack of development, and its spillover effects such as lower levels of human capital and technological prowess, is the source of larger problems than climate change.

Notably, the methodology used to translate future PAR into mortality probably overestimates the latter because it doesn't allow fully for increases in adaptive capacity due to both economic development and technological progress (or time). However, both mortality without climate change and increase in mortality due to climate change should be overestimated to the same degree. Since impact analyses generally underestimate — if not totally neglect — future improvements in adaptive

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[5] Had I assumed a malaria death toll of 2 million in 1990 (see footnote 4), the maximum contribution of climate change to total deaths from the three risk factors listed in table 3 would have been smaller, ranging from 3.1% for the B2 scenario to 8.7% for the A1FI scenario. Also, had lower estimates been used for increases in PAR due to climate change, the contribution of climate change would also be reduced. For instance, using (a) low subsidence for coastal flooding, with delayed adaptive response and high growth in coastal areas (from Nicholls 2004), and (b) lower bound estimates for hunger (from Parry et al. 2004), the contribution of climate change to mortality in 2085 for the three risk factors would be between 0.1% for the A2 scenario to 8.5% for the A1FI scenario.

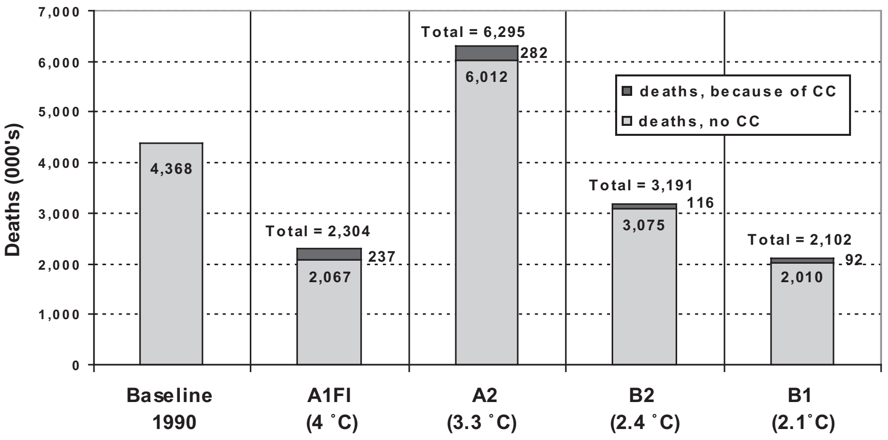

Figure 1. Deaths in 2085 due to hunger, malaria and flooding, with and without climate change.
For simplicity only upper bound estimates are shown. Source: Table 3.

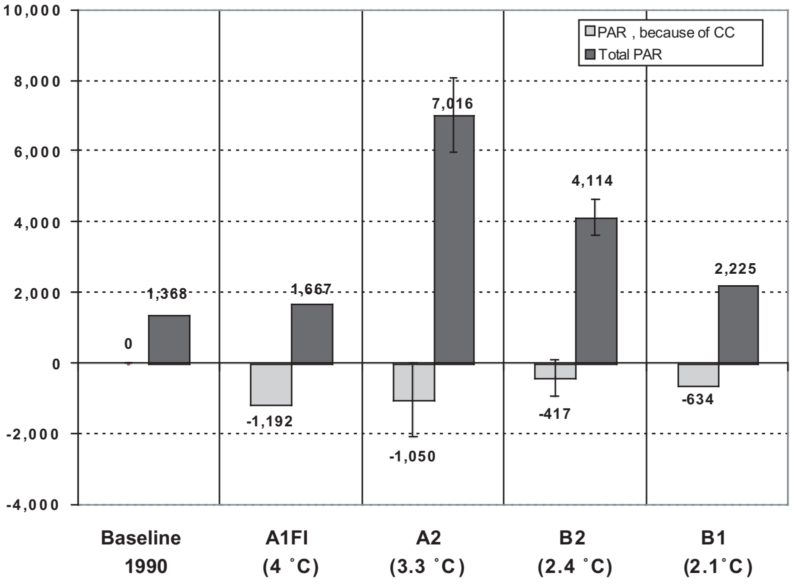

Figure 2. Population at risk (PAR) from water stress in 2085, with and without climate change. The vertical bars indicate the populations at risk based on the mid-point estimates of several model runs, while the vertical lines indicate the range of estimates. Source: Goklany (2007a), based on data from Arnell (2004).

capacity, future mortality is probably overestimated for each scenario, with larger overestimates for wealthier scenarios.

Population at Risk of Water Stress

Figure 2 indicates the PAR for water stress in 2085. It indicates that climate change would, according to the Arnell (2004) results, reduce the net global PAR of water stress. This occurs because additional warming increases average global precipitation, and although some areas may receive less, other, more populated areas receive more.

Figure 2 overestimates PAR with and without climate change since Arnell (2004) ignores adaptation.

Together, Figure 2 and Table 3 suggest that non-climate-change-related factors should generally outweigh climate change with respect to public health-related aspects of human well-being, at least through the foreseeable future.

Ecological Impacts

For ecological impacts, I will use Goklany's (2007a) results based on Levy et al. (2004) and Nicholls (2004) for the amount of habitat diverted in 2100 to cropland worldwide (currently the single most important threat to terrestrial biodiversity), net biome productivity in 2100, and the loss of global coastal wetland area in 2085. Results are shown in Figures, 3, 4 and 5, respectively.

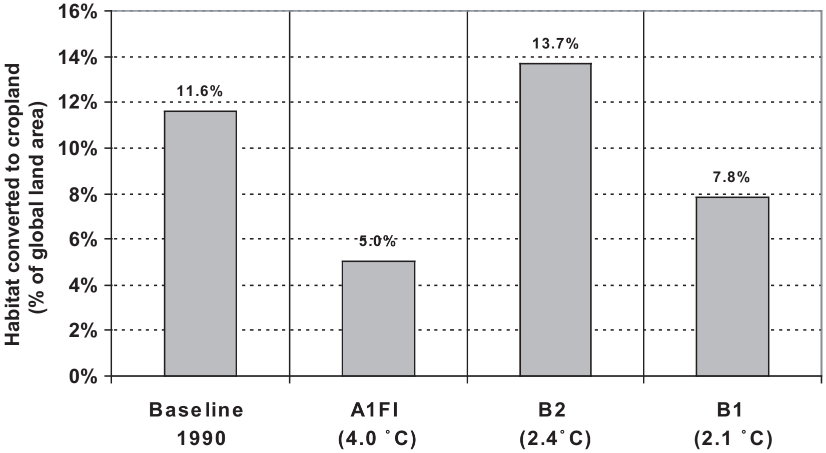

Figure 3. Habitat converted to croplands in 2100. Source: Levy et al. (2004).

Figure 3 indicates that under the IPCC's richest-but-warmest scenario, habitat converted to cropland would be reduced, at least through 2100 (compared to 1990 levels). This is probably because of a combination of higher carbon dioxide levels, i.e., higher carbon fertilization, and greater economic development, i.e., greater access to technologies (Goklany 2007a, b). Both factors would lead to higher crop yields. Figure 3 also indicates that the cooler scenarios would lead to greater pressure on biodiversity in 2085. [Note that the original source of the data, Levy et al. (2004), did not provide results for the poorest, A2, scenario.]

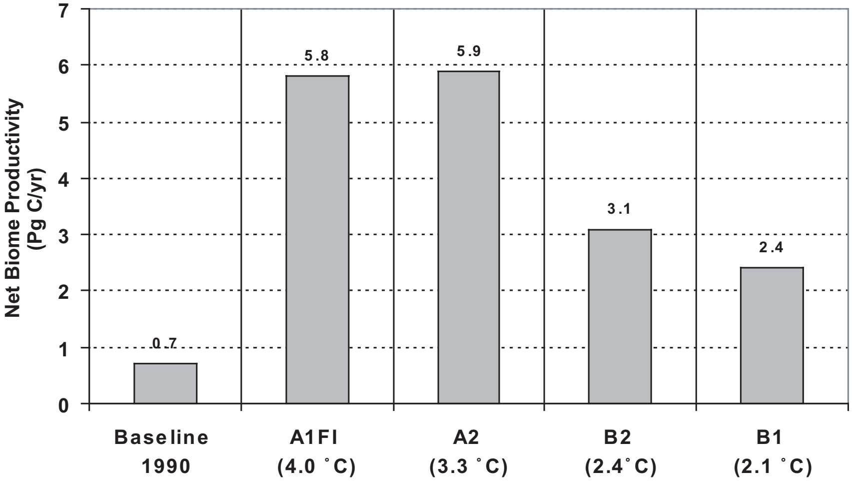

Figure 4. Net biome productivity in 2100. Source: Levy et al. (2004).

Figure 4 indicates that net biome productivity, which is also a measure of global carbon sink capacity, will be higher in 2100 than in 1990 under each scenario.

Figure 5 indicates that between 1990 and 2085, the contribution of sea level rise to global wetland loss will be outweighed by non-climate-change related factors under all scenarios.

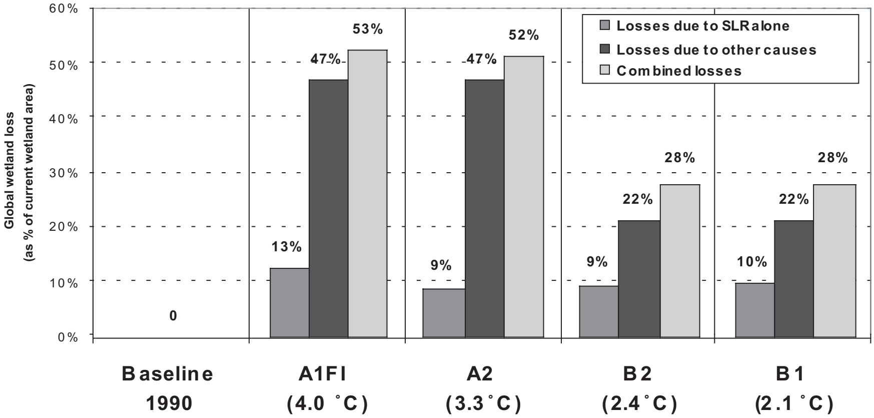

Figure 5. Average global loss of coastal wetlands in 2085, relative to 1990 levels. The average is based on the mid-point of the high and low subsidence cases. Losses due to climate change and other factors are not additive. Source: Goklany (2007a), based on Nicholls (2004).

Summary

Collectively, Table 3, and Figures 1 through 5 indicate that while climate change may be important, through the foreseeable future, other problems, particularly lack of development, would have a much greater impact on human and environmental well-being.

4. COSTS AND BENEFITS OF MITIGATION AND ADAPTATION

That non-climate-change related factors outweigh climate change in their contributions to various climate-sensitive risks has profound implications for the development of effective approaches to reducing these risks. Compounding this is that, in the near term, mitigation to reduce GHGs will have little or no impact on reducing the impacts of climate change due to the inertia of the climate system.

Table 4 indicates the impact of two mitigation scenarios on mortality and habitat loss for three key scenarios examined thus far, namely, A1FI (the richest-and-warmest), A2 (the poorest), and B1 (the coolest). Qualitatively, results for the B2 scenario are no different from these three. The two mitigation scenarios represent the two poles at either end of the spectrum in terms of stringency, namely, the Kyoto Protocol at the low end of effectiveness and cost and, at the highest end, a scenario that would ensure no climate change beyond 1990 levels. These decreases, derived from Table 3 and Figures 1–3, are shown relative to the unmitigated case, that is, no emission controls whatsoever.

Table 4. Impact of Mitigation Policies, 2085–2100, Upper Bound Estimates

	A1FI (richest-but-warmest)		A2 (poorest)		B1 (coolest)	
	Kyoto Protocol	No Climate Change after 1990	Kyoto Protocol	No Climate Change after 1990	Kyoto Protocol	No Climate Change after 1990
Decline in mortality from malaria, hunger and coastal flooding (in thousands) in 2085	21 (1%)	237 (10%)	51 (1%)	282 (4%)	10 (0%)	92 (4%)
Decline in population at risk from water stress (in millions) in 2085	-83 (-5%)	-1,192 (-72%)	0	0	-44 (-2%)	-234 (-11%)
Habitat available for the rest of nature measured by extent of cropland in 2100	Small decrease in available habitat	Larger decrease	NA	NA	Small decrease in available habitat	Some decrease

Sources: Figures 1 through 3, this paper; Goklany (2005). Notes: Figures in parentheses indicate percent declines in total mortality or PAR, as appropriate. Negative signs in the second–to-last row (for water stress) indicate that mitigation will exacerbate matters in 2085. Regarding habitat (last row), estimates of future cropland in the absence of climate change were unavailable from the FTA, i.e., Levy et al. (2004). NA = not available.

To construct this table, I optimistically assumed that by 2085 the Kyoto Protocol would reduce global temperature and sea level rise by 7 percent (Wigley 1998), reducing the impacts of climate change on malaria, hunger and water stress by a like amount, and impacts of coastal flooding by 21 percent (Goklany 2005, 2007a, 2007b). As will become evident, the validity of the arguments and conclusions in this paper hold irrespective of the precise estimates regarding the Protocol's effectiveness.

Table 4 demonstrates that, at least through 2085, the effects of mitigation could be a mixed bag—declines in mortality from malaria, hunger, and coastal flooding but increases in PAR from water stress and decreases in the habitat available for other species. This illustrates one of the major shortcomings of mitigation, namely, mitigation is indiscriminate—it reduces all impacts, whether they are positive or negative.

Table 4 also demonstrates that the Kyoto Protocol's benefits are trivial compared to the magnitudes of the problems that it would address. For example, it would reduce cumulative mortality for malaria, hunger and coastal flooding by 0–1 percent, compared to 4–10 percent were climate to be somehow frozen at its 1990 level. Those relatively minor benefits, however, would cost significant amounts of money. For instance, if the Kyoto Protocol were fully implemented by all signatories (including the United States and Australia), it would likely cost Annex 1 countries about $165 billion per year in 2010, based on the lower end of the range of estimates produced by the IPCC (2001b) report.[6] The cost of the no-climate-change scenario, assuming it's even feasible, would be far greater, but the literature doesn't provide any good cost estimates for such a scenario.

4.1. Focused Adaptation

Table 4 indicates that freezing climate at its 1990 level would cost somewhere above $165 billion annually but leave untouched 90–96 percent of the mortality problem for the three listed threats. By contrast, focusing policies on reducing threats to human welfare that may be exacerbated by climate change would improve human well-being more cost effectively. This is necessarily the case because cost-effective solutions to a larger portion of the problem will invariably include cost-effective solutions to a subset of the problem.

Moreover, policies and measures that would reduce vulnerability to the non-climate-change-related portion of the problem would also reduce the component related to climate change (Goklany 2005). In particular, activities that would reduce present day vulnerabilities to climate-sensitive problems would also reduce similar problems in the future whether they are caused by climate change or other factors. For instance, a successful malaria vaccine would help reduce malaria regardless of whether it would be caused by climate change or something else.

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[6] Compliance with the Kyoto Protocol is estimated at 0.1-2.0 percent of Annex I countries' GDP in 2010 (IPCC 2001b). I assume 0.5 percent in 2010, equivalent to $165 billion (in 2003 dollars) (Goklany 2005). The full range would be from $33-660 billion annually.

Such an approach—which I call "focused adaptation"—would, unlike mitigation, bring substantial benefits through the foreseeable future, mainly because mitigation would not affect the much larger share of mortality due to non-climate-change-related factors. As shown in Table 3, the non-climate-change-related component of mortality from hunger, malaria, and coastal flooding ranges from 4.4 million in 1990 to 2.1–6.0 million in 2085 (depending on the scenario). Moreover, due to the inertia of the climate system, mitigation would not reduce even the small climate change component of the problem significantly until a few decades have elapsed.

Mitigation has the additional problem that it indiscriminately reduces all impacts of climate change— whether positive or negative—as illustrated by the effect of mitigation on the global PAR for water stress in Table 4. Adaptation can, however, selectively capture the benfits of climate change while reducing its negatives. And while the impacts of global warming are uncertain, there is no doubt that malaria, hunger, water stress, and coastal flooding are real and urgent problems here and now. Thus, focused adaptation is far more likely to deliver benefits than mitigation, and deliver those benefits sooner rather than later.

Significantly, work on focused adaptation measures can commence, and in some areas has already begun, without detailed knowledge of the impacts of climate change. Cases in point are the development of malaria vaccines, transferable property rights for water resources, development of early warning systems for climate-sensitive events ranging from storms to potential epidemics of various kinds, and elucidation of mechanisms that confer resistance in crops to drought, water logging, or saline soils (Goklany 2007b, 2007c). To the extent that such measures do not rely on the location-specific details of inherently uncertain impacts analyses, focused adaptation reduces the risk of having wasted resources by pouring them into problems that may or may not occur at specific locations (Goklany 1995).

Ancillary benefits of adaptation focused on reducing vulnerability to malaria and hunger include better health, increased economic growth, and greater human capital, which should advance human well-being and the capacity to address a much wider variety of problems (Goklany 2000; UNMP 2005a). These "co-benefits," in fact, are among the goals and purposes of sustainable development as articulated in the Millennium Development Goals (UNMP 2005a). In other words, focused adaptation to selectively reduce vulnerability to existing climate-sensitive problems would advance sustainable development in addition to explicitly laying the foundations for adapting to future climate change.

Finally, the conclusion that focused adaptation is for the foreseeable future superior in terms of both global benefits and global costs is independent of any choice of discount rates. That is because the benefits of focused adaptation will generally follow relatively soon after costs are incurred. But the climate system's inertia ensures that the costs of emission reductions will have to be borne for decades before any benefits accrue.

Examples of focused adaptation and costs are discussed below.

Malaria

The UN Millennium Project (2005b) reports that the global death toll from malaria could be reduced by 75 percent by 2015 from the 2005 baseline at an annual cost of

$3 billion. Adaptations focused on reducing current vulnerabilities to malaria include measures targeted specifically at malaria as well as measures that would generally enhance the capacity to respond to public health problems and deliver public health services more effectively and efficiently. Malaria-specific measures include indoor residual (home) spraying with insecticides such as DDT, insecticide-treated bed nets, improved case management, more comprehensive antenatal care, and development of safe, effective, and cheap vaccines and therapies (UNMP 2005b; WHO 1999). Moreover, if these measures are even partly successful, they could further reduce the likelihood of outbreaks because the risk of exposure would be lower.

I will assume below—based on the ratio of estimated deaths in 2085 to that in 1990 under the A2 scenario (the worst scenario for malaria) and rounding up to the nearest whole number— that expenditures should be tripled (see Table 1), regardless of the emission scenario, in order to reduce malaria deaths by 75 percent.

Hunger

An additional $5 billion annual investment in agricultural R&D—15 percent of global agricultural R&D funding during the 1990s—should raise productivity sufficiently to more than compensate for the annual shortfall in productivity caused by climate change under the worst scenario (estimated at 0.02 percent from Parry et al. 2004). That should more than eliminate any increase in hunger (and related mortality) due to climate change—particularly if the additional investment is targeted toward solving developing countries' current food and agricultural problems that might be exacerbated by warming.

An alternative cost estimate can be derived from the UN Millennium Project (2005a, 2005c: 18), which estimates that 5–8 percent of the extra funding for MDGs would be needed to realize the MDG for hunger, namely, reducing global hunger 50 percent by 2015. This is equivalent to $12 billion in 2010 to $15 billion in 2015. In the following I will assume $15 billion annually for 2010–2015.

Current agricultural problems that could be exacerbated by warming and should be the focus of vulnerability-reduction measures include growing crops in poor climatic or soil conditions (e.g., low-soil moisture in some areas, too much water in others, or soils with high salinity, alkalinity, or acidity). Because of warming, such conditions could become more prevalent, agriculture might have to expand into areas with poorer soils, or both. Actions focused on increasing agricultural productivity under current marginal conditions would alleviate hunger in the future whether or not the climate changes. Significant efforts are already underway along these lines (e.g., Ligi and Kaskey 2007).

Given the uncertainties associated with location-specific impacts of climate change, particularly with respect to precipitation, prudence dictates that adaptation measures should be relatively insensitive to location-specific details of impacts estimates (and GCM results). For example, since both CO_2 and temperatures will likely increase despite uncertainties on the details, crop varieties should be developed to take advantage of such conditions (Goklany 2007b, 2007c). Progress on these approaches does not have to depend on improving our skill in forecasting location-specific details of climate change and its impacts. These focused adaptation measures should be complemented by development of higher-yield, lower-impact crop varieties and improved agronomic practices so that more food is produced per unit of land and/or water diverted to agriculture. In addition to reducing hunger, that would benefit terrestrial and freshwater biodiversity, and sustainable development (Goklany 2007b, 2007c).

Coastal Flooding

IPCC (2007: Figure 6.10, based on Tol 2007) indicates that the annual cost of protecting against a sea level rise of about 0.66 meters in 2100—equivalent to about 0.52 meters in 2085 compared with 0.34 meters under the warmest (A1FI) scenario—would vary from $2.6 to $10 billion during the 21st century. I will assume $10 billion for the purposes of this paper. Governments could, moreover, discourage maladaptation by not subsidizing insurance and/or protective measures that allow individuals to offload private risks to the broader public, which might also lead to more thoughtful consideration (or reconsideration) of capital investments in vulnerable areas.

Water Stress

Although, as Figure 2 shows, climate change could relieve water stress, several measures are available to help societies cope with present and future water stress regardless of their cause. They include institutional reforms to treat water as an economic commodity by allowing market pricing and transferable property rights to water. Such reforms should stimulate broader adoption of existing but underused conservation technologies and lead to more private-sector investment in R&D, which would reduce water demand by all sectors. For example, new or improved crops and techniques for more efficient use of agricultural water would enhance agricultural productivity and reduce the risk of hunger, pressures on freshwater biodiversity, and increase opportunities for other in-stream uses (e.g., recreation).

Improvements in water conservation following such reforms are likely to be most pronounced for the agricultural sector, which is responsible for 85 percent of global water consumption and is the single largest current threat to freshwater biodiversity. A reduction of 18 percent in agricultural water consumption would, on average, double the amount of water available for all other uses (Goklany 2005).

Public education could also enhance conservation by increasing the acceptability of re-using water. Some industrial uses may not need water treated to drinking water standards, as indicated by Singapore's experience (Singapore Public Utilities Board 2008). In fact, today's technology enables even sewage water to be treated to meet drinking water standards but it has to be palatable to the public (Archibold 2007).

Conservation of Species and Biodiversity

Some perceive that adaptation is unsuitable for addressing climate change impacts on natural systems (IPCC 2001a; Wilbanks et al. 2003) because they tend to view climate change in isolation from others pressures on such systems. But consider that conversion of land and water to agricultural uses is the greatest threat to terrestrial and freshwater biodiversity, respectively (Goklany 2007c). Thus, increasing the productivity and efficiency of agricultural land and water use would reduce these critical threats to biodiversity (Goklany 1995, Green et al. 2005). Accordingly, the focused adaptation measures outlined above to address hunger and water stress would, in addition to reducing those specific problems, also provide "co-benefits" by reducing pressures on species and biodiversity. Other measures could also include the establishment of gene banks (Wilbanks et al. 2003), measures to preserve and propagate endangered or threatened species through modern biological techniques (Estabrook 2002; Lanza et al. 2000), and techniques based on restoration biology, or adaptive management of disturbance regimes such as fires to help mediate transitions from one ecosystem regime to another as environmental conditions change (Goklany 2007c).

4.2 Sustainable Economic Development: A Third Approach

So far I have examined two approaches to address warming through the foreseeable future. The first, mitigation, would reduce impacts—positive and negative—across the board. That approach entails significant near-term costs, whereas any payoff will be delayed far into the future. The second approach, focused adaptation, would reduce vulnerability to climate-sensitive effects now and through 2085 by focusing on individual threats and attacking those threats simultaneously.

However, developing countries are most at risk of climate change not because they will experience greater climate change, but because they lack adaptive capacity to cope with its impacts. Hence, another approach to addressing climate change would be to enhance the adaptive capacity of developing countries by promoting broad development, i.e., economic development and human capital formation, which, of course, is the point of sustainable economic development. Moreover, since determinants of adaptive and mitigative capacity are largely the same, enhancing the former should boost the latter. Perhaps more important, advancing economic development and human capital formation would advance society's ability to cope with all manner of threats, whether climate related or not (Goklany 1995, 2007c).

The costs and benefits of sustainable economic development can be garnished from literature on the MDGs, which were devised to promote sustainable development in developing countries. The benefits associated with these goals—halving global poverty; halving hunger, halving the lack of access to safe water and sanitation; reducing child and maternal mortality by 66 percent or more; providing universal primary education; and reversing growth in malaria, AIDS/HIV, and other major diseases—would exceed the benefits flowing from the deepest mitigation (see Table 4). Yet the additional annual cost to the richest countries of attaining the MDGs by 2015 is estimated at 0.5 percent of their GDP (UNMP 2005a), approximately the same as that of the ineffectual Kyoto Protocol.

Since focused adaptation would only reduce climate-sensitive barriers to sustainable economic development (e.g., malaria, hunger, water stress) without necessarily addressing other significant problems (e.g., access to safe water and sanitation, illiteracy, child and maternal mortality), broad pursuit of sustainable economic development would deliver greater benefits but might cost more, although arguably economic development pays for itself in the long run.

4.3 Mitigation Versus Adaptation

Table 5 compares for the A1FI (warmest-but-richest) and the A2 (poorest) emission scenarios, costs and benefits of two mitigation scenarios—the Kyoto Protocol and freezing climate change at 1990 levels— against two adaptation scenarios, namely, focused adaptation and sustainable economic development. This table provides benefits in terms of

- declines in mortality from hunger, malaria, and coastal flooding,
- changes in net PAR of water stress,
- progress toward the MDGs, and
- habitat lost to cropland.

This table shows that, focused adaptation would deliver far greater benefits than would even halting climate change but at one-fifth the cost of the ineffectual Kyoto Protocol ($34 billion annually versus $165 billion for 2010-2015), whereas broad development would provide even greater benefits at the same cost as the Protocol.

Given the sorry track record of external aid over the past decades—particularly where institutions to bolster economic development, human capital, and technological change are weak and governance is poor—several analysts are skeptical that external aid can ensure sustainable economic development (e.g., Easterly 2006). They correctly note, sustainable economic development can rarely, if ever, be imposed or purchased from outside. The necessary institutional changes have to come from within. Nevertheless, according to Table 5, even if the UNMP's target goals are met only at the 20 percent level for whatever reason (e.g., corruption, rosy cost estimates generated by UNMP, overconfidence in success, unforeseen circumstances) the residual benefits would exceed what can be obtained through mitigation, at least through the foreseeable future, and probably at lower cost. And this argument ignores the possibility that mitigation projects themselves can be subject to waste, fraud and abuse.

Notably, climate change would cause 0.1–0.3 million deaths annually by 2085 from hunger, malaria and flooding (see Figure 1), but lesser amounts in the interim. This is dwarfed by the toll due to non-climate-change related factors, which could range from 4.4 million in 1990 to 2.0–6.0 million in 2085. The *difference* in *cumulative mortality* from 1990–2085 between the adaptation and mitigation options is in the range of all deaths worldwide in wars, genocide, and other atrocities during the 20th century, which Leitenberg (2006) estimates at 231 million people.

Thus, consideration of cumulative reductions provides further support for the adaptive approaches, because they would provide a steady and significant stream of benefits starting in the very near term, whereas benefits of mitigation will be relatively insignificant for decades due to the inertia of the climate system.

Table 5. Benefits (in 2085) and Costs (~2010-2015) for Mitigation and Adaptation Scenarios

	A1FI (warmest-but richest)				A2 (poorest)			
	Mitigation		Adaptation		Mitigation		Adaptation	
	Kyoto Protocol	No Climate Change after 1990	Focused Adaptation	Sustainable economic development	Kyoto Protocol	No Climate Change after 1990	Focused Adaptation	Sustainable economic development
Decrease in mortality from malaria, hunger and coastal flooding (in thousands)*	21	237	1,480	1,480	51	282	3,784	3,784
*Decrease in mortality relative to baseline** (in percent)*	*1%*	*10%*	*64%*	*64%*	*1%*	*4%*	*60%*	*60%*
Decrease in net population at risk from water stress (in millions)*	-83	-1,192	0 to 1,667†	0 to 1,667†	-147 to 0	-2,100 to 0	≤ 5,966 to 8,066†	≤ 5,966 to 8,066†
*Decrease in population at risk relative to baseline** (in percent)*	*-5%*	*-72%*	*0 to 100%†*	*0 to 100%†*	*-2% to 0%*	*-35% to 0%*	*0 to 100%†*	*0 to 100%†*
Progress toward Millennium Development Goals • 50% reduction in poverty • 67-75% reduction in child & maternal mortality rates • 50% improvement in access rates for safe water and sanitation • 100% reduction in illiteracy	Almost none	Some	Substantial	Should be met	Almost none	Some	Substantial	Should be met
Available habitat (as measured by extent of global cropland)	Small decrease	Larger decrease	Some increase	Some increase	NA	NA	NA	NA
Annual costs	~ $165 billion	>> $165 billion	< $34 billion†	~ $165 billion†	~ $165 billion	>> $165 billion	< $34 billion†	~ $165 billion†

Note: * Negative numbers indicate that the policy indicated will worsen the situation. ** "Baseline" is the total mortality or PAR considering both climate change and non-climate-change risk factors. †† The cost estimate does not include costs of reducing water stress beyond what might be reduced due to climate change itself.
Sources: Figures 1-3, and 5, this paper; Goklany (2007a); UNMP (2005a, b, c); IPCC (2007).

5. ADAPTIVE MANAGEMENT OF CLIMATE CHANGE RISKS

It has sometimes been argued fairness demands that present generations expend resources on mitigation now, instead of leaving future generations with a bigger mess and a larger clean-up bill. But as the data presented thus far clearly demonstrates, well-being tomorrow is enhanced by a greater amount, more surely and more rapidly through focused adaptation, sustainable development, or both—not by mitigation.

The above analyses indicates that policies to address climate change in the near-to-medium term should eschew direct GHG controls that go beyond "no-regret" policies, that is, policies that would entail no net costs. Instead, policymakers should work to enhance adaptation and promote economic development.

First, policymakers should work toward increasing adaptive capacity, particularly in developing countries, by promoting efforts to reduce vulnerability to today's urgent climate-sensitive problems—malaria, hunger, water stress, flooding, and other extreme events — that might be exacerbated by climate change (Goklany 1995, 2005). The technologies, human capital, and institutions that will need to be strengthened or developed to accomplish this will also be critical in addressing these very problems in the future if and when they are aggravated by climate change. Increasing adaptive capacity might also increase the level at which GHG concentration would need to be stabilized to "prevent dangerous anthropogenic interference with the climate system"—the stated "ultimate objective" of the UN Framework Convention on Climate Change.[7] Alternatively, increasing adaptive capacity could postpone the deadline for stabilization, which would allow societies additional time to acquire wealth and better afford costly mitigation technologies, and to invest in both existing and "bleeding edge" technologies that have yet to be fully developed or proven at appropriate scales. Either way, it could reduce the costs of meeting the ultimate objective.

Second, policymakers should strengthen or develop the institutions necessary to advance and/or reduce barriers to economic growth, human capital and the propensity for technological change. Doing so would improve both adaptive and mitigative capacities, as well as the prospects for sustainable development. (Goklany 1995, 2000, 2005).

Third, policymakers should implement no-regret mitigation measures now while expanding the range and diversity of future no-regret (i.e., no-cost) options. The latter could be advanced by research and development to improve existing—and develop new—technologies that would reduce GHGs more cost-effectively than currently possible. This would reduce the costs of future emission reductions, even if they have to be deeper to compensate for a delay in more aggressive responses.

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[7] Article 2 of the UN Framework Convention on Climate Change (UNFCCC) specifies that its "ultimate objective… is to achieve… stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." See: United Nations, *United Nations Framework Convention on Climate Change*, http://unfccc.int/resource/docs/convkp/conveng.pdf.

Fourth, policymakers should allow the market to dictate which no-regret options should be implemented where. Among other things, that implies reducing direct or indirect subsidies to increase energy use, land clearance, coastal development, and other activities that contribute to greater GHG emissions or climate change damages. OECD nations should also reduce, if not eliminate, agricultural subsidies and barriers to trade. They are expensive for consumers in OECD nations, and they damage the economies and well-being of many developing nations whose economies are dominated by the agricultural sector, which then reduces their adaptive capacity (Goklany 1995, 2007c).

Fifth, understanding of the science, impacts, and policies of climate change should be advanced in order to develop more effective response strategies to forestall "dangerous" impacts of climate change (per Article 2 of the UN Framework Convention on Climate Change) while simultaneously advancing human well-being.

Sixth, the impacts of climate change and, apropos of the unintended consequences of subsidized biofuel production for example, climate change policies (Sonja Boehmer-Christiansen, personal communication) should be monitored to give advance warning of "dangerous" impacts and, if necessary, to rearrange priorities should the adverse impacts on human and environmental well-being occur faster, or threaten to be more severe or more likely than currently projected.

Together, these policies constitute an adaptive management approach to addressing climate change that would help solve today's urgent problems while bolstering our ability to address tomorrow's climate change challenge.

6. CONCLUSION

Climate change is not now—nor is it likely to be for the foreseeable future—the most important environmental problem facing the globe, unless present-day problems such as hunger, water-related diseases, lack of access to safe water and sanitation, and indoor air pollution are reduced drastically. Otherwise, with respect to human well-being, it will continue to be outranked by these other problems and, with respect to environmental well-being, by habitat loss and other threats to biodiversity.

Through 2085, human well-being is likely to be highest under the richest-but-warmest (A1FI) scenario and lowest for the poorest (A2) scenario. Matters may be best in the A1FI world for some critical environmental indicators through 2100, but not necessarily for others. Either focused adaptation or broad pursuit of sustainable development would provide far greater benefits than even the deepest mitigation—and at no greater cost than that of the barely-effective Kyoto Protocol.

For the foreseeable future, people will be wealthier—and their well-being higher—than is the case for present generations both in the developed and developing worlds and with or without climate change (Goklany 2007a). The well-being of future inhabitants in today's developing world would, even in the absence of any mitigation, exceed that of the inhabitants of today's developed world under all but the poorest scenario. Future generations should, moreover, have greater access to human capital and technology to address whatever problems they might face, including climate change. Hence the argument that we should shift resources from dealing with the real and urgent problems confronting present generations to solving potential problems of tomorrow's wealthier and better positioned generations is unpersuasive at best and verging on immoral at worst.

Equally important, resources expended on solving today's climate-sensitive problems and advancing sustainable economic development will build human capital, advance technology, and enhance the adaptive and mitigative capacities of future generations. That is, helping current generations also helps future generations.

If one believes that developed countries have a moral and ethical obligation to deal with climate change, this obligation cannot, and should not, be met through aggressive emission reductions at this time—"cannot" because the planet is already committed to some climate change—and "should not" because the threats that climate change would exacerbate can be reduced more effectively and economically through focused efforts to reduce vulnerability or through broader efforts to advance economic development. Any such obligation is best discharged through efforts to reduce present-day vulnerabilities to climate-sensitive problems that are urgent and could be exacerbated by climate change.

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