MANAGING CLIMATE CHANGE RISKS IN THE CONTEXT OF OTHER, MORE URGENT RISKS TO HUMANITY

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Summary

Several British-sponsored state-of-the-art assessments of the global impacts of climate change on various climate-sensitive threats (namely, malaria, hunger, water stress, coastal flooding, habitat loss, carbon sink capacity, and coastal wetlands) using the major scenarios developed by the IPCC indicate that through 2085 to 2100, i.e., the foreseeable future, the contribution of climate change to such threats will generally be overshadowed by non-climate change related factors. For example, under the richest-but-warmest (A1FI) scenario, which is projected to increase global temperature by 4.0°C by 2085, climate change would be responsible for only 21% of the people at risk (PAR) of hunger. Translating estimates of PAR into mortality indicates that climate change would in 2085 be responsible for 4-10% of the mortality for hunger, malaria and coastal flooding under the four major IPCC scenarios, while the net PAR of water stress could *increase* from 0-72%.

Regarding environmental well-being, both global sink capacity and available habitat for ecosystems and species are projected to be higher in 2100 under the (richest-but-warmest) A1FI scenario than poorer-but-cooler (B1 and B2) scenarios or under the actual (1990) baseline, while non-climate change related factors will dominate coastal wetland loss.

These results indicate that climate change is unlikely to be the world's most important environmental problem of this century unless existing problems such as hunger, water-related diseases, lack of access to safe water and sanitation, and indoor air pollution are substantially reduced.

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Second, halting climate change, whose costs would dwarf the annual $165 billion estimated for the Kyoto Protocol in 2010, would reduce cumulative mortality from hunger, malaria and coastal flooding in 2085 by 4-10% while increasing PAR for water stress and, possibly, worsening matters for biodiversity in 2100. But information from the UN Millennium Project and the IPCC suggests that cumulative mortality could be reduced by 50-75% at an annual cost of less than $34 billion through measures focused specifically on reducing the vulnerability to these threats. Alternatively, broad pursuit of economic and technological development would deliver these benefits and more (e.g., reducing poverty, illiteracy, and child and maternal mortality by 50-100%) at approximately the same cost as the Kyoto Protocol.

Moreover, accounting for market, non-market and other losses in welfare due to climate change, human and environmental well-being will probably be highest under the richest-but-warmest scenario, and lowest for the poorest scenario. In fact, in 2100, future well-being in the developing world should exceed present well-being in today's developed world under all but the poorest scenario. Future generations should also have greater access to human capital and technology to address whatever problems they might face, including climate change. Hence, arguments that present generations should divert scarce resources from dealing with today's urgent problems to solving potential problems of tomorrow's wealthier and better positioned generations are unpersuasive.

If, arguably, developed countries have a moral and ethical obligation to address climate change, for the foreseeable future 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 economically over the foreseeable future through adaptive measures rather than through aggressive mitigation. 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.

Climate change might eventually hinder sustainable development in developing countries, but over the next several decades it is the lack of sustainable economic and technological development that hinders their ability to cope not only with climate change but also other, more important sources of adversity. In addition, resources expended on solving today's climate-sensitive problems or advancing sustainable economic development will build human capital and advance technology, both of which will enhance the adaptive and mitigative capacities of future generations. Thus investing in focused adaptation and sustainable economic development will advance well-being for both present and future generations.

Accordingly, through the foreseeable future, human and environmental well-being can be advanced faster, farther, more surely and more economically through adaptive measures focused on reducing vulnerability to climate-sensitive threats or through broad efforts to advance sustainable economic development rather than through emission reductions that go beyond no-regret measures, unless mitigation technologies become much more cost-effective than they are today.

In the meantime, we should implement no-regret mitigation measures and, through aggressive research and development, strive to expand the universe of no-regret actions so that if, and when, monitoring of climate change and its impacts indicate that stronger measures are warranted, they can be undertaken more cost-effectively.

Such an adaptive management approach to addressing climate change risks would better take care of the urgent problems our brethren face today while enabling our wealthier children to take better care of whatever problems they might face tomorrow, including the problem of climate change.

MANAGING CLIMATE CHANGE RISKS IN THE CONTEXT OF OTHER, MORE URGENT RISKS TO HUMANITY

Indur M. Goklany

1. Introduction

Most scenarios of the future suggest that the world will get more populated and wealthier during this century. While this ought to advance human well-being, it may also increase climate change which might at least partly offset any advances in well-being. The IPCC reports in its last (2001) assessment that modest global warming (of the order of 1 to 2°C over 1990 levels) could increase global economic product (GEP) with gains in the higher latitude developed countries more than offsetting losses in developing countries (IPCC, 2001: 943-948). However, global temperature increases beyond that could reduce GEP and wreak substantial environmental damage.

Such considerations have led many highly regarded policymakers such as Prime Minister Blair and Presidents Clinton and Chirac to proclaim that climate change is the most important environmental problem facing the globe this century (Clinton, 1999; Cordis News, 2004) and, unless checked drastically, would before long reduce human and environmental well-being.

To shed light on the above claims, this paper will examine the climate change problem in the wider context of other problems that humanity faces now and in the future. Notably, climate change exacerbates existing problems — hunger, water stress, malaria, coastal flooding, loss of habitat and other threats to species and ecosystems — rather than creates new ones. Accordingly, this paper will compare the relative contribution of climate change and non-climate-change-related factors to these problems to help determine whether, absent drastic emission reductions, climate change is likely to be the largest environmental problem facing the globe in the foreseeable future. The paper will also explore whether unmitigated climate change would reduce future human and environmental well-being below present day levels, a notion implicit in calls for immediate and aggressive reductions in greenhouse gases (GHGs).

The paper will then compare the global benefits and costs of reducing the impacts of climate change through "mitigation" (i.e., greenhouse gas emission reduction) strategies against strategies to reduce society's vulnerability to these impacts (i.e., "adaptation"). This comparison will show that in the near-to-medium term, vulnerability-reduction, appropriately focused, will provide greater benefits at lower costs than mitigation efforts. But if the negative consequences of climate change continue to build and overtake the humanity's ability to adapt, mitigation may nevertheless be inevitable in the longer term. A further complication is that because of the inertia of the climate system, decades may pass before any mitigation measures succeed in significantly reducing the rate or amount of climate change.

The paper will weave these diverse strands together to identify a web of policies that will allow adaptation and mitigation strategies to evolve and be integrated over different time scales to effectively and efficiently manage the near, medium and long term global risks of climate change in the context of other similar risks to environmental and human well-being despite the uncertainties regarding the magnitude and timing of these risks.

1.1. Wealth, Technology, Well-being and Adaptive Capacity

Economic growth broadly increases human well-being, by increasing wealth, technological development and human capital. These factors enable society to address virtually any kind of adversity, whether it is related to climate or not, while specifically increasing society's capacity to reduce climate change damages through either adaptation or mitigation (Goklany, 1995, 2007a; Yohe, 2001; Smit et al., 2001).

Many determinants of human well-being — hunger, malnutrition, mortality rates, life expectancy, the level of education, and spending on health care and on research and development — improve along with the level of economic development, as measured by GDP per capita (Goklany, 2002).

Increasing wealth also improves some, though not necessarily all, indicators of environmental well-being. Wealthier nations have higher cereal yield (an important determinant of cropland, which is inversely related to habitat conversion), greater access to safe water and sanitation. They also have lower birth rates (Goklany, 2007b).[2] Notably, access to safe water and access to sanitation double as indicators of both human and environmental well-being, as does crop yield since higher yield not only means more food and lower hunger, it also lowers pressure on habitat (Goklany, 1998; Green et al., 2005).

Cross country data also indicate that for a fixed level of economic development, these indicators of human and environmental well-being (e.g., malnutrition, mortality rates, life expectancy, access to safe water, crop yields, and so forth) improve with time, indicating the likely beneficial effect of technological advances (Goklany, 2007b). In other words, for any given level of per capita income, human well-being as measured, for instance, by life expectancy or infant mortality improves with time because of creation of new — and broader diffusion of existing — technologies. Similarly one should expect, all else being equal, that society's ability to cope with any adversity, including climate change, should also increase with the passage of time.

Thus, over time, the combination of economic and technological development should increase society's adaptive capacity which, barring inadvertent maladaptation, ought to reduce the future impacts of climate change (Goklany, 2007a). This is evidenced, for example, in the remarkable declines — 99 percent or greater — during the 20th century in mortality and morbidity rates in the United States for various water-related diseases, e.g., typhoid, paratyphoid, dysentery, malaria and various gastrointestinal diseases) (Goklany, 2007b: 153; USBC, 1975: 77).

1.2. The Fast Track Assessment

The information used in this paper for the most part draws upon results of the "Fast Track Assessment" (FTA) of the global impacts of climate change sponsored by the U.K. Department of Environment, Forests and Rural Affairs (DEFRA) and reported in a special issue of *Global Environmental Change: Part A* (volume 14, issue 1, pp. 1-99, 2004) edited by Dr. Martin Parry, and supplemented, as necessary, by other DEFRA-sponsored studies. Many, if not most, authors of these papers have served as coordinating lead authors, lead authors or contributing authors of the IPCC's Third and Fourth Assessment Reports. Dr. Martin Parry is, moreover, the current Chairman of the

[2] One indicator that, so far at least, has not shown an improvement with wealth is total CO_2 emissions. Also, some environmental indicators, e.g., air pollutants such as sulfur dioxide and particulate matter, generally worsen initially as incomes increase before declining at higher income levels (Shafik, 1994; Grossman and Krueger, 1995; Dasgupta et al., 2006).

IPCC's Work Group II which oversees the impacts, adaptation and vulnerability sections of the Assessments.

Like all estimates of the impacts of climate change, results of the FTA are plagued with uncertainties resulting from, among other things, the fact that such estimates are derived using a series of linked models with the uncertain output of each model serving as the input for the next model. To compound matters, each model is necessarily a simplified representation of reality.

Usually, the chain of models starts with emission models, which are driven by various socioeconomic assumptions for the next 100 years or more in order to generate emission scenarios extending to the latter part of this century. But even users of these emission scenarios acknowledge that 2085 is at the outer limit of the foreseeable future since socioeconomic scenarios are not deemed credible beyond that (see, e.g., Arnell et al., 2002). In fact, Lorenzoni and Adger (2006; p. 74), in a paper commissioned for the Stern Review note that, "Changes in socioeconomic systems cannot be projected semi-realistically for more than 5-10 years at a time."

These emission scenarios are then used in other models to estimate future trends in atmospheric greenhouse gas concentrations. Next, this information is fed into coupled atmosphere-ocean general circulation models (GCMs) to estimate spatial and temporal changes in climatic variables, which are used as inputs to simplified and often inadequate biophysical models which project location-specific biophysical changes pertaining to the resources that are affected by climate change (e.g., vegetation and other species, crop or timber yields).

Notably, impacts assessments should, in general, be done at a local scale because the resources that are affected by climate change are spatially heterogeneous, as are the socioeconomic conditions that affect these resources and determine whether and how human beings will respond to changes. Therefore, the changes in climatic variables should also be determined at the local scale. But as the spatial scale decreases, uncertainties in climatic variables increase.

Then, depending on the human or natural system under consideration, the outputs of these biophysical models may have to be fed into additional models to calculate the social, economic and environmental impacts on those systems.

In addition to the cascading uncertainties that propagate from model to model, the cumulative effects of which have yet to be quantified, the results of these impacts assessment are subject to potentially large systematic errors which tend to substantially overstate negative impacts while simultaneously understating positive impacts of climate change. These systematic errors are due to the fact that the assessments' methodologies generally do not account fully, if at all, for the increases in adaptive capacity resulting from either increases in wealth postulated under the socioeconomic assumptions used to generate emissions scenarios, or the creation of new or improved technologies that would come on line over time. [More on this below.] In other words, the impact assessments are inconsistent with the assumptions built into emissions scenarios used to drive climate change.

Despite these shortcomings, for the purposes of this paper I will, for the most part, take the results of the FTA at face value because it has figured prominently in the international debate on global warming,[3] and because it allows us to develop estimates of the relative contribution of climate change to various climate-sensitive problems in the future.

Like the FTA, this paper does not consider low-probability but potentially high-consequence outcomes such as a shut down of the thermohaline circulation or the melting of the Greenland and Antarctic Ice Sheets. They are deemed unlikely to occur during this century (see, e.g., DEFRA, 2004; Gregory, 2005; Wunsch, 2004; IPCC 2007).

1.3. IPCC's Scenarios for the Future and Implications for Adaptive Capacity

The FTA employed emission scenarios developed by the IPCC's Special Report on Emissions Scenarios (SRES 2000) to project future climate change from 1990 (the base year for each scenario) through 2100. The dominant characteristics of the "storylines" used in the SRES are shown in Table 1. These characteristics describe the demographic, technological, economic and social trajectories driving emissions in the four scenarios that were used by the FTA. This table also provides corresponding estimates in 2085 of atmospheric CO_2 concentrations, and climate change (as

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[3] For example, results of the FTA's results for the impacts of climate change on food, agriculture, water resources and coastal flooding were a prominent part of a 2005 UK Government sponsored symposium on *Avoiding Dangerous Climate Change* staged as part of the run up to the 2005 Gleneagles Summit of the G-8 (DEFRA, 2005), and which also informed the more recent Stern Review of the Economics of Climate Change. Prior to that, Her Majesty's Government's Chief Science Advisor Sir David King's (2004) claim that "climate change is the most severe problem that we are facing today—more serious even than the threat of terrorism" was based, in part, on older FTA estimates which were published in another special issue of *Global Environmental Change* (Parry and Livermore, 1999; Arnell et al. 2002; see Goklany and King, 2004).

represented by increases in globally averaged temperature) and sea level rise between 1990 and 2085 (Arnell et al., 2004). The columns in this, and most subsequent, tables are arranged by scenario in the order of decreasing global temperature changes. Using the labels provided by the IPCC, these scenarios from left to right are A1FI (warmest), A2, B2 and B1 (coolest).[4]

Table 1: Characteristics and assumptions for the 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
CO_2 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

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

The FTA used these climate change projections (Arnell et al., 2004) to estimate the global impacts on various climate-sensitive threats which also serve as determinants of human and environmental well-being. Specifically, with respect to threats affecting human well-being the FTA analyzed hunger (Parry et al., 2004), water stress (Arnell, 2004), coastal flooding (Nicholls 2004), and malaria (van Lieshout et al., 2004). With respect to environmental well-being, the FTA projected net biome

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

productivity (a measure of the strength of the terrestrial biosphere as a carbon sink), and the global extent of coastal wetlands and croplands (Levy et al., 2004).

Examination of Table 1 suggests that, on one hand, the impacts of climate change should decrease as one goes from scenario A1FI on the left to B1 on the right (in accordance with the pattern of declining climate change, *ceteris paribus*). On the other hand, economic and technological development — both critical determinants of adaptive capacity (Goklany, 1995, 2006; Smit et al. 2001; Yohe 2001) — ought to attenuate the impacts through a combination of autonomous and pro-active adaptations. Considering future levels of economic and technological development this attenuation should be greatest for the A1FI scenario, followed by the B1, B2 and A2 scenarios, in that order. Thus, even though the A1FI scenario has the highest climate change it would not necessarily have the worst outcomes, because it should also have the highest adaptive capacity.

1.4 Characterization of Threats and Nomenclature

In the following, the magnitude of the problem regarding each threat in the absence of climate change will be denoted by $P_{0,}$ while the magnitude of the problem due to climate change will be indicated by ΔP. Thus, the magnitude of the total problem [P_T] with climate change equals $P_0 + \Delta P$.

In consonance with the FTA, the magnitude of the problem (P) due to each climate-sensitive threat affecting human well-being, namely, malaria, hunger, water stress and coastal flooding, will be measured by the global population at risk (PAR) or suffering from the specific climate-sensitive threat. For these threats, P will henceforth be used interchangeably with PAR, as will ΔP with ΔPAR. With respect to environmental well-being, P will be measured by various indicators of habitat loss, which is generally acknowledged to be the most important threat to global terrestrial biodiversity (e.g., Green et al., 2005; Goklany, 1998), and by the global terrestrial sink capacity (i.e., the capacity of the earth to absorb carbon dioxide from the atmosphere).

2. Population at Risk for Various Climate-sensitive Threats, with and without Climate Change

In this section I present the FTA's estimates of the populations at risk in 2085 with and without climate change (i.e., ΔPAR and P_0, respectively) for four climate-sensitive threats to human well-being, namely, hunger, water stress, coastal flooding and malaria, under each scenario summarized in Table 1.

In comparing P_0 and ΔPAR under the various scenarios, it should be noted that, first, the A1FI and B1 scenarios are assumed to have the same population in 2085 (see Table 1). These assumptions are, however, exogenously-imposed. In fact, in the real world, lower total fertility rates are generally associated with higher levels of economic development. Arguably, therefore, the A1FI world should have a lower population in 2085 than the B1 world. Accordingly, the populations at risk — i.e., both P_0 and ΔPAR — for the A1FI scenario are probably overestimated relative to the B1 scenario. And so are emissions and the associated climate change, which further skews (upward) the population at risk for A1FI relative to B1.

Second, while the FTA studies assume that no new governmental policies and measures will be implemented to reduce damages from climate change, some studies (e.g., the ones for hunger and coastal flooding) allow for some "spontaneous" adaptive responses because it should be expected that even in the absence of new governmental policies, people would employ existing technologies to protect themselves from economic or bodily harm under a "business-as-usual" world. On the other hand, the study for water stress doesn't allow for any adaptation. However, even where the FTA studies allow for some adaptation, they limit the range of available technological options to "currently" available technologies (see, e.g., Parry et al., 2004, p. 57).[5] But we should expect that the menu of technological options would be much broader, more cost-effective and more affordable in the future under any SRES scenario because: (a) the world will be wealthier under any of the scenarios (see Table 1) and, therefore, better able to develop, afford and implement new as well as improved technologies, (b) technology will, through the accretion of knowledge, advance even if society doesn't get any wealthier, and (c) even in the absence of specific policy changes, new and improved technologies will inevitably be developed to specifically cope with the negative impacts of climate change. Limiting adaptation options between now and 2085 to "current" technologies is tantamount to estimating today's food production based on the technology of 1920 (or earlier). Any such estimate is bound to underestimate food production and overestimate hunger.[6]

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[5] Generally the adaptation technologies available in these studies are from the early 1990s or earlier vintages. Thus the food and hunger study doesn't include consideration of genetically modified crops.

[6] Since 1920, U.S. wheat and corn yields have tripled and quintupled, respectively, partly, if not largely, due to technological changes (NASS, 2007). Similarly, total cereal yields have multiplied by 2.5 in the developing

Thus, even where the FTA studies allow for some adaptation, their results tend to overestimate both P_0 and ΔPAR, with the upward bias increasing with the future level of economic development. Accordingly, the overestimates are greatest for the A1FI scenario, followed by B1, B2 and A2, in that order.

Hunger. The FTA's estimates of PAR for hunger in 2085 both with and without climate change for the various scenarios are shown in Table 2 in terms of millions of people and the percent of global population. These estimates, which assume CO_2 fertilization in the event of climate change, are taken from Parry et al. (2004). They show that whether or not climate changes beyond 1990 levels, no matter which scenario we choose, through 2085 the future world will be better off with respect to hunger than it was in 1990 despite any increase in population. In 2085, the warmest scenario might actually result in lower levels of hunger than some cooler scenarios. Hunger in 2085 will be lowest in the B1 scenario, followed by A1FI, B2 and A2 (in that order). Thus, the warmest scenario (A1FI) does not lead to the lowest level of well-being, despite the tendency to overestimate its adverse impacts relative to other scenarios. For some scenarios (A2 and, possibly, B2), climate change might, in fact, reduce the incidence of hunger at least through 2085. Finally, for each scenario, ΔPAR is smaller than P_0, which shows that through 2085 at least, the impact of climate change is secondary to the impact of other non-climate-change-related environmental factors.

The estimates shown in Table 2 are based on the assumption that direct CO_2 effects on crop yields would be realized. If, however, these direct effects are not realized, then Parry et al.'s analysis indicates that climate change would exacerbate the total population at risk under all scenarios while ΔPAR would still be less than P_0 for all but the A1FI scenario. But such outcomes are unlikely because the probability that direct CO_2 effects on crop growth are zero or negative is slight, particularly since future societies, especially the A1FI society, should have a greater capacity to adapt.

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countries since 1961 (FAO, 2007). Much of these improvements would not be captured using the methodology used in the FTA.

Table 2: Population at risk (PAR) in 2085 for hunger with and without further climate change

	Units	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
Population at risk in the absence of climate change (P_0)	Millions	798-872 (15.1% to 16.5%)	105 (1.3%)	767 (5.4%)	233 (2.3%)	90 (1.1%)
Additional population at risk because of climate change (ΔPAR)	Millions		28 (0.4%)	-28 to -9 (-0.2% to-0.1%)	-11 to +5 (-0.1% to 0.05%)	10 (0.1%)
Total population at risk (= P_0 + ΔPAR)	Millions	798 to 872 (15.1% to 16.5%)	133 (1.7%)	739 to 758 (5.2% to 5.3%)	222 to 238 (2.2% to 2.3%)	100 (1.3%)

NOTE: Figures in parentheses are in percent of global population. Source: Parry et al. (2004).

The Stern Review (2006), based on Long et al. (2006) argues that the beneficial effect of carbon fertilization has been overestimated. Accordingly, it uses the results from Parry et al. (2004) that assume "no fertilization."[7] But Long et al (2006) suggest that the CO_2 fertilization effect to be a third to half as large in areas where insufficient nitrogen is applied or if crops are not well-watered, rather than zero. Long et al. justify their low estimate of the fertilization effect on the basis that global nitrogen usage per hectare is lower than in the OECD. Although this might be true today, increased use of nitrogen is precisely the kind of adaptation that would become more affordable in the future as countries, even developing countries, become wealthier (see Table 1). In fact, this is one of the autonomous adaptations allowed by Parry et al. (2004). Moreover, the development of crops that would be drought-resistant and/or utilize nitrogen more efficiently is among the more active areas of crop research (Goklany 2001). Recently, Monsanto and BASF announced a $1.5 billion effort to speed these developments (Ligi and Kaskey 2007). In addition, Tubiello et al. (2006) find that Long et al's analysis is "incorrect, being based in part on technical inconsistencies and [lacks] statistical significance."

[7] Although the Stern Review claims to use results from simulations assuming low fertilization effects, it, in fact, employs the results of the "no fertilization" runs (Carter et al, 2006).

Thus, but for the FTA's systematic overestimates of P_0 and ΔPAR for the A1FI world relative to the B1 world, the A1FI scenario might have resulted in the lowest overall levels of hunger with or without climate change.

Note while the contribution of climate change to total PAR in 2085, estimated at 21 percent, seems large, it results from a small (2 percent) climate change-related drop in future global food production between 1990 and 2085 (Parry et al. 2004). In other words, unmitigated warming would reduce the annual growth in food productivity from 0.84 percent per year to 0.82 percent per year. This indicates that, not surprisingly, a small decline in the rate of productivity growth — perhaps "forced" by the assumption to "disallow" new technologies from being used for autonomous adaptation — would lead to disproportionately large effects in terms of population at risk of hunger (Goklany, 2003). This also suggests that a small boost in annual productivity of the food and agricultural sector could go a long way toward ensuring that hunger does not increase in the future.

Finally, the estimates provided in Table 2 indicate that in order to compare the consequences of various scenarios, it is insufficient to examine only the impacts of climate change. One should look at the total level of hunger. Otherwise, based merely on an examination of ΔPAR, one could conclude, erroneously, that, with respect to hunger, A2 is the best of the four worlds examined. But, based on total PAR, A2 would be the worst. This also illustrates that efforts focused on minimizing the consequences of climate change to the exclusion of other societal objectives might actually reduce overall human welfare.

Water Stress. The FTA's estimates of PARs for water stress in 2085 with and without climate change are shown for each scenario in Table 3 in terms of both millions of people and the percent of global population (Arnell, 2004).[8] A population is deemed to be at risk if its available water supplies fall below 1,000 m^3 per capita per year. The ΔPARs in Table 3 account for the fact that because of climate change some populations will move in and out of the water stressed category.

[8] Arnell (2004) also uses the "10-year return period minimum annual runoff" as a measure of water availability. Even under this variation, climate change relieves water stress in 2085 (compared to the "no climate change" condition). Hence, those results are not shown.

Information in Table 3 indicates that for each scenario, P_0 exceeds ΔPAR in 2085. In other words, with respect to water stress, non-climate change related factors are more important than climate change under each scenario, at least through the foreseeable future. As with hunger, climate change by itself might, in fact, *reduce* the total PAR for water stress. In the absence of climate change, A1FI and B1 have the smallest PAR in 2085, while A2 generally has the highest. This is true in terms of both absolute numbers and the percent of total population for the relevant scenario. In the absence of climate change, the A1FI and B1 scenarios have identical PARs due to the population assumptions built into the scenario story lines. With climate change, the A1FI world continues to have the lowest PAR but that for B1 falls to second place.

Table 3: Population at risk (PAR) in 2085 for water stress, with and without further climate change

	Units	**Baseline 1990**	**A1FI 2085**	**A2 2085**	**B2 2085**	**B1 2085**
Population at risk in the absence of climate change (P_0)	Millions	1,368 (25.8%)	2,859 (36.2%)	8,066 (56.8%)	4,530 (44.4%)	2,859 (36.2%)
Additional population at risk because of climate change (ΔPAR)	Millions		-1,192 (-15.1%)	- 2,100 to 0 (-14.8% to 0%)	- 937 to 104 (-9.2% to 1.0%)	-634 (-8.0%)
Total population at risk (= P_0 + ΔPAR)	Millions	1,368 (25.8%)	1,667 (21.1%)	5,966-8,066 (42.0% to 56.8%)	3,593-4,634 (35.2% to 45.4%)	2,225 (28.2%)

NOTE: Figures in parentheses are in percent of global population. Source: Arnell (2004, Table 8 on p. 41).

Notably, Arnell's analysis totally ignores any adaptation despite the ready availability of time-tested adaptive responses on both the supply and demand side, e.g., water storage facilities to augment water supplies during drier periods, or water pricing and other conservation measures (Goklany, 2005). Thus it overestimates both P_0 and ΔPAR. These overestimates are greatest for the A1FI (richest) scenario and lowest for the A2 (poorest) scenario and, although the ranking among the scenarios would not change, the differences in both P_0 and PAR between the various scenarios would have been magnified had adaptation been considered.

Coastal flooding. The FTA's estimates of the PAR for coastal flooding with and without any climate change induced sea level rise between 1990 and 2085 are shown in Table 4. Note that sea level will rise relative to the land not only because of climate change but also because the land may subside for a variety of reasons not related to climate change, e.g., extraction of water, gas or oil under the coastline. In this table, PAR is measured by the average number of people who would experience coastal flooding by storm surge in 2085 with and without climate change, assuming that populations would be attracted preferentially to the coast,[9] and "evolving" protection with a 30-year lag time. The low and high end of the ranges for PAR for each entry in Table 4 assume low and high subsidence due to non-climate-change-related human causes, respectively.

Nicholls (2004) makes a creditable effort to incorporate improvements in adaptive capacity due to increasing wealth. Nonetheless some of its assumptions are questionable. For instance, it allows societies to implement measures to reduce the risk of coastal flooding in response to 1990 surge conditions, but ignores such changes due to subsequent sea level rise (Nicholls, 2004, p. 74). But one would expect that whenever any measures are implemented, society would consider the latest available data and information on the surge situation at the time the measures are initiated. That is, if the measure is initiated in, say, 2050, the measure's design would at least consider sea level and sea level trends as of 2050, rather than merely the 1990 level. Nicholls also allows for a constant lag time between sea level rise and initiating protection. But one should expect that if sea level continues to rise, the lag between upgrading protection standards and higher GDP per capita will be reduced over time. Moreover, it is conceivable that the richer a society the faster this reduction. In fact, if future empirical data confirms that trends in sea level rise are robust, it is possible that protective measures may be taken in advance, i.e., the lag times may even become negative, even under a "business-as-usual" world.

In addition, Nicholls (2004) does not allow for any deceleration in the preferential migration of the population to coastal areas, which is not unlikely if coastal flooding becomes more frequent and

[9] The high coastal population growth scenario assumes that coastal population grows twice as fast as the general population, or, if populations are projected to drop, it drops at half the pace of the general population (Nicholls, 2004, Table 6).

costly. Alternatively, if the preferential migration continues unabated, a country's expenditures on coastal protection might increase because its coastal population increases relative to its total population. Such an outcome would be consistent with democratic governance.

Table 4: Population at risk (PAR) in 2085 for coastal flooding with and without further climate change induced sea level rise (SLR)

	Units	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
Population at risk in the absence of climate change (P_0)	millions	10 (0.2%)	1-3 (0.0% to 0.0%)	30-74 (0.2% to 0.5%)	5-35 (0.0% to 0.3%)	2-5 (0.0% to 0.1%)
Additional population at risk because of climate change (ΔPAR)	millions		10-42 (0.1% to 0.5%)	50-277 (0.4% to 2.0%)	27-66 (0.3% to 0.6%)	3-34 (0.0% to 0.5%)
Total population at risk (= $P_0 + \Delta$PAR)	millions	10 (0.2%)	11-45 (0.1% to 0.6%)	80-351 (0.6% to 2.5%)	32-101 (0.3% to 1.0%)	5-39 (0.0% to 0.5%)

NOTE: For coastal flooding, PAR is measured as the average number of people who experience flooding each year by storm surge or "average annual people flooded" (AAPF). The low (high) end numbers are based on an assumption of low (high) subsidence. Figures in parentheses are in percent of global population. Source: Nicholls (2004).

Nicholls (2004, Table 7) also suggests that subsidence is more likely under the A1FI and A2 worlds than the B1 and B2 worlds. Although this assumption conforms with the SRES's storylines regarding the priority given to environmental issues, it contradicts real world experience which indicates that once richer countries are convinced of a problem, whether it is environment or health related, they generally respond quicker to remedy the problem, spend more, and have greater environmental protection than poorer ones, especially at the high levels of development that, as indicated in Table 1, are projected to exist virtually everywhere later this century under all the IPCC's scenarios (see also

Goklany, 2007b). Hence, one should expect that the richest (A1FI) world would spend more and be better protected from subsidence, than would the B1 (and A1 and B2) worlds.

Putting aside these shortcomings, the information in Table 4 shows that in the absence of climate change, the PAR for coastal flooding in 2085 under the A1FI and B1 worlds would be lower than what it was in 1990, but it would be higher under the A2 world; and it may or may not be higher under the B2 world. With climate change, the PARs would increase under each scenario, with A2 having the highest total PAR by far, followed, in decreasing order, by B2, and perhaps A1FI and B1. Notably, the difference in PAR between A1FI and B1 scenarios is not very large, despite the several assumptions that downplay the adaptive effects of wealth.

Malaria. The van Lieshout et al. (2004) report on the FTA's analysis for malaria only provides estimates for changes in global PAR due to climate change (i.e., ΔPAR) but not for PARs in the absence of climate change, or for total PARs with climate change.[10] But we saw in Table 2 that the scenario with the highest ΔPAR does not always have the highest total PAR, and the latter is a more relevant measure of human well-being. Thus, their analysis doesn't allow us to determine whether the contributions to malaria would be dominated by climate change or other factors, or whether well-being (as measured by the total PAR for malaria) would be greater in a richer-but-warmer world compared to poorer-but-cooler worlds.

Accordingly, to compare the relative contributions to PAR from climate change and non-climate-change-related factors, I will use the results of an earlier (pre-SRES) version of the Fast Track Assessment of the global impact of climate change (Martens et al., 1999; Arnell et al. 2002) that was also sponsored by DEFRA. That earlier analysis used a "business-as-usual" scenario, the so-called IS92a scenario, which was developed for the 1995 IPCC impact assessment. It neither included any additional greenhouse gas controls nor allowed for any adaptation. Under this scenario, the global population and average GDP per capita in 2085 were projected at 10.7 billion and $17,700 (in 1990 U.S. $) (Hulme et al., 1999). The UK Meteorological Office's HadCM2 model projected that under this scenario, the globally averaged temperature would increase by 3.2°C between 1990 and 2085

[10] This author contacted various co-authors of the van Lieshout et al. paper to obtain their results for PAR with and without climate change, but to no avail.

(Parry et al., 2001), which approximates the temperature increase using HadCM3 under the A2 scenario (see Table 1).

That study's results for malaria are summarized in Table 5. It indicates that the global population at risk of malaria transmission in the absence of climate change (P_0) would double from 4,410 million in 1990 to 8,820 million in 2085, while ΔPAR in 2085 would be between 256 million and 323 million. In other words, climate change would contribute only a small portion (no greater than 3.5 percent) of the total PAR for malaria in 2085 (Goklany, 2005).

Table 5: Population at risk (PAR) in 2085 for malaria, with and without further climate change

	Units	**Baseline 1990**	**2085**
Population at risk in the absence of climate change (P_0)	millions	4,410	8,820
Additional population at risk because of climate change (ΔPAR)	millions		256-323
Total population at risk (= P_0 + ΔPAR)	millions	4,410	9,076-9,143

NOTE: This table is based on a pre-SRES scenario. HadCM2 estimates that under this scenario, globally averaged temperature will increase about 3.2°C. in 2085. Source: Arnell et al. (2002).

Note that the current range of malaria is dictated less by climate than by human adaptability. Despite any global warming that might have occurred so far, malaria has been eradicated in richer countries although it was once prevalent there in earlier centuries, and sometimes extended into Canada and as far north as the Arctic Circle (Reiter, 2000; Fallis, 1984; Watson 2006). This is because wealthier societies have better nutrition, better general health, and greater access to public health measures and technologies targeted at controlling diseases in general and malaria in particular. In other words, today's wealthier and more technologically advanced societies have greater adaptive capacity, and that is manifested in the current geographic distribution of malaria prevalence around the globe (Goklany, 2007b). This reaffirms the importance of incorporating adaptive capacity — and changes in future adaptive capacity due to economic growth and technological change — into impact assessments. In fact, analysis by Tol and Dowlatabadi (2001) suggests that malaria is functionally eliminated in a society whose annual per capita income reaches $3,100. But as shown in Table 1, even under the poorest (A2) scenario, the average GDP per capita for developing countries is projected to be $11,000. Hence, few, if any, countries ought to be below the $3,100 threshold in 2085. In addition, given the rapid expansion in our knowledge of diseases and development of the institutions devoted to health and medical research, the $3,100 threshold will almost certainly drop in the next several decades as public health measures and technologies continue to improve and become more cost-effective.

3. Ecological Changes in 2085-2100, with and without Climate Change

In Table 6, I provide information on the variation in three specific ecological indicators across the different scenarios: net biome productivity (a measure of the terrestrial biosphere's net carbon sink capacity); the area of cropland, a crude measure of the amount of habitat converted to agricultural uses which is perhaps the single largest threat to global terrestrial biodiversity (Goklany, 1998); and the global loss of coastal wetlands relative to 1990.

Table 6: Ecological indicators under different scenarios, 2085-2100

		Baseline 1990	**A1FI**	**A2**	**B2**	**B1**
CO_2 concentration (in 2100)	ppm	*353*	970	856	621	549
Net Biome Productivity with climate change (in 2100)	Pg C/yr	*0.7*	5.8	5.9	3.1	2.4
Area of cropland with climate change (in 2100)	% of global land area	*11.6%*	5.0%	NA	13.7%	7.8%
Global losses of coastal wetlands in 1990-2085						
Losses due to SLR alone	% of current area		5 - 20%	3 - 14%	3 - 15%	4 - 16%
Losses due to other causes	% of current area		32 - 62%	32 - 62%	11 - 32%	11 - 32%
Combined losses	% of current area		35 - 70%	35 - 68%	14 - 42%	14 - 42%

Sources: Arnell et al. (2004); Nicholls (2004); Levy et al. (2004)

Under each scenario the biosphere's sink capacity is higher in 2100 compared to 1990 mainly because, according to the projections, the positive effect of carbon fertilization will not be offset by the negative effects of higher temperatures. Sink capacities under the A1FI and A2 scenarios are approximately the same in 2100, and greater than the sink strengths under the B1 and B2 scenarios. Partly for the same reason and also because of its low population, the amount of cropland is lowest for the A1FI world, followed by the B1 and B2 worlds. (Cropland estimates were not provided for the A2 scenario.) Thus, through the foreseeable future, the A1FI scenario would have the least habitat loss and, therefore, pose the smallest risk to terrestrial biodiversity from this particular threat, while the B2 scenario would have the highest habitat loss.

Regarding the loss of coastal wetlands, estimated losses due to sea level rise (SLR) for each scenario are substantial but the contribution of climate change to total losses in 2085 are smaller than losses due to subsidence from other man made causes, confirming the results of earlier studies (Nicholls 1999). Table 6 shows that total wetland losses are much higher for the A1FI and A2 scenarios than for the B1 and B2 scenarios, but this is due mainly to the assumption that under the first two scenarios, societies would take fewer measures to alleviate non-climate-change-related subsidence (Nicholls 2004, p. 76) which, as noted, is suspect.

4. Is Climate Change the Most Important Environmental Problem for the Foreseeable Future?

A review paper in *Nature* claims that global warming may have been responsible for about 0.17 million deaths worldwide in 2000. This estimate is based on an analysis by McMichael et al. (2004) put out under the auspices of the World Health Organization. However its authors themselves 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*." [Emphasis added.] (McMichael et al., 2004, p. 1546).

In other words, the 0.17 million estimate should be viewed with skepticism since science was admittedly sacrificed in hot pursuit of a pre-determined policy objective. But, absent serendipity, one cannot base sound policy on poor science.

Nevertheless, for the purposes of this paper, I will accept this problematic estimate at face value. Notably, 0.17 million deaths per year would constitute 0.28 percent of global mortality, according to the *World Health Report 2002* (WHO, 2002). The same report indicates that climate change doesn't even make the top 10 global health risk factors related to food, nutrition, and environmental and occupational exposure. Specifically, it attributes 1.12 million deaths in 2001 to malaria; an additional 3.24 million deaths to malnutrition;[11] 1.73 million deaths due to unsafe water, and inadequate sanitation and hygiene; 1.62 million deaths due to indoor air pollution from indoor heating and cooking with wood, coal, and dung; 0.8 million to urban air pollution; and 0.23 million to lead exposure (Goklany 2007b). Climate change is clearly not the most important environmental problem facing the world today.

Is it possible, however, that in the foreseeable future, the impact of climate change on public health could outweigh that of other factors?

To shed light on this question, I will translate the PAR and ΔPAR in 2085 shown in Tables 2, 4 and 5 for hunger, coastal flooding, and malaria, respectively, into "ball park" estimates for mortality assuming that the mortality scales linearly with PAR between 1990 and 2085, and that there has been no change in mortality for these threats between 1990 and 2001.[12] Because Table 5 for malaria only

[11] 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).

[12] This assumption is necessary because mortality for hunger and malaria are not readily available for 1990. According to FAO (2004), the number of people suffering from chronic undernourishment in the developing countries was virtually unchanged between 1990-1992 and 2000-2002 (going from 824 million to 815 million in developing countries between these two periods). According to WHO (1995), malaria killed 2 million in 1993 (compared to 1.12 million in 2001). Thus, to the extent the ratio of deaths-to-PAR may have declined between 1990 and 2001, future deaths due to malaria would be underestimated. Finally, according to EM-DAT (2005), 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 Christmas tsunami of 2004). Table 7 assumes: (a) an estimate of 8,000 deaths in 1990 due to these extreme weather event categories, and (b) all deaths for these categories are due to coastal flooding.

has information regarding the IS92a scenario, additional assumptions are necessary to derive mortality for each of the SRES scenarios. Specifically, with respect to malaria, mortality estimates for each SRES scenario are derived by assuming that: (a) in the absence of climate change, population at risk scales linearly with the global population in 2085 under each scenario, and (b) the ratio of ΔPAR to PAR varies with the square of the ratio of the global temperature change.

Note that the methodology used to translate PAR into mortality probably overestimates the latter because it doesn't allow for the possibility that increases in adaptive capacity due to both economic development and technological progress (or time) might reduce mortality more than PAR. However, this would be consistent with the methodologies used in the impacts assessments in that they don't account for new technologies for hunger, or either increasing wealth or new technologies for malaria. In any case, both mortality without climate change (M_0) and the increase in mortality due to climate change alone (ΔM) should be overestimated to the same degree. Also, since impacts analyses generally underestimate changes in adaptive capacity, both M_0 and ΔM are probably overestimated for each scenario, with larger overestimates for the wealthier scenarios.

Table 7 shows results for mortality without climate change (M_0), the increase in mortality due to climate change alone (ΔM), and the sum of the two (M) in 2085 for each scenario and risk factor. In order to keep the table simple, Table 7 only shows the mortality using the high end PAR for each scenario.

This table shows that *for each SRES scenario*, the contribution of climate change to the total mortality burden from malaria, hunger and coastal flooding is substantially smaller than that due to other factors. The former varies from 3.6 percent for the B2 scenario to 10.3 percent for the A1FI scenario. Thus, if climate change was halted at its 1990 level, that would reduce the mortality burden in 2085 from these three factors by no more than, for example, 10.3 percent for the A1FI scenario (corresponding to 237,000 deaths out of a possible 2,067,000).

These results, in conjunction with those from Table 3 for populations at risk of water stress and Table 6 for ecological indicators indicate that the effect of non-climate-change related factors generally outweighs the effects of climate change with respect to either human or environmental well-being.

Thus Table 7 underestimates the relative importance of malaria compared to the other threats, while overestimating future deaths due to coastal flooding.

Climate change is therefore unlikely to be the most important environmental problem confronting human or environmental well-being, at least through the foreseeable future.

Table 7: Deaths (in thousands) in 2085 due to hunger, malaria and coastal flooding, with and without further climate change

	1990 baseline	A1FI 2085	A2 2085	B2 2085	B1 2085
M_0 = mortality in the 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
M_0 (Subtotal)	***4,368***	***2,067***	***6,012***	***3,075***	***2,010***
ΔM = 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
ΔM (Subtotal)	***0***	***237***	***282***	***116***	***92***
Total mortality = $M_0 + \Delta M$					
TOTAL MORTALITY	**4,368**	**2,304**	**6,295**	**3,191**	**2,102**

NOTE: This table assumes the high end of adverse impacts of climate change (see text). Sources: Tables 2, 4 and 5.

5. Is a Richer-but-warmer World Worse off than Poorer-but-cooler Worlds?

The Stern Review estimated that unmitigated climate change will reduce welfare by an amount equivalent to a reduction in consumption per capita of 5-20 percent "now and forever" if one accounts for market and non-market impacts and the risk of catastrophe (Stern Review, 2006, Executive Summary, p. x). It also suggests that by the year 2200 the 95th percentile of the equivalent per capita GDP losses could rise to 35.2 percent (Stern Review, pp. 156 and 158). Several researchers have disputed the Review's impacts estimates as overblown (Byatt et al., 2006; Carter et al, 2006; Dasgupta, 2006; Nordhaus, 2006; Tol and Yohe, 2006) and the Review's authors themselves emphasize "strongly" that the numbers should not "be taken too literally" (Stern Review, FAQ, 2007, p. 2). I will, nevertheless, put aside these concerns and, in this section, be guided by the Review's results in order to estimate whether unmitigated climate change will lower future well-being to below today's levels. Specifically, I will assume, for the sake of argument, that climate change under the warmest scenario (A1FI) would result in a welfare loss equivalent to 35.2 percent in 2100.

Table 8 shows, for each SRES scenario listed in table 1, the GDP per capita in 1990 (the base year for the SRES scenarios) and 2100 in the absence of any climate change. It also provides estimates of equivalent welfare losses per capita assuming unmitigated climate change, and adjusts the GDP per capita in 2100 downward to account for this loss assuming that the loss would increase with the square of the average global temperature increase from 1990 to 2085 per Table 1.

Table 8 indicates that notwithstanding gross inflation of the adverse impacts of climate change, welfare should be higher in 2100 than it was in 1990. Remarkably, even after accounting for climate change, welfare in developing countries (on average) should be higher in 2100 than it was for developed countries in 1990 for all but the A2 scenario. This also calls into question arguments that present generations are morally bound to take aggressive actions now to mitigate climate change because future generations will, otherwise, be worse off in the future. Future generations will not only be better off, they should also have at their disposal better and more effective technologies to address not just climate change but any other sources of adversity.

Second, well-being in 2100 should, in the aggregate, be highest for the richest-but-warmest (A1FI) scenario and lowest for the poorest (A2) scenario. This conclusion was reached despite the previously noted tendency of impacts analyses to overestimate net adverse impacts, especially for wealthier societies.

To summarize, over this century the SRES scenario that leads to the greatest risk of climate change is also the one that leads to the greatest gains in human welfare. Notwithstanding climate change, through this century human well-being is likely to be highest in the richest-but-warmest (A1FI) world and lower in poorer-but-cooler worlds. Thus, if humanity has to choose between the four scenarios examined here, it should for the next few decades strive to realize the richest-but-warmest (A1FI) world.

Table 8: GDP per capita (in 1990 U.S. $, market exchange rates) for developing and industrialized countries in 2100, adjusted for maximum losses due to climate change per the Stern Review (2006).

Year	**1990**	**2100**			
Scenario	***Actual***	***A1FI***	***A2***	***B2***	***B1***
Temperature increase in 2085 [°C]	—	4.0	3.3	2.4	2.1
Developing countries					
GDP per capita, no climate change	$875	$66,500	$11,000	$18,000	$40,200
Maximum cost of climate change*	0	$23,408	$2,635	$2,281	$3,900
Net consumption per capita, with climate change	$875	$43,092	$8,365	$15,719	$36,300
Industrialized countries					
GDP per capita, no climate change	$14,500	$107,300	$46,200	$54,400	$72,800
Maximum cost of climate change*	0	$37,770	$11,069	$6,894	$7,063
Net consumption per capita, with climate change	$14,500	$69,530	$35,131	$47,506	$65,737

* Assuming (a) climate change will reduce welfare by 35.2% for A1FI in 2100 (see text), (b) welfare losses vary with the square of the average global temperature change, and (c) the cost of climate change in 1990 is zero. [Sources: Warren (2006b), Arnell et al. (2004), World Bank (2006); Stern Review (2006).]

6. Costs and Benefits of Mitigation and Adaptation

6.1 Mitigation

In the near term mitigation will have little or no impact on reducing the impacts of climate change, because of the inertia of the climate system. However, over time, its effect will build up. In Table 9, I show the decrease in: (a) mortality from hunger, malaria and coastal flooding, and (b) the population at risk of water stress under the A1FI (richest-but-warmest), A2 (poorest) and B1 (coolest) emission scenarios in 2085 using two mitigation scenarios 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 high end, a scenario that would ensure no climate change beyond 1990 levels. These decreases, derived from Tables 3 and 7, are shown relative to the unmitigated case, i.e., no emission controls whatsoever.

To construct this table, I optimistically assumed that by 2085 the Protocol would reduce climate change, as represented by the changes in global temperature and sea level, by 7 percent, which would then reduce the impacts of climate change on malaria, hunger and water stress by a like amount, and the impacts of coastal flooding by 21 percent (Goklany, 2005). This is based on Wigley (1998) which estimates that if the Kyoto Protocol were to be fully implemented that would reduce the amount of warming in the 2080s by no more than 7 percent. See Goklany (2003) for further details. As will become evident, the validity of the arguments and conclusions in this paper hold regardless of the assumptions about the effectiveness of the Kyoto Protocol in reducing climate change.

This table shows 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 populations at risk from water stress, and decreases in the habitat available for other species. This also illustrates one of the major shortcomings of mitigation, namely, mitigation is indiscriminate — it reduces all impacts, whether they are positive or negative. Second, the table also shows that the benefits of the Kyoto Protocol are relatively trivial compared to the magnitudes of the problems that it purportedly would reduce. For example, it would reduce cumulative mortality for malaria, hunger and coastal flooding by 0-1 percent, compared to 4-10 percent if climate were to be somehow frozen at its 1990 level.

Table 9: Effectiveness of the Kyoto Protocol or a halt in climate change Changes in 2085-2100 in mortality for malaria, hunger and coastal flooding, population at risk for water stress, and in habitat available for other species

	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

NOTE: The negative sign in the second last row (for water stress) indicates that mitigation will make matters worse in 2085. * The figures in parantheses indicate the percent declines in total mortality from malaria, hunger and coastal flooding (or populations at risk from water stress) under the control scenarios. NA = not available. Sources: Tables 3, 6 and 7; Goklany (2005).

In the following discussion, I will assume that the Kyoto Protocol will cost $165 billion per year in 2010.[13] On the other hand, the cost of the no-climate-change scenario, assuming it's even feasible, would be astronomical. As will be evident in the following, the results of this study are robust to the precise cost of halting climate change, so long as they are greater than $165 billion per year.

6.2 Reducing Current Vulnerabilities via Focused Adaptation

Table 7 indicates that despite freezing climate at its 1990 level at a cost upward of $165 billion annually, 90-96 percent of the mortality problem for the three listed threats would be unsolved. By

[13] IPCC (2001) estimates that in 2010 the Protocol could cost between 0.1 and 2.0 percent of the GDP of Annex I countries. I will assume that its cost is 0.5 percent of their cumulative GDP, which is at the lower end of this range. This translates to $165 billion (in 2003 dollars). See Goklany (2005).

contrast, policies focused on solving the whole problem not only would have a larger target of opportunity (namely, 100 percent of the problem), they will be at least as, if not more, cost-effective than mitigation. This is because the set of economically efficient options available to solve the whole problem encompasses the subset of economically-efficient options available to solve any portion of the problem, whether through mitigation or other means. Thus focusing on the former will necessarily enhance human well-being more than policies that would only mitigate climate change.

Equally important, measures that would reduce vulnerability to the non-climate-change-related portion of the problem (P_0 or M_0) would also reduce the climate change related component (ΔP or ΔM) (Goklany, 2005). In particular, policies and measures 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. This is because the technologies, practices, systems, and human and social capital devised to cope with these problems today will aid societies in coping with these same problems in the future. For instance, a successful malaria vaccine would help reduce malaria cases regardless of whether the avoided cases would be due to climate change or other factors.

Such an approach which, for lack of a better term, I will call "focused adaptation," would, unlike mitigation, bring substantial benefits in the near-to-medium term. This is mainly due to the fact that mitigation will not affect mortality due to the non-climate change related component of the threat. As shown in Table 7, mortality from hunger, malaria and coastal flooding in the absence of climate change ranges from 4.4 million in 1990 to 2.1-6.3 million in 2085 (depending on the scenario). In addition, mitigation wouldn't reduce the climate change component of the problem significantly until a few decades have elapsed (due to the inertia of the climate system).

Following are a few examples of focused adaptation policies and measures that would reduce climate-sensitive problems now and in the future regardless of whether climate change causes or contributes to them.

Malaria. At an additional cost of $3 billion/yr, malaria's current global death toll of about a million/yr can be reduced by 75 percent, according to the UN Millennium Project (2005b). These expenditures may have to be increased by 2085 to keep pace with the projected increase in the global population at risk from malaria in the absence of climate change (see Table 7). I will assume, 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, regardless of the emission scenario in order to reduce malaria deaths by 75 percent.

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, insecticide-treated bednets, improved case management, more comprehensive antenatal care, and development of safe, effective and cheap vaccine(s) and therapies (WHO, 1999; UNMP, 2005b). Moreover, if these measures are even partly successful, they could further reduce the likelihood of outbreaks because the risk of exposure would be lower.

Hunger. An additional $5 billion annual investment in agricultural R&D — approximately 15 percent of global funding of agricultural research and development during the 1990s — should raise productivity sufficiently to more than compensate for the estimated 0.02 percent annual shortfall in productivity caused by climate change (Goklany, 2005). This should reduce total PAR by significantly more than the largest estimate under any scenario for ΔPAR (see Table 2), 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 work of the UN Millennium Project, which estimates that somewhere between 5-8 percent of the extra funding needed to realize the Millennium Development Goals would be required to reduce global hunger by 50 percent in 2015 (UNMP, 2005c, p. 18). This works out to less than $12 billion in 2010 and about $15 billion in 2015 (calculated using UNMP, 2005c, and UNMP, 2005a, p. 57). I will for purposes of this discussion assume $15 billion per year for the 2010-2015 period.

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. Thus actions focused on increasing agricultural productivity under current marginal conditions would alleviate hunger in the future whether or not climate changes. Similarly, since both CO_2 and temperatures will, like it or not, increase, crop varieties should be developed to take advantage of such conditions as, and when, they come to pass (Goklany, 2007a, 2007b). Notably, in the initial stages at least, progress on these approaches does not depend on improving our skill in forecasting location-specific details of climate change impacts analyses. These focused adaptation measures should be complemented by development of higher yield, lower impact crop varieties and agronomic practices so that more food is produced and utilized by consumers per unit of land or water devoted to food production. This would help reduce hunger while providing numerous ancillary benefits for biodiversity and sustainable development (see below).

Coastal Flooding. According to estimates in the latest IPCC (2007) report, 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 as compared to 0.34 meters under the 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. [See Figure 6.10 in IPCC (2007), attributed to Tol (2006).] Governments could, moreover, discourage maladaptation by refusing to subsidize insurance and/or protective measures which allow individuals to offload private risks to the broader public.

Water stress. Although climate change could relieve water stress (see Table 3), there are, nevertheless, many measures that would help societies cope with present and future water stress regardless of their cause. These include institutional reforms to treat water as an economic commodity by allowing market pricing and transferable property rights to water. This should stimulate widespread adoption of existing but underused conservation technologies and lead to more private-sector investment in R&D that would reduce the demand for water by all sectors. For example, new or improved crops and techniques for more efficient use of water in agricultural would enhance agricultural productivity and reduce the risk of hunger.

Improvements in water conservation following such reforms are likely to be most pronounced for the agricultural sector, which is responsible for 85% of global water consumption. A reduction of 18% in agricultural water consumption would, on average, double the amount of water available for all other uses, including household, industry, and in-stream uses (such as recreation and conservation of aquatic species). The last would reduce pressures on freshwater biodiversity as a result of water diversion, which is the greatest threat to freshwater biodiversity (Goklany, 2005).

6.3 Comparing Mitigation against Adaptation

In Table 10, I compare the costs and benefits of focused adaptation against two scenarios of mitigation — the Kyoto Protocol and a halt in climate change as of 1990 — for the A1FI (warmest-but richest) and the A2 (poorest) emission scenarios with respect to declines in mortality from hunger, malaria and coastal flooding. Thus, at a cost of $34 billion per year (for the 2010-2015 period), focused adaptation could deliver far greater benefits than even halting climate change, but at a fifth of the cost of the Kyoto Protocol.

The table, moreover, doesn't show the differences between the cumulative reductions in mortality or population at risk between the present and 2085 due to focused adaptation relative to the mitigation options. This ought to be very large, and in favor of adaptation, because unlike mitigation, focused adaptation will also reduce present-day climate-sensitive problems in the near-to-medium term.

Thus, focused adaptation will start to provide a steady stream of benefits in the very near term while, because of the inertia of the climate system, the benefits of mitigation will not be significant until decades have elapsed. One might, nevertheless, argue that under the precautionary principle it would be appropriate to pursue aggressive mitigation (in contrast to "no-regret" mitigation measures[14] which would help solve current urgent problems while also limiting greenhouse emissions). While such an argument might be valid in the long term, for the foreseeable future there are plenty of unsolved problems that afflict current generations that could gainfully use the economic and human resources that might otherwise be diverted toward aggressive mitigation. In fact, focused adaptation can itself be viewed as a no-regret action since, as we have seen, it can substantially reduce existing problems such as hunger and malaria that currently beset the developing world while simultaneously helping ensure that world prepares to cope with the future impacts of climate change.

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[14] "No-regret" actions are cost-beneficial actions that would or should be undertaken for economic or environmental reasons unrelated to climate change. Examples of no-regret actions include elimination of subsidies, replacement of inefficient processes or appliances for business reasons, or replacement of coal with natural gas in order to reduce air pollution. Note that the suite of no-regret actions is constantly expanding as societies' technological options increase due to greater wealth and technological change. Thus, an action that does not fit that description today may appropriately be classified as a no-regret action tomorrow.

Table 10: Benefits (in 2085) and costs (~2010-2015) for various 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***
Decline in mortality from malaria, hunger and coastal flooding (in thousands)*	21 (1%)	237 (10%)	1,480 (64%)	1,480 (64%)	51 (1%)	282 (4%)	3,784 (60%)	3,784 (60%)
Decline in net population at risk from water stress (in millions)†*	-83 (-5%)	-1,192 (-72%)	Climate change may reduce net PAR	Climate change may reduce net PAR	0	0	Climate change may reduce net PAR	Climate change may reduce net PAR
Progress toward other MDGs • 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	MDGs should be met	Almost none	Some	Substantial	MDGs should be met
Available habitat (as measured by extent of global cropland)	Small decrease in habitat	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

† The negative sign indicates that mitigation will make matters worse in 2085.
* The figures in parantheses indicate the percent declines in total mortality from malaria, hunger and coastal flooding (or populations at risk from water stress) under the control scenarios. NA = not available. Sources: Tables 3, 6 and 7; Goklany (2005)

Mitigation has the additional problem that it indiscriminately reduces all impacts of climate change, whether they are positive or negative. But adaptation can selectively capture the positive aspects 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 is mitigation, and to deliver those benefits sooner rather than later.

Ancillary benefits (or "co-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, in addition to climate change (Goklany, 2000, 2007a; UNMP, 2005a). These co-benefits, in fact, are among the goals and purposes of sustainable development, as explicitly articulated in the Millennium Development Goals.

Several measures noted above that would reduce current hunger and water stress would also provide co-benefits by enhancing agricultural productivity per unit of land and water. In turn, that would reduce human demand for agricultural land and water, which is the greatest current threat to both terrestrial and freshwater biodiversity, and is likely to remain so through the foreseeable future (Goklany, 1998, 2000). It would also aid mitigation by limiting land under cultivation thereby reducing losses of carbon stores and sinks, and the socioeconomic costs of reserving land for conservation or carbon sequestration. These co-benefits would, moreover, advance sustainable development in their own right.

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, or elucidation of mechanisms that confer resistance in crops to drought, water logging, or saline soils. To the extent that such measures do not rely on the location-specific details of impacts analyses, that reduces the risk of having wasted resources by pouring them into problems that may or may not occur at specific locations (Goklany, 1995).

Finally, the conclusion that focused adaptation is for the foreseeable future superior in terms of both global benefits and global costs is robust to the choice of discount rates, including a zero discount rate. This is because, first, the benefits of focused adaptation will generally follow relatively soon after its costs are incurred. On the other hand, the climate system's inertia ensures that costs of emission reductions will have to be borne for decades before any benefits accrue. Second, as has been shown, the contribution of climate change to the various climate-sensitive threats is generally outweighed by that of other factors.

7. Integrating Mitigation, Adaptation and Sustainable Development

The foregoing examined two approaches to address warming through the foreseeable future. The first, mitigation, would reduce impacts — positive and negative — across the board. This entails significant near term costs, and the pay-off, if any, 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 the individual threats, and attacking these threats simultaneously.

Developing countries are most vulnerable to warming not because they will experience greater climate change, but rather because they lack adaptive capacity to cope with its impacts. Hence, a third approach to addressing climate change would be to enhance their adaptive capacity by promoting broad development, i.e., economic development and human capital formation, which, of course, is the point of sustainable development (Goklany, 1995, 2007a). Moreover, since the determinants of adaptive and mitigative capacity (IPCC, 2001; Yohe 2001) are largely the same, enhancing the former should also boost the latter (Goklany, 2007a). Thus, pursuit of sustainable development would simultaneously advance the capacity to adapt to or mitigate climate change. Perhaps more important, that would also advance society's ability to cope with all other manners of threats, whether it is related to climate or not (Goklany, 2000).

One approach to estimating the costs and benefits of sustainable development is to examine the literature on the Millennium Development Goals, which were devised to explicitly advance sustainable development in developing countries. The benefits associated with these goals — halving global poverty, hunger, lack of access to safe water and sanitation; reducing child and maternal mortality by 66% or more; universal primary education; and reversing growth in malaria, AIDS/HIV, and other major diseases — would exceed the benefits flowing from focused adaptation or even the deepest mitigation (see Table 10). Yet, according to the UN Millennium Project (2005a), the additional annual cost to the richest countries of attaining the Millennium Development Goals by 2015 is pegged at about 0.5 percent of their GDP. That is approximately the same cost as that of the ineffectual Kyoto Protocol.[15]

Moreover, since measures to advance sustainable development would address urgent problems that developing nations currently face (e.g., malaria, hunger, HIV/AIDS, and poor access to safe water and sanitation), while mitigation would only address future and less certain damages due to climate change, the benefits associated with sustainable development would be obtained sooner and more certainly than through mitigation alone. In addition, increased adaptive capacity would either raise the level at which GHGs would need to be stabilized to forestall warming from becoming "dangerous", or allow mitigation to be postponed, or both (Goklany, 2000). In any case, costs associated with any eventual stabilization of greenhouse gas concentrations could be reduced, particularly if, in the interim, resources are expended to improve the cost-effectiveness of mitigation options. Advancing sustainable development would also advance mitigative capacity so that mitigation, if or when it becomes necessary, is more affordable and/or more effective. In fact, such an approach would be entirely consistent with the UN Framework Convention on Climate Change's objectives outlined in Article 2: "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."

8. The Adaptive Management of Climate Change Risks

The foregoing casts doubt on key premises underlying calls to take aggressive actions now that would go beyond "no-regret" policies in order to reduce GHG emissions in the near term,[16] namely, there is no greater environmental problem in the 21st century than climate change, that a richer-but-

[15] Note that the conclusion that broadly and substantially advancing sustainable development would provide greater benefits at lesser costs than mitigation (at least through 2085) is independent of whether the Millennium Development Goals are, in fact, met by 2085. Even if the goals articulated by the Millennium Development Goals were postponed, say, to 2085, as Table 10 shows, their benefits would still outweigh those obtainable through mitigation and, presumably, at a lower cost than estimated by the UN Millennium Project.

[16] See footnote 14.

warmer world will soon be worse for the globe than a poorer-but-cooler world, and that the adverse impacts of climate change would be more efficiently and effectively reduced through mitigation rather than adaptation. The above analysis suggests these premises are unlikely to be valid before at least 2085-2100. Even assuming that it takes 50 years to replace the energy infrastructure, that means we have a few decades (i.e., 2035-2050) before we need to commit to an aggressive GHG reduction program that goes beyond "no-regrets."

Only if new information emerges suggesting that the adverse impacts of greenhouse gas induced climate change are growing more rapidly or are likely to be greater than currently indicated would mitigation measures become justifiable. The issue isn't whether adaptation or mitigation should be the sole approaches to addressing climate change. Clearly, the two approaches are not mutually exclusive. The issue, in fact, is one of the magnitude and relative balance of resources expended on these strategies, and how that balance might shift over time to ensure that well-being is optimized.

Accordingly, in the near-to-medium term, we should focus on:

- Increasing adaptive capacity, particularly of developing countries, by investing in efforts now 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. This might also increase the level at which GHG concentrations would need to be stabilized to "prevent dangerous anthropogenic interference with the climate system," which is the stated "ultimate objective" of the UN Framework Convention on Climate Change.[17] Alternatively, it could postpone the deadline for stabilization. In either case, it could reduce the costs of meeting the ultimate objective;
- Strengthening or, where needed, developing the institutions necessary to advance and/or reduce barriers to economic growth, human capital and the propensity for technological change. These

[17] 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."

factors underpin both adaptive and mitigative capacities, as well as sustainable development (Goklany, 1995, 2000, 2007a);

- Implementing no-regret mitigation measures now while expanding the range and diversity of future no-regret options through R&D to improve existing —and develop new — technologies that would reduce atmospheric greenhouse gas concentrations more cost-effectively than currently possible. Should new information indicate more aggressive mitigation action is necessary, future emission reductions might then be cheaper, even if they have to be deeper to compensate for a delay in a more aggressive response in the short term;
- Allowing the market to run its course in implementing no-regret options as their range expands with improvements in cost-effectiveness. Among other things, this implies reducing subsidies that directly or indirectly increase energy use, land clearance, use of fertilizers or other activities that contribute to greater greenhouse gas emissions, and reducing other perverse subsidies that encourage maladaptation. As part of this effort, OECD nations should also reduce, if not eliminate, agricultural subsidies and barriers to trade. Not only are such subsidies and barriers expensive for consumers in these nations, they damage the economies and well-being of many developing nations whose economies and employment are dominated by the agricultural sector (Goklany 1995, 2007a);
- Developing a more robust understanding of the science, impacts and policies of climate change in order to develop response strategies that would forestall "dangerous" impacts of climate change (per the UNFCCC's Article 2) while at the same time advancing human well-being; and
- Monitoring the impacts of climate change to give advance warning of "dangerous" impacts and, if necessary, to rearrange priorities should the adverse impacts of warming on human and environmental well-being occur faster, threaten to be more severe or more likely than is 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.

9. Is it Unfair to Future Generations to Defer Aggressive Mitigation?

It has been argued that it is only fair that present generations expend resources on mitigation now otherwise future generations would be left with a bigger mess and a larger clean-up bill. But the major share of the benefits of mitigation is likely to occur in the longer term. It might, therefore, be more equitable, especially to present generations, to expend resources on adaptive strategies now and defer purely mitigative actions for a few years until they can better pay for themselves, especially since future generations are likely to be wealthier, have greater access to technology and human capital, and should, therefore, be able to solve many of their problems with relatively greater ease.

Table 10 shows that resources expended in the short-to-medium term on mitigation that goes beyond no-regrets could indeed be put to better use in reducing current risks and vulnerabilities (Schelling 1995, Dowlatabadi 1997, Goklany 2000, Tol and Dowlatabadi 2000, Lomborg 2004). Focused adaptation and broad development would provide benefits in both the short and the long term because the technologies, processes and systems developed to adapt to climate-sensitive risks today will be the basis for future, more effective adaptations.

Thus future generations would also benefit from resources spent today on adaptive strategies, particularly if these resources go toward enhancing adaptive capacity and advancing sustainable development. Similarly, future generations would also benefit from resources devoted to research and development of mitigation technologies and strategies. While we do have an obligation to future generations, arguably that obligation is discharged if we are diligent in expanding technological options for both adaptation and mitigation, and amassing the economic, social and human capital that they can draw upon to address the problems of their day.

Second, it is claimed that adaptation is "unfair" since those doing the adapting are "not always responsible for causing climate change" (Dang et al. 2003), and that responsible parties should compensate those who are not. However, before assigning responsibility one has to first determine who is "responsible" and for what. On that score, while it is possible to assign greenhouse gas (GHG) emissions to nations based on the geographic location of the emission activities, we should be cognizant that GHG emissions are the effluvia of civilization and all its activities. It is not only energy consumption that contributes to these emissions, but land clearance, crop production, animal husbandry, trade, tourism, and so forth. Moreover, because of the globalized economy, which sustains today's civilization, economic activity in one country helps provide livelihoods and incomes for many inhabitants of other countries, and vice versa. In fact, a substantial portion of economic growth in developing countries is attributable to trade, remittances, tourism and direct investment from developed countries. Without such economic activities, U.S. emissions, for example, might be lower, but so would jobs and incomes elsewhere (e.g., in India, Bangladesh, the Philippines, or Jamaica). Thus, the improvements in human well-being that have occurred in many developing countries (particularly since World War II) are partly due to the GHG-fueled economic growth in developed countries (Goklany 2007b).

Greenhouse gas fueled economic growth also enabled today's rich societies to invest in research and development that helped, for instance, raise crop yields worldwide, develop new and more effective medicines (e.g., for HIV/AIDS), provide aid in times of famine or other natural disasters, provide funding for reducing TB and malaria, create and support the Internet, and other items now considered by some to be global public goods (ODS 2004). Also, absent such economic growth, the sum of human capital worldwide would have been much less. Consider, for instance, the millions of non-Americans who have been cycled through universities in the U.S. who, then, have gone back to help in their native countries' economic and technological development. Thus, all countries indulge in or benefit to one degree or another from activities that contribute to climate change. Hence, before determining responsibility and/or compensation one should try to estimate whether direct and indirect costs of climate change will, in fact, exceed direct and indirect benefits of the activities that fuel climate change.

It might be argued that if the actions of A produce both benefits and harms to B, A should compensate B for the harms, but she cannot subtract the benefits in escaping responsibility (because, after all, B did not solicit A to undertake the actions in question). This would be disingenuous because benefits are nothing but negative harms, and should, therefore, necessarily be subtracted in estimating net harm to B. Also, if B insists on not subtracting benefits from the compensation package, he loses his moral claim for any compensation because one can't insist on compensation on one hand, and be a free rider on the other.

Some might also argue that one should not take indirect effects of GHG-producing activities into consideration: only direct effects should be considered. But the notion of assigning responsibility (or demanding compensation) for climate change is itself based on indirect (and inadvertent) outcomes. After all, developed countries did not emit GHG emissions with the express intent to harm anyone. There has to be symmetry in these matters.

Let's assume for the sake of argument that one can indeed estimate the fraction of global warming caused by the United States (for instance), the next step is to estimate the net harm that has been caused to, say, Bangladesh (ignoring for now issues such as whether today's generation should be liable for damages incurred by previous generations). To make such estimates, it is not sufficient to know the direct impacts of climate change on Bangladesh, but also the indirect consequences of all GHG producing activities. This involves developing answers to questions such as: had there been no GHG producing activities in the United States, what would have been Bangladesh's level of human well-being? What would be its life expectancy (which is currently 62 years and was about 35 years in 1945) had there been no GHG emissions in the interim? What about its hunger and malnutrition rates? How many Bangladeshis were saved in the 1960s and 1970s because of food aid from the developed countries? How much of the past increase in Bangladesh's agricultural productivity is due to higher CO_2 levels, or indirectly due to efforts that were possible because the U.S. was wealthy enough to support/stimulate them? If future agricultural productivity declines due to climate change, how do you subtract out past benefits from future harms? These are just a small sample of issues that have to be addressed before assigning responsibility to various actors for climate change.

Finally, even if one could assign responsibility for climate change, it does not follow that it would be more fair if developed nations were to expend resources on ambitious mitigation measures now based partly on the premise that it would reduce future climate change risks for developing nations, when the same resources would, in the short-to-medium term, provide greater and faster benefits to precisely those nations by reducing existing — and generally larger — climate-sensitive risks and vulnerabilities (see Table 10).

10. Conclusion

Climate change is not now, nor is it likely to be through 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) world and lowest for the poorest (A2) world. 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.

Through the foreseeable future, despite any climate change, future generations will be wealthier — and their well-being higher — than it is today for present generations both in the developed and developing worlds. Well-being of future inhabitants in today's developing world would 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.

Equally important, resources expended on solving today's climate-sensitive problems or advancing sustainable economic development will build human capital, advance technology and further sustainable economic development, all of which will enhance the adaptive and mitigative capacities of future generations.

If for whatever reason, developed countries have a moral and ethical obligation to deal with climate change, for the foreseeable future 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, not to mention, more 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.

In the long term, climate change might hinder sustainable development in developing countries, but over the next several decades it is the lack of sustainable economic and technological development that hinders their ability to cope not only with climate change but other sources of adversity as well. Investing in focused adaptation and sustainable economic development will advance well-being for both present and future generations.

For the next several decades, advancing adaptive capacity through either focused adaptation or broad efforts to advance sustainable economic development will provide greater benefits at lower cost than mitigation, unless mitigation technologies become much more cost-effective than they are today.

In the meantime, we should continue to implement no-regret mitigation measures and, through greater research and development, expand the universe of no-regret actions so that if, and when, monitoring of climate change and its impacts indicate the need for more drastic action, further reductions can be cheaper even if they have to be deeper to compensate for a delay in an aggressive response.

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