Is climate change the number one threat to humanity?

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ABSTRACT

This paper challenges claims that global warming outranks other threats facing humanity through the foreseeable future (assumed to be 2085–2100). World Health Organization and British government-sponsored global impact studies indicate that, relative to other factors, global warming's impact on key determinants of human and environmental well-being should be small through 2085 even under the warmest Intergovernmental Panel on Climate Change (IPCC) scenario. Specifically, over 20 other health risks currently contribute more to death and disease worldwide than global warming. Through 2085, only 13% of mortality from hunger, malaria and extreme weather events (including coastal flooding from sea level rise) should be from warming. Moreover, warming should reduce future global population at risk of water stress, and pressures on ecosystems and biodiversity (by increasing net biome productivity and decreasing habitat conversion). That warming is not fundamental to human well-being is reinforced by lower-bound estimates of net GDP per capita. This measure adjusts GDP downward to account for damages from warming due to market, health and environmental impacts, and risk of catastrophe. For both developing and industrialized countries, net GDP per capita—albeit an imperfect surrogate for human well-being—should be (a) double the current U.S. level by 2100 under the warmest scenario, and (b) lowest under the poorest IPCC scenario but highest under the warmest scenario through 2200. The warmest world, being wealthier, should also have greater capacity to address any problem, including warming. Therefore, other problems and, specifically, lowered economic development, are greater threats to humanity than global warming.

INTRODUCTION

Some scientists and policymakers claim that global warming is among the most, if not *the* most, important issue facing mankind.[1,2,3,4] U.N. Secretary General Ban Ki-moon, for example, calls global warming "the most important priority for human beings,"[5] echoing similar statements by other world leaders, past and present.[6,7,8] Such claims have obvious implications for the allocation of society's always-scarce resources to address the many challenges that humanity faces. However, there are no scientific studies that justify such claims at the global scale.

Justification must necessarily be based on a showing that the net global impact of warming exceeds that of other problems now and through the foreseeable future. I will, consistent with other studies, assume that the foreseeable future extends to 2085-2100.[9,10] This is probably optimistic because emission scenarios are driven by socioeconomic assumptions and projections which arguably "cannot be projected semi-realistically for more than 5–10 years at a time."[11]

Although most impact studies have been undertaken at less-than-global scales, some, e.g., the so-called Fast Track Assessments (FTAs) sponsored by the British Government,[12,13,14] are indeed global in scale.[15] The individual FTAs projected the global impacts for hunger,[16,17] malaria,[18,19] water resources,[20,21] coastal flooding,[22,23] forests and land cover[24,25] through 2085. However, like many other impact studies, each FTA study was restricted to one or two determinants of human or environmental well-being. Thus one must synthesize results of several analyses to better understand the full scope of global warming.

Even where studies estimate global impacts, they do not always attempt to put the impact of warming in the context of the other factors affecting the determinant(s) being studied, although there are exceptions.[26] This makes it difficult to resolve whether global warming is indeed the most important problem facing humanity.[*] Nevertheless, such studies can illuminate this issue because every impact study necessarily estimates future impacts both with and without global warming. This allows us to estimate the contribution of global warming to total future impact for each determinant. Results for key determinants could then be synthesized to determine the importance of warming relative to other risks. Unfortunately most impacts assessments place little emphasis on addressing this issue.

The Curious Disinterest of Impacts Scientists in Placing Warming in its Wider Context

Parry et al.'s 2001 paper defining critical climate change threats and targets illustrates the tendency in the literature to place little emphasis on comparing the relative magnitude of the impacts of climate change with those from other factors. The authors emphasized that unmitigated climate change would place "additional millions at risk."[15] However, they overlooked the fact that for three of the four determinants examined, many more millions, if not billions, would be at risk even absent any climate change.

[*] In contrast to most impacts studies, integrated assessments and cost-benefit analyses are often global in scale and cover a wide variety of sectors, but they too restrict themselves to an examination of global warming (e.g., the Stern Review),[45] once again precluding any comparative analysis.

For instance, although climate change would increase the population at risk (PAR) for malaria by as much as 320 million in 2085, PAR in the absence of warming would be 8,800 million.[15,27] That is, climate change would contribute less than 4% to the total PAR for malaria. Similarly, warming would contribute 23% to total hunger in 2085 (91 million out of 391 million), assuming carbon fertilization (see below). By comparison, for coastal flooding, the one determinant for which future population at risk (PAR) is projected to be dominated by warming, PAR would increase from 13 million to 94 million.

But perhaps the most remarkable aspect of Parry et al. was that, it only reported "the number of people living in water-stressed countries … which would experience a reduction in water availability due to climate change" (p. 181, footnote 1). Thus it reported that warming would increase water shortage for over 3 billion people in 2085. But it ignored the numbers for whom warming would **reduce** water stress. In fact, the underlying analysis[20] indicated that the **net** global population under water stress could decline by more than 2 billion.[27] While there is probably an asymmetry in terms of human well-being between increasing and decreasing water stress, readers (including policy makers) are owed both set of numbers, so that they can judge for themselves whether and how to balance these countervailing effects. Equally important, the water-stressed population was estimated at 6.5 billion, even if there were no warming.

Thus, considering the various determinants in aggregate, other factors are likely to be more important than warming for the period of analysis (through 2085).[27] Despite its policy relevance, this information was not presented in Parry et al. although, judging from the article's title, policymakers were apparently among its desired audience.[15]

Similarly, the IPCC's Fourth Assessment Report (AR4) Summary for Policy Makers (SPM) pays scant attention to how the impacts of warming compare in magnitude to other factors, despite comments on its drafts that this omission be rectified.[28*] Perhaps its disinterest stems from its almost singular focus on the adverse impacts of climate change.[†]

So, curiously, while policymakers proclaim that warming is (among) the most important problems facing humanity, impacts scientists seem largely uninterested in pursuing that issue

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[*] One comment, for example, stated,

> "[G]lobal impact assessments undertaken by Parry et al. (1999, 2004) indeed indicate that large numbers will be thrown at risk for hunger because of CC; however, they also indicate that many more millions would be at risk whether or not climate changes... Policy makers are owed this context. Withholding this nugget of information is a sin of omission. Without such information, policy makers would lack necessary information for evaluating response strategies and the trade-offs involved in selecting one approach and not another. One consequence of using Parry et al.'s results to compare population at risk for hunger with and without climate change is that it indicates that measures to reduce vulnerability to current climate sensitive problems that would be exacerbated by CC could have very high benefit-cost ratios. In fact, analyses by Goklany (2005a) using results from Parry et al. (1999) and Arnell et al. (2002) suggests that over the next few decades, vulnerability reduction measures would provide greater benefits, more rapidly, and more surely than would reactive adaptation measures or, for that matter, any mitigation scheme." (Ref. 28, Comment E-SPM 148, p. 28).

To which, the IPCC writing team responded thus,

> "This whole text, from lines 11 to 26, has been deleted. Tables SPM-1 and SPM-2 give greater insights into risks of hunger etc, with full confidence range from negative to positive changes."

But, in fact, Tables SPM-1 and 2 provided no comparison of populations at risk with and without climate change.

[†] Consider the following comment-and-response on the SPM's "second order" draft:

> COMMENT: "C. With respect to the entries related to water stress, we note that Arnell's (1999) analyses of the global impact of CC on water stress indicates that **fewer people** might be under stress (if one measures stress by counting the number of people living in areas where annual water availability drops below 1,000 m3), although the number of countries with water-stressed (*sic*) populations might increase. This result is confirmed by Arnell (2004). Moreover, neither study accounts for any adaptations." [Emphasis in the original.]
> "D. It is disingenuous to report the population 'new water stressed' without also noting that as many, if not more, may no longer be water stressed (if Arnell's analyses are to be trusted)."
>
> RESPONSE: "C and D. These water stress numbers represent those becoming newly water stressed and reflect the infrastructure costs associated with meeting the demand where less water is available." [Ref. 28, Comment E-SPM-168, p. 32.]

despite having ready access to relevant information. Nevertheless, some studies have explicitly addressed whether global warming is the most important problem facing humanity.[29]

Existing Studies Comparing Climate Change with Other Risk Factors

The few studies that have attempted a comparative analysis on a global scale covering multiple determinants show that other, non-climate change related problems are larger in magnitude today and likely to remain so through the foreseeable future. Perhaps the first such study, by Goklany in 2000,[30] was largely based upon information contained in the IPCC's Second Assessment Report. It focused on various critical determinants of human and environmental well-being, specifically, food security, deforestation, biodiversity, and human health.

This analysis was redone[27] using the Fast Track Assessment (FTA) results[12,13] on the global impact of climate change on food security, malaria, water resources, coastal flooding, global land cover, and coastal wetlands. These FTA results were also factored into the IPCC's Third Assessment Report.[31] This analysis was revised[9,10] yet again, after FTA results were updated using the IPCC scenarios developed in its Special Report on Emission Scenarios (SRES)[32] for inclusion into the Fourth Assessment Report (AR4).[33] These studies reaffirmed the conclusions from the previous comparative studies.[27,30] More recently, van Vuuren et al., based on an analysis of future malaria, water stress, energy use, sea level rise and agriculture, concluded that, "While climate change may have an impact on millions of people, other challenges are likely to influence people and governance more significantly."[34]

In the following, I will build upon these studies to determine whether climate change is among the most important problems facing humanity, with the focus on death and disease from a variety of factors, including hunger, malaria, and extreme weather events (including coastal flooding from sea level rise); water shortage; and threats to ecosystems and biodiversity. This paper, however, does not address hypothesized low-probability but potentially high consequence outcomes such as a shutdown of the thermohaline circulation or the melting of the Greenland and Antarctica Ice Sheets, which have been deemed unlikely to occur in the foreseeable future.[35,36,37]

To address the question posed in the title of the paper, the analysis must necessarily be undertaken at a global level. However, I will disaggregate some impacts to developing and industrialized countries because developing countries are probably more vulnerable to global warming and, therefore, likely to bear a disproportionate share of the damages.[31,33]

The analysis presented here relies largely on projected impacts of global warming into the future. However, in order to place its results in context, I will briefly discuss the uncertainties and, more significantly, systematic biases that beset such projections.

UNCERTAINTIES AND SYSTEMATIC BIASES IN IMPACTS ASSESSMENTS

A substantial share of the uncertainty associated with impacts assessments in general and the FTAs in particular stems from the fact that impacts estimates are derived using a series of linked models. Each model in this series is driven by a set of assumptions, the uncertain outputs of the previous model (if any), or both.[9] To compound matters, many of these models have not been verified and validated using empirical, "out-of-sample" data, that is, data that were not used to develop, calibrate or otherwise fine tune the models.[36] It may be argued with some justification that complex models may not be verifiable[31,38] but that does not change the fact that the models have **not** been verified. Therefore, their results should be considered to be inherently uncertain.

The first step in developing impacts estimates is to formulate assumptions regarding the evolution of the socioeconomic drivers of greenhouse gas (GHG) emissions (namely, population, economic growth, and technological change) spanning the duration of the analysis, which for the SRES was from 1990 (the base year) through 2100.[32] These assumptions are then fed into emissions models to develop emissions scenarios over the 1990–2100 time frame. However, as noted, our ability to accurately forecast socioeconomic factors for longer than a few years is questionable, at best.[11]

Nevertheless, in the third step these emission scenarios are used to drive coupled atmosphere-ocean general circulation models (AOGCMS, i.e., climate models) to estimate spatial and temporal changes in climatic variables spanning the period of the analysis. Notably, the finer the geographic scale, the larger the uncertainties in these estimates. This is particularly true for precipitation (Ref. 37, pp. 600–01), which is a key determinant of the abundance, health and distribution of critical natural resources (e.g., water, food, forests, pasture and other vegetation) that sustain virtually all living species. Unfortunately, these climatic changes must necessarily be estimated at relatively fine scales because the distribution and status of these natural resources are spatially heterogeneous (as are the socioeconomic factors that determine autonomous adaptation, a critical step in impacts assessments).[39] But, as noted by the US Climate Change Science Program, “modern AOGCMs generally simulate continental and larger-scale mean surface temperature and precipitation with considerable accuracy, but the models often are not reliable for smaller regions, particularly for precipitation.”[40] Moreover, models often disagree over whether specific areas will experience additional precipitation (Ref. 37, Chapter 11; Ref. 39, p. 151; Ref. 40), which casts doubt on whether they should be used as predictive (as opposed to diagnostic) tools.

Notwithstanding these shortcomings, these climatic changes serve as inputs to the fourth set of models, namely, biophysical models, to project location-specific temporal biophysical changes (e.g., crop or timber yields).

If these biophysical changes have socioeconomic consequences or if they could otherwise elicit autonomous adaptive responses, the outputs of these biophysical models should be fed into a next set of models to calculate the socioeconomic impacts. In theory, these models should include a “feedback” module to account for autonomous adaptations. Feedbacks should be based on future adaptive capacity and other factors affecting adaptation (see below).[31,39]

While the first four steps in the process of impacts estimation lead to an accumulation of uncertainties, this step, for practical purposes, systematically biases the estimates in the direction of overestimating net negative impacts of climate change. This is because the feedback modules used at this step, if any, fail to consider adequately society’s capacity to adapt autonomously to either mitigate or take advantage of climate change impacts.[9,41] This violates the IPCC's methodological guidelines for impact assessments, which require consideration of autonomous or automatic adaptations.[39] These adaptations depend on, among other things, adaptive capacity, which should advance with time due to the assumption of economic growth embedded in each IPCC emission scenario.[9,41,42,43] However, these advances are rarely accounted for fully in impacts assessments.[9,10,41,43] Consequently, the assessments are internally inconsistent because future adaptive capacity does not reflect the future economic development used to derive the emission scenarios that underpin global warming estimates. Adaptive capacity should also increase because of secular technological change, i.e., the accretion of technology (including knowledge) over time. But that too is usually not fully incorporated, if at all, in most impact assessments.[9,41,43] Hence these assessments overestimate negative impacts while simultaneously underestimating positive impacts.[41,43]

Future Net GDP per Capita under the IPCC's SRES Scenarios

How much is GDP per capita projected to increase under the various IPCC scenarios, and what difference might that make to adaptive capacity and projected impacts?

Table 1 lists the characteristics and assumptions used to develop the IPCC's four main scenarios in its Special Report on Emission Scenarios (SRES).[21,25,44] The scenarios are arranged from the warmest to the coolest from left to right. The table indicates that under each IPCC scenario, future GDP per capita, a surrogate for wealth, should be much higher for developing and industrialized countries than it was during the baseline year (1990). However, the Table 1 estimates are for the situation **prior** to any global warming. Therefore, it is conceivable that damages from climate change could reduce future GDP per capita to below baseline or current levels.

Figure 1 provides **lower-bound** estimates of developing and industrialized countries' **net** (average) GDP per capita for 1990, 2100 and 2200 for the four main IPCC SRES scenarios **after** accounting for reductions in GDP due to climate change.[42] This is calculated for each scenario by subtracting from the GDP per capita in the absence of warming (from Table 1), the Stern Review's 95th percentile (upper bound) estimates of losses in GDP due to unmitigated warming.[45] But to quote Tol (2008), the Stern Review's central estimate "lies beyond the 95th percentile—that is, it is an outlier."[46] Moreover, the Stern Review's central estimate, like other studies, overestimates the costs/damages from global warming partly because it too does not fully account for increases in future adaptive capacity.[47]

Figure 1 indicates that **net** average GDP per capita of developing countries in 2100 would range from $10,000 (in 1990 US$) for the A2 (poorest) scenario to $62,000 for the A1FI (richest-but-warmest) scenario. For context, consider that in 2006 GDP per capita for industrialized countries was $19,300; the United States, $30,100; and developing countries, $1,500.[42] That is, net GDP per capita for today's developing and industrialized countries should be much higher in 2100 (and 2200) than it is currently or, for that matter, was during the baseline year (Figure 1). This conclusion should be robust since net GDP per capita was calculated using the upper bound estimate of the losses in GDP from climate change from a study which already had a tendency to overestimate impacts.

Factors Affecting Adaptation

Greater economic development, i.e., **net** GDP per capita, should translate into higher adaptive capacity because an increase in economic resources ought to increase access to both the technologies and the human capital needed to cope with change, whether that change is due to global warming or any other agency.[41,48] In addition, several factors that advance human capital—e.g., educational attainment, improved health, expenditures for health and research[49]—are also correlated with increases with GDP per capita.[41,48] This may partly be due to the fact economic development and human capital reinforce each other and partly because factors that enhance one also enhance the other.[41,48] Moreover, if existing technologies are inadequate for coping with change, wealthier societies have a greater capacity to research, develop, and deploy needed new technologies. A case in point is the world's response to HIV/AIDS. Once a mysterious new disease that spelled almost certain death for its victims, it is now a disease that is manageable, particularly in the wealthier world. The effort to tame this disease was spearheaded by, and accomplished at considerable cost to, the wealthier nations, who then have made the fruits of this exercise available to poorer countries (Ref. 43, p. 21; Ref. 48, pp. 67–68). Arguably, this was enabled by the greater wealth and human capital available to the wealthier countries. This would be consistent with the notion that wealthier societies are more resilient to adversity in general.

Another important factor contributing to adaptive capacity that is often ignored in impact assessments is, as noted, secular technological change (Ref. 33, Chapter 17; Refs 9, 41, 43).

Long-term projections that neglect economic development and secular technological change generally overstate future negative impacts on critical aspects of human well-being, often by an order of magnitude or more.[43,48] For example, the FTA's malaria study assumed static adaptive capacity between baseline and projection years (1990–2085).[19] Applying the same assumption to project U.S. deaths in 1970 from various water-related diseases—dysentery, typhoid, paratyphoid, other gastrointestinal disease, malaria—using data from 1900 implies freezing death rates at 1900 levels. But, in fact, from 1900–1970 they declined by 99.6%–100.0%.[43] Similarly, because of the increase in adaptive capacity globally, global death rates from extreme weather events have declined by 98% since the 1920s.[50] Simplistic projections that do not fully account for economic and technological development are the major reason why highly publicized projections from *The Limits to Growth* and *The Population Bomb*, for instance, failed the reality test.[43,48]

Another factor is the unequal distribution of wealth or access to resources. The more skewed this distribution, the more it could diminish a society's capacity to cope with adverse situations.[51] This is because the greater the inequality in a society the less the access to resources for people at the lower end of the income distribution relative to those at the upper end (Ref. 120) and, therefore, the less their relative ability to cope with adversity. This is obscured when one focuses on average GDP per capita and ignores income distribution.[*] Moreover, as illustrated by the death tolls following Hurricane Katrina and the 2003 European

[*] Pogge's argument[120] that a nation's growth trajectory is better characterized by using gross national income (GNI) per capita rather than GDP per capita has substantial merit, although it may be better still to use real consumption rather than income, particularly if large transfer payments are involved or if a substantial share of income is derived from the informal sector.[121,122] For the purpose of this paper, however, these arguments are academic since the SRES scenarios provide future projections of GDP but not GNI or consumption levels.

heatwave, adaptive capacity is not sufficient.[52] Such capacity has to be deployed and used. Lack of sufficient social capital or political will may preclude full use of available adaptive capacity, which may be exacerbated by miscalculations of risk or poor judgment.[53] Other important factors include the responsiveness of authorities to public concerns, and corruption.[54,55,56] However, future trends in these factors and their effects on adaptation are generally not projected as part of impacts assessments. Accordingly, I will assume that they will stay unchanged, although if the environmental transition hypothesis is valid, political will should increase with the level of economic development (Ref. 43, pp. 4–5; Ref. 48, pp. 105–111). This would be consistent with: (a) studies which suggest that increases in economic insecurity or unemployment are associated with declines in support for environmental policies in general and global warming control policies in particular;[57,58] (b) the lack of enthusiasm for greenhouse gas emission targets and timetables at least among many decision-makers of major emitting developing countries in the BRIC (Brazil, Russia, India and China) group;[59,60] and (c) the diminishing support in today's economically uncertain times for greenhouse gas controls and a decline in concern over climate change in several major industrialized countries (e.g., Japan, Canada, Russia, the U.S., U.K. and other countries in Western Europe).[61,62,63,64,65]

A decline in support for relatively expensive measures at a time of real or perceived decline in economic well-being should, however, not be misconstrued as implying that poorer populations care less about the environment. It might merely reflect the fact that these populations are pragmatic about opportunity costs that might affect their well-being. It also suggests that populations favor relatively high discount rates in that they give greater weights to short term economic prospects than longer term impacts of climate change. Both of these possibilities are entirely consistent with the environmental transition hypothesis.*

The uncertainties and biases associated with projected impacts in general also extend to the FTA studies to one degree or another. Nevertheless, I will use their results in the following analysis because they are global in scope and provide impact estimates for key determinants of well-being. Third, they have been peer-reviewed, and generally reflect the state-of-the-art. Fourth, they have figured prominently in the international debate over global warming. Specifically, their results informed the IPCC's Third and Fourth Assessments and the Stern Review.[31,33,45]

However, despite the likelihood that FTAs overestimate impacts due to their inadequate treatment of adaptive capacity, I will not adjust the FTA results downward. Thus, my results are based on overestimates of the impacts of warming.

CONTRIBUTION OF CLIMATE CHANGE TO MORTALITY FROM VARIOUS HEALTH RISKS

Ranking Global Warming Based on Current Impact on Death and Disease

* Under the environmental transition hypothesis, as populations become wealthier and gain access to greater human capital, "they are better able to afford and employ cleaner technologies" for cleaning up the environment (Ref. 43, p. 5; see, also, Ref 48, pp. 106-109).

The World Health Organization annual report for 2002 (WHO 2002) provided estimates of death and disease attributable to global warming and 25 other health risks based on its Global Burden of Disease study for 2000.[66] Although there are uncertainties associated with these estimates, they are derived using a common and consistent approach, which allows one to broadly rank these health risks based on their contribution to the global burden of either death or disease.[67]

The burden of disease is estimated using lost "Disability-Adjusted Life Years" (DALYs).[68] It is designed to combine both mortality and morbidity into one indicator. The higher the number of lost DALYs the greater the burden of disease. This widely used summary measure of population health is also used by the public health community and other organizations to compare the health burden of different diseases, evaluate cost-effectiveness of interventions, and identify priorities,[69,70] despite reservations on the part of some analysts.[71,72]

The methodology for global warming is described in McMichael et al.,[73] which attributes 154,000–166,000 deaths and 5.5 million DALYs lost to warming in 2000. These estimates have been propagated widely via numerous review articles[74,75,76,77] and the IPCC's latest (fourth) assessment report (Ref. 33, p. 407), despite the fact that McMichael et al. acknowledges that its methodology did not "accord with the canons of empirical science [because] 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" (Ref. 73, p. 1546). That is, the policy agenda trumped rigorous science. Nevertheless, WHO (2002) indicates that global warming would be outranked by at least twenty other health risk factors.[78]

WHO (2009) updates WHO (2002) estimates of death and disease for 2004 for 24 risk factors, including global warming.[79] It attributes 141,000 deaths (0.2% of all deaths) and 5.4 million lost DALYs (0.4% of all disease) in 2004 to global warming, slightly lower than previous estimates. According to WHO (2009), global warming exacerbates death and disease from 37 health outcomes or conditions, e.g., diarrhea, malaria, and undernutrition (see Table 2). These conditions are not new to mankind. They are poverty-related, and are absent or have been virtually eliminated from the industrialized world.[80] Global warming apparently exacerbates existing poverty-related health risks rather than creates new health risks.

Notably, neither stroke nor cardiovascular disease is listed in Table 2. But data from industrialized countries show that more people die in winter than in summer (see Table 3).[81,82,83,84,85,86,87] substantially due to seasonal increases in deaths from these two conditions during the colder months.[88,89] Table 3 shows that excess winter mortality[*] for just two countries—the U.S. (108,500 in 2008) and Japan (50,887, 2006–07 average)—exceeds WHO (2009)'s estimate of annual deaths worldwide from global warming (159,000 vs. 141,000).

Several studies suggest that this phenomenon may also exist in warmer areas of the world and in developing countries, e.g., Kuwait,[90] Tunisia,[87] Hong Kong,[87] and, possibly, São Paolo,[91] Cuba[92] and Hawaii.[93]

Notwithstanding the fact that WHO (2009) ignores any potential reductions in excess winter mortality, Figure 2 uses its results to rank the 24 health risk factors.[80] It shows that global

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[*] Excess winter mortality is based on the difference in the average daily mortality for the four coldest months of the year compared to the rest of the year. Calculations for England and Wales are done using the meteorological year rather than calendar year starting in August of the previous year.[82]

warming ranks second-last based on global mortality (left hand panel) or last based on the global burden of disease, i.e., lost DALYs (right hand panel). The rankings are unchanged if one focuses only on developing countries. Considering only industrialized countries, global warming would be ranked 23rd based on mortality and 21st based on the burden of disease. However, the 24 risk factors account for only 73% and 52% of global mortality and lost DALYs in 2004, respectively. A more complete accounting would have involved additional risks which, if anything, would probably have dropped global warming even lower in the rankings.

Thus, WHO (2009) reaffirms the earlier result, namely, numerous other health risks currently outrank global warming.

Health Risks: Global Warming vs. Poverty[80]

Poverty has a much larger adverse public health impact than global warming.

An analysis of the sensitivity of the disease burden to poverty for the 24 risk factors studied in WHO (2009) indicates that 99.4% of the death and disease attributed to the ten most sensitive risk factors were in developing countries (Ref. 80).[*] These risks are: global warming, underweight (largely synonymous with chronic hunger); zinc deficiency; Vitamin A deficiency; unsafe sex; unsafe water, sanitation and hygiene; unmet contraceptive needs; indoor smoke from solid fuels; sub-optimal breast feeding; and iron deficiency. Cumulatively, WHO (2009)

[*] Sensitivity was determined for each risk factor using the ratio of its disease burden per capita for low-income countries to that of lower-middle-income countries.[80]

attributes 11.4 million deaths and 384 million lost DALYs to these ten poverty-related risks, which are 70–80-times larger than global warming. That is, current health effects of warming range from small to trivial compared with many other poverty-related health risks (see Figure 2). Second, a small increase in poverty would lead to a disproportionately large increase in death and disease in general.

Equally important, the global warming burden is the most sensitive to poverty. According to WHO (2009), only 100 (or 0.08%) of the 141,300 global deaths from warming in 2004 occurred in industrialized countries. Similarly, only 0.06% of the disease burden from warming was in industrialized countries. Thus, a reduction in poverty should drastically reduce warming's health impact.

Moreover, improvements in public health, for which life expectancy is perhaps the best surrogate, are associated with greater economic development.[41,43,48] Global life expectancy had been stuck for millennia at around 25 years but, as shown in Figure 3, it finally began to increase in the late 18th century along with economic development (measured by GDP per capita).[48,94] Concurrently, CO_2 emissions also started rising.[95,96] Global life expectancy currently is 69 years.[97]

That global improvements in public health are associated with increases in CO_2 emissions is hardly surprising: Since the start of the Industrial Revolution economic growth has been largely underwritten by greater energy use in all sectors of human activities, including the agricultural, manufacturing, transportation, service, and residential sectors. Willy-nilly, the increase in energy usage for the past two centuries is practically synonymous with fossil fuels. The long term increase in life expectancy can, in effect, be viewed as a result of sustained reductions in poverty due to economic growth, and associated technological improvements directly or indirectly related to public health.[41,43,48] Hence, if greenhouse gas emission controls reduce economic growth, that would retard poverty reduction.[27,30,98,99] For example, according to one estimate,[80] increased biofuel production since 2004 may have increased deaths by 192,000 and disease by 6.7 million lost DALYs (in 2010) by modestly increasing poverty.[*]

Because the health impact of poverty-related health risks is 70–80 times greater than for warming, it may be several decades before such increases in death and disease from emission controls are offset by any reductions from lower warming, especially considering the inertia of the climate system.

Future Global Warming Health Impacts in Perspective

There are no studies that project future death and disease for a group of health risks that *also* includes global warming. Consequently, Goklany[10,78] drew upon the Fast Track Assessments (FTAs) to estimate warming's contribution to total mortality in 2085 from "key areas of risk",

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[*] It has been argued that the health co-benefits of GHG reductions (e.g., due to reduction in traditional air pollutants such as particulate matter) are substantial and would improve the benefit-cost ratio of GHG emission reductions. While this is true, the problem with this argument is that societies are already capturing these benefits at a fraction of the cost of GHG reductions, and it would make eminent sense if they were captured on their own merits rather than through reductions in GHGs. The argument is akin to insisting that one should be happy to spend $100,000 on an over-priced white elephant, if it is bundled with a TV worth $1,000. So why pay, in effect, $99,000 for the white elephant, unless it can be shown that it is worth at least $99,000? To sustain the argument that it makes sense to buy both TV and white elephant, one has to be able to show that once the costs and benefits of the TV by itself have been subtracted from the costs and benefits of the entire package, the residual benefits would exceed the residual costs.

specifically, hunger, malaria, and extreme weather events (for which coastal flooding was used as a surrogate).[*] However, as already emphasized, there are substantial uncertainties and systematic biases that tend to overestimate impacts associated with the FTA estimates

Contribution of Global Warming to Future Deaths from Key Climate-sensitive Health Risks

Figure 1 suggests that even if one assumes no technological improvements after 1990, adaptive capacity for the average developing country should in 2100 substantially exceed current levels under any IPCC scenario.[41,42] Moreover, regardless of the scenario, there should be few, if any, people living in absolute poverty as currently defined ($1.25 per day in 2005 US dollars, or $456 per year). In fact, *ceteris paribus*, absolute poverty is most likely to be eradicated under the wealthiest scenario (A1FI), which is also the warmest scenario. Under this scenario, net GDP per capita in developing countries ($62,000) in 2100 would be double the U.S.'s in 2006 ($30,000).[42]

Thus, all else being equal, by the latter part of this century, death and disease from global warming should be substantially diminished, if not eliminated, because warming worsens poverty-related health risks instead of creating new ones (see Table 2). The FTA studies,

[*] To put these risks in context, in 2004, hunger (approximated by "underweight" in Figure 2) accounted for 2.2 million deaths and malaria for 890,000 deaths. On average (2000–04), there were 19,000 deaths from all extreme weather events (Ref. 52). Malaria accounted for the bulk of deaths (83%) attributed in 2004 collectively to malaria, tropical diseases, dengue, Japanese encephalitis, trachoma, and intestinal nematode infections (Ref. 119). Hence malaria can be considered to be a proxy for a wide variety of tropical vector-borne diseases.

however, largely miss this reduction because of their inadequate treatment of increases in adaptive capacity.

For example, the FTA's malaria study essentially froze adaptive capacity at base year (1990) level through 2085.[19] However, Tol and Dowlatabadi have estimated that malaria is functionally eliminated if average GDP per capita exceeds $3,100 (also in 1990 US$).[98] Therefore, by 2085, malaria should be virtually eliminated (as should most, if not all, 37 health conditions listed in Table 2).

The FTA's hunger analysis[17] is probably less prone to systematic error. It allows for increases in fertilization and irrigation because of economic development, and modest annual yield increases from the base year. However, it does not consider any new post-early-1990s technologies that could be designed to specifically cope with or take advantage of climate change.[9] But agricultural technologies have already evolved substantially since then. Consider, for example, the penetration of genetically modified crops, and improvements in precision agriculture even in developing countries.[100,101,102] Consider also the spectacular advances in communications, a key determinant of adaptive capacity (particularly with respect to extreme weather events and weather-related human activities, e.g., farming): From 1990–2009, Internet users in Sub-Saharan Africa increased from 0 to 74 million, and cell phone users went from 0% to 37% of the population.[97]

Disregarding the FTAs' tendency to systematically overestimate net adverse impacts, Goklany used their results to estimate the future (2085) contribution of global warming to mortality from malaria, hunger, and extreme weather events (using coastal flooding as a surrogate).[78]

Specifically, he used (a) the FTA's estimates of populations at risk (PARs) in the base year (1990) from hunger,[17] malaria,[18*] and coastal flooding,[23] and (b) the corresponding mortality estimates for the early 1990s from the WHO (for hunger and malaria) and the International Disaster Data Base (EM-DAT) (for extreme weather events) to estimate the coefficients of proportionality between the respective PARs and deaths.[78] These coefficients were then applied to the FTA's corresponding PAR estimates for these health risks with (and without) global warming to estimate mortality for 2085 with (and without) warming under each scenario.[103]

Summing the mortality estimates with and without climate change from these climate-sensitive health risks, Goklany estimated that global warming would contribute no more than 7%–13% to total mortality from malaria, hunger, and extreme weather events in 2085 (see Figure 4).[78]

The above calculation used Parry et al.'s hunger results that included CO_2 fertilization, which indicated that in 2085 climate change would be responsible for 21% of the total PAR for hunger under the A1FI scenario.[17] [This compares to 14% estimated by Fischer et al.[104] and 11%–14% estimated by Tubiello and Fischer[105] in 2080, both under the A2 (poorest-but-most-populous) scenario.] Long and coworkers contend that yield increases due to CO_2 fertilization should be half that estimated by Parry et al. because its estimates were based on growth chambers studies which consistently overestimate yield increases relative to FACE experiments.[106,107,108] They argue that the scale of growth chambers is unrealistically small and they lack the

[*] Because van Lieshout et al.[19] which reported on the more recent FTA study for malaria, neglected to provide estimates of the populations at risk (PAR) of malaria in the absence of global warming, Goklany (Ref. 78) used the results of the previous FTA malaria study.[18] That study provided estimates of PAR in 2085 in (a) the absence of warming and (b) a warming of 3.2 °C. Per Refs. 9 and 10, it was also assumed that the additional population at risk due to global warming varies with the square of the global temperature change in order to develop estimates consistent with the temperature increases estimated under the various IPCC scenarios.

"potentially limiting influence of pests, weeds, nutrients, competition for resources, soil water and air quality, [which] may overestimate field responses on the farm."[107] However, much of farming is devoted to controlling exactly these kinds of negative influences on yields. And such control would be more feasible as societies become wealthier (see Figure 1) and technology advances. Also, it is unclear whether the CO_2 distribution around plants in a FACE set-up realistically represents the distribution in a higher CO_2 world, and whether that would affect results.

Also, Bloom et al. showed that CO_2 enrichment inhibited the assimilation of nitrate into organic nitrogen compounds which may be largely responsible for carbon dioxide acclimation, and decrease in photosynthesis and growth of C3 plants.[109] But this may also be addressed through more intensive fertilizer management. Regardless, if these assessments are correct, then at least a portion of the overestimation of PAR for hunger due to the imperfect treatment of adaptive capacity could be offset.

To summarize, warming is unlikely to be among the most important risks to public health now or in the foreseeable future.

WATER STRESS

The possibility of water shortages leading to droughts and hunger are recurring themes in the climate change literature.[31,33] However, several global impact studies indicate that warming may reduce net global PAR for water stress.

Deaths from droughts are probably the best indicator of the socioeconomic impact of such water shortages. However, since the 1920s despite a more-than-tripling of the global population, deaths and death rates from droughts have declined by 99.97% and 99.99%, respectively.[50]

Yet another concern is access to safer water. But between 1990 and 2008, although global population increased 27%, the percentage of global population with such access increased from 76.8% to 86.8%. This translates into an additional 1.8 billion people gaining access to safer water over this period.[110,111] Simultaneously, 1.3 billion more people got access to improved sanitation.

Even in Sub-Saharan Africa the population with access to improved water sources increased from 48.9% to 59.7% from 1990–2008, which translates into 240 million additional people.

Such improvements attest to the fact that despite any warming, climate-sensitive indicators of human well-being can and have advanced. That is, human adaptive responses have more than offset any possible deterioration from warming.

Regarding the future, Figure 5 provides estimates of the global PAR for water stress in 2085 from the FTA water resources analysis.[21] It displays changes in PAR due to climate change alone and total PAR after climate change. Despite totally ignoring autonomous adaptations which, therefore, overestimates net adverse impacts, the FTA study indicates that warming could, as previously noted, **reduce** net global PAR for water stress.[78] This occurs because warming should increase global precipitation, and although some areas may receive less precipitation, other, more populated areas are, serendipitously, projected to receive more.

Other studies, e.g., Oki and Kanae's review of global freshwater impact studies, also suggest a net decline in water stress due to warming[112]. Similarly, Alcamo et al.[26] found that by 2050, relative to current conditions, water stress would increase in 62%–76% of total global river basin area but decrease in 20%–29% under the A2 and B2 scenarios. However, in only 10% of the area would climate change be the principal cause of the increasing stress. In the other 90%, it would be higher water withdrawals. On the other hand, climate change would be the major factor in most of the area (approximately 50–80%) experiencing decreasing stress.

More recently, van Vuuren et al.[34] found that net PAR for water stress would decline in 2100 under a scenario corresponding to a global temperature increase of 3.5 °C above the 1960-1990 average. This analysis also ignored changes in adaptive capacity which, as noted, overestimates increases in the water-stressed population while underestimating declines. Using a similar methodology, Arnell et al.'s (2011)[113] results also show that the net increase in the water-stressed population from 2000 to 2100 would be dominated by non-climate change factors by at least three to one (relative to warming). They also show that climate change may not increase the net water-stressed population through 2100 (relative to "no climate change"). Similarly, even after mitigation to limit the average global temperature increase to 2°C, the net water-stressed population may be higher relative to the "no climate change" case. Equally importantly, mitigation may actually increase the net water-stressed population over the unmitigated climate change scenario.

Thus warming is not the paramount determinant of the population at risk of water stress through the foreseeable future.   More significantly, climate change may over the foreseeable future solve more water-related problems than it would create.

ECOLOGICAL IMPACTS

Despite concerns about the ecological impacts of warming, the FTA studies suggest that it may actually reduce existing stresses on ecosystems and biodiversity through 2085–2100.

Table 4, provides FTA results for 2085–2100 regarding the variation in three specific ecological indicators across the different IPCC scenarios.[23,25] One indicator is the net biome productivity (a measure of the terrestrial biosphere's net carbon sink capacity). The second indicator is the area of cropland (a crude measure of the amount of habitat converted to human use; the lower it is, the better is it for maintaining biodiversity and ecosystems). Such land conversion to agriculture is perhaps the single largest threat to global terrestrial biodiversity.[114,115] The third indicator is the global loss of coastal wetlands relative to 1990 levels.

The table shows that biosphere's sink capacity under each scenario would be higher in 2100 than in the base year (1990), largely due to higher CO_2 concentrations and because these effects were not projected to be overridden by the negative effects of higher temperatures over that period. For the same reasons, global sink capacity would be higher for the A1FI and A2 scenarios.

Partly for the same reasons and its lower population compared to other scenarios, the amount of cropland in 2100 would be lowest for the A1FI world. This is followed by the B1 and B2 worlds. [Levy et al. did not provide cropland estimates for the A2 scenario.] Thus, through 2100 the warmest (A1FI) scenario would have the least habitat loss and, therefore, pose the smallest risk to terrestrial biodiversity and ecosystems, while the B2 scenario would pose the greatest risk to habitat, biodiversity and ecosystems.

Regarding coastal wetlands, although losses due to sea level rise (SLR) are substantial, the contribution of global warming to total losses in 2085 are smaller than losses due to subsidence from other man-made causes.[23] Table 4 shows that wetland losses are much higher for the A1FI and A2 scenarios than for the B1 and B2 scenarios. This is, however, due mainly to the assumption that the first two scenarios would have higher non-climate change related subsidence (Ref. 23, p. 76) but this assumption is questionable.[9]

SYNTHESIS OF IMPACTS ON KEY DETERMINANTS OF WELL-BEING

The foregoing analysis compared the impacts of global warming through the foreseeable future against the impacts of other factors on key determinants of human and environmental well-being.

Regarding human health, WHO (2009) estimates indicate that global warming is presently outranked by at least 22 other health risk factors (Figure 2). By 2085, despite using impacts estimates that tend to overestimate net negative impacts, warming is projected to contribute less than one-seventh of the total mortality from hunger, malaria and extreme weather events even under the warmest IPCC scenario (Figure 4). Thus, global warming is unlikely to be the most important health risk facing mankind through the foreseeable future notwithstanding claims to the contrary.[75,78]

With respect to water stress, despite massive population growth, the share of global population with access to safe water and improved sanitation currently continues to increase, and deaths from drought have declined by 99.9% since the 1920s. In the future, water-stressed populations may increase, but largely due to non-climate change factors. Moreover, warming, by itself, may reduce net water-stressed population (Figure 5). Aggressive mitigation to limit the global temperature increase to 2 °C may, furthermore, increase net water-stressed population, relative to the "unmitigated climate change" case.[113]

Regarding ecological impacts through 2100, global warming might (a) increase net biome productivity, which translates into greater vegetation and net carbon sink capacity; and (b) decrease the amount of habitat converted to human use, which would reduce pressures on biodiversity and ecosystems (Table 4). However, coastal wetlands are projected to be further reduced, but more because of non-climate change factors than climate change (Table 4).

These results also indicate that if climate were to be rolled back and frozen at its 1990 level—something that is infeasible with current technology without also risking rolling back economic development and increasing poverty to levels corresponding to pre-World War II levels[*]—then

[*] Assuming it takes, say, four decades for global temperatures to reach equilibrium with CO_2 levels, stabilizing climate at 1990 levels implies limiting CO_2 levels at the 1950 level. However, global population has much more

in 2085, mortality from malaria, hunger and extreme weather events would be reduced by no more than 13%, the net water-stressed population might increase globally, and threats to biodiversity and ecosystems might, likewise, increase.

Thus, in aggregate, although climate change may be important, other factors would have a much greater net adverse impact on human and environmental well-being through the foreseeable future.

FUTURE NET GDP PER CAPITA AND HUMAN WELL-BEING IN A WARMING WORLD

The above conclusion is reinforced by estimates of future net GDP per capita. Figure 1 indicates that net GDP per capita in both developing and industrialized countries should be highest under the richest-but-warmest (A1FI) scenario and lowest under the poorest-but-most-populous (A2) scenario at least through 2200.

It has been shown elsewhere, that improvements in a variety of direct or indirect indicators of human well-being are correlated with GDP per capita.[41,43,48] These indicators include life expectancy, infant mortality, food supplies per capita, absence of malnutrition, educational attainment, access to safe water and sanitation, health expenditures, and research and development expenditures. For most of these indicators, the relationship is logarithmic in GDP per capita. Notably, the UN Development Program's (UNDP's) most commonly used Human

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than doubled since then (Figure 3). Thus, stabilizing climate at 1990 levels would require reducing CO_2 emissions per capita—and GDP per capita—to pre-World War II levels, which risks reducing economic development and increasing the share of population in absolute poverty also to pre-World War II levels, barring a clean technology revolution that has, so far, eluded humanity. See Figure 3.

Development Index (HDI)[116]— which was developed as an indicator of human well-being that would supplement, if not supplant, GDP per capita[117]—is also correlated with (a) GDP per capita with a correlation coefficient of 0.74, and (b) logarithm of GDP per capita with a coefficient of 0.94 (based on cross country data for 2009).[118] This is to be expected because not only is the logarithm of per capita GDP (or income) a component of HDI, the other two components are life expectancy and an educational factor,* both of which are themselves correlated with the logarithm of GDP per capita.[41,48]

Accordingly, GDP per capita should itself serve as an approximate indicator for human well-being. And since the Stern Review estimates include losses from market effects, non-market effects from environmental and public health impacts, and the risk of catastrophe, the net GDP per capita shown in Figure 1 should also serve as a useful but imperfect indicator of human well-being that fully considers the effects of unmitigated warming.

In any case, because climate change impacts assessments as a rule do not provide projections of life expectancy and educational factors that could be employed to estimate HDI, future net GDP per capita, despite its imperfections, is perhaps the best one can do for an indicator of future human well-being that also accounts for the impacts of warming.

Figure 1, therefore, indicates that if humanity has a choice, it ought to strive for the developmental path corresponding to the richest scenario notwithstanding any associated global warming.

* The HDI has evolved over time. Until 2010 the wealth factor was based on GDP per capita, when it was replaced by gross national income per capita. The education factor was also modified in 2010. This factor is currently derived from a combination of adult literacy and gross enrollment in schools.[115]

This should, moreover, have additional knock-on benefits. First, adaptive capacity should be highest under the wealthiest scenario, *ceteris paribus*.[41] Thus, society's ability to cope with (or take advantage of) any global warming ought to be highest under this scenario. [Note that the upper bound estimates of damages from unmitigated climate change are already factored into the derivation of net GDP per capita.] Second, the health impact of global warming should be least under the richest scenario because this impact is related to poverty, and poverty is most likely to be eliminated—and eliminated sooner—under this scenario. Third, many health risks that currently rank higher than global warming are also poverty-related (Figure 2). More importantly, the cumulative contribution of various poverty-related diseases to global death and disease is 70–80 times greater than warming. But these diseases are also most likely to be eradicated under the wealthiest-but-warmest scenario. Fourth, mitigative capacity should also be highest under the wealthiest scenario.[41]

Finally, the wealthiest scenario should also have the highest adaptive and mitigative capacities to address not just climate change but any other problem. As shown elsewhere,[41,43,48] the determinants of human well-being improve with economic and technological development. The relationship is somewhat more complex for environmental determinants: initially these determinants deteriorate, but then go through an "environmental transition" after which they begin to improve, with development.[43,48] This is why the wealthiest countries generally have a cleaner environment, greater reversion of agricultural lands to nature and, *de facto*, more stringent environmental protections than developing countries (consistent with the notion that wealthier countries have greater political will). Given the projections of net GDP per capita

(Figure 1), all countries are more likely to be on the right side of the environmental transition by 2100, particularly under the warmest scenario.

A corollary to this is that if greenhouse gas policies effectively increase poverty, e.g., by slowing economic growth or increasing the prices of basic needs (such as food to adequately fulfill the body's energy requirements or fuel to maintain safe ambient conditions) then the resulting mortality increases might, given the climate system's inertia, exceed any reductions in these health effects due to GHG reductions for decades.

A case in point is biofuels. Much of the increase in biofuel production is the result of policies designed to displace fossil fuel consumption, partly due to the perceived need to limit GHG emissions. This has had the unintended consequence of increasing food prices and, indirectly, hunger and poverty in developing countries. The increase in poverty due to increased biofuel production since 2004 in response to such policies is estimated to have increased deaths in 2010 by 192,000 and disease by 6.7 million lost DALYs[78] which exceeds the 141,000 deaths and 5.4 million lost DALYs attributed to warming.[79]

To summarize, climate change is not the world's most important problem. Other problems have a larger negative impact on human and environmental well-being. Reduced economic development, in particular, would be a bigger problem, especially for developing countries. And if climate change policies compromise such development, they too can become problems despite the best of intentions. On the other hand, greater economic and technological development would help society deal not only with climate change, but other, higher priority problems simultaneously.

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Table 1: Characteristics and Assumptions of Various Scenarios. Sources: Ref. 9, based on Refs. 21, 25, and 44.

	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

Notes: (1) GDP and GDP/capita are in 1990 U.S. dollars. (2) Global temperature change is based on the HadCM3 climate model.

Potential Outcomes	Mortality	Lost DALYs (000s)
Diarrheal diseases	64.9	2,174.9
Malaria	27.0	1,041.0
Lower respiratory infections	16.7	592.1
Measles	6.2	217.1
Pertussis	5.6	211.5
Protein-energy malnutrition	5.0	476.4
Other unintentional injuries	3.0	166.9
Other infectious diseases	2.4	89.6
Tetanus	2.3	76.6
Birth asphyxia and birth trauma	2.1	92.5
Neonatal infections and other	2.0	70.4
Meningitis	1.9	82.9
Syphilis	0.9	32.1
Tuberculosis	0.4	13.9
Upper respiratory infections	0.2	7.8
Prematurity and low birth weight	0.2	5.9
Diphtheria	0.1	7.4
Leishmaniasis	0.1	3.5
Dengue	0.1	2.6
Japanese encephalitis	0.1	2.4
Chlamydia	0.0	1.5
Gonorrhoea	0.0	0.6
Other STDs	0.0	3.4
Poliomyelitis	0.0	0.5
Hepatitis B	0.0	3.5
Hepatitis C	0.0	0.3
Trypanosomiasis	0.0	0.3
Chagas disease	0.0	0.1
Schistosomiasis	0.0	0.2
lymphatic filariasis	0.0	18.1
Onchocerciasis	0.0	0.0
Leprosy	0.0	0.7
Trachoma	0.0	0.0
Ascariasis	0.0	5.5
Trichuriasis	0.0	0.0
Hookworm disease	0.0	0.0
Other intestinal infections	0.0	0.1
Otitis media	0.0	1.7
TOTAL	141.3	5,403.9

Table 2: Deaths and lost DALYs attributed to global warming by disease or injury outcomes for the year 2004. Source: Ref. 79.

Table 3: Excess Winter Mortality in Various Industrialized Countries. Sources: Refs. 81–87.

	Excess Winter Mortality (deaths per year)	Basis	Years for data	Source
US	**108,500**	2008	2008	US NCHS (2009,2010)[85,86]
Canada	**10,266**	2007	2007	Statistics Canada (2011)[87]
England & Wales	**25,400**	winter of 2009-2010	2009-2010	UKONS (2011)[82]
Australia	**6,779**	2008	2008	Australian Bureau of Statistics (2009)[83]
New Zealand	**1,532**	2008	2008	Statistics New Zealand (2010)[84]
Japan	**50,887**	avg	2006-07	Falagas et al. (2009) [81]
France	**24,938**	avg	1995-2006 exc 2004	Falagas et al. (2009) [81]
Italy	**37,498**	avg	1950-2007	Falagas et al. (2009) [81]
Spain	**23,645**	avg	1960-70, 1975-2007	Falagas et al. (2009) [81]
Sweden	**4,034**	avg	1987-2007	Falagas et al. (2009) [81]
Greece	**5,820**	avg	1960-2005	Falagas et al. (2009) [81]
Cyprus	**317**	avg	1996, 1998-2000, 2002-2006	Falagas et al. (2009)[81]
NOTE: Winter months = Jan, Feb, Mar, Dec in Northern Hemisphere; Jun, Jul, Aug, Sep in Southern Hemisphere				

Table 4: Ecological indicators under different scenarios, 2085-2100. Sources: Ref. 9, based on Refs. 23, 25, and 44.

		Baseline 1990	**A1FI (warmest)**	**A2**	**B2**	**B1 (coolest)**
Global temperature increase (ΔT) (in 2085)[a]	^{o} C	*0*	4.0	3.3	2.4	2.1
Global population (in 2085)[a]	billions	*5.3*	7.9	14.2	10.2	7.9
GDP/capita, global average (in 2085)[a]	$/capita	*3.8*	52.6	13.0	20.0	36.6
CO_2 concentration (in 2100)[b]	ppm	*353*	970	856	621	549
Net Biome Productivity with climate change (in 2100)[b]	Pg C/yr	*0.7*	5.8	5.9	3.1	2.4
Loss of habitat to cropland with climate change (in 2100)[b]	% of global land area	*11.6%*	5.0%	NA	13.7%	7.8%
Global losses of coastal wetlands (in 2085)[c]						
Losses due only to sea level rise	% of current area	*NA*	5 - 20%	3 - 14%	3 - 15%	4 - 16%
Losses due to other causes	% of current area	*NA*	32 - 62%	32 - 62%	11 - 32%	11 - 32%
Combined losses	% of current area	*NA*	35 - 70%	35 - 68%	14 - 42%	14 - 42%

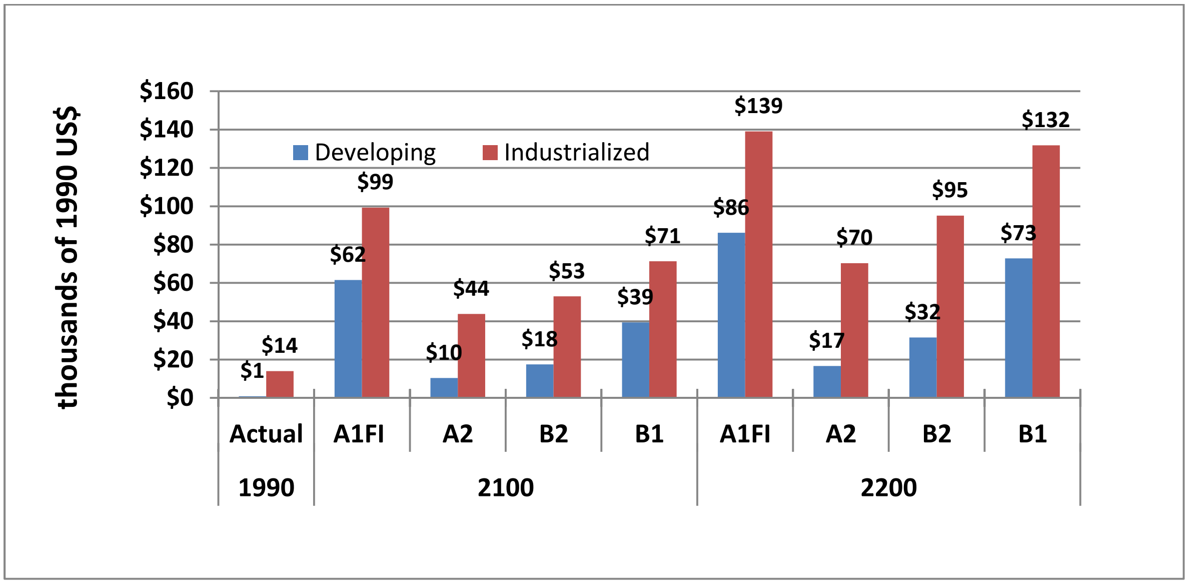
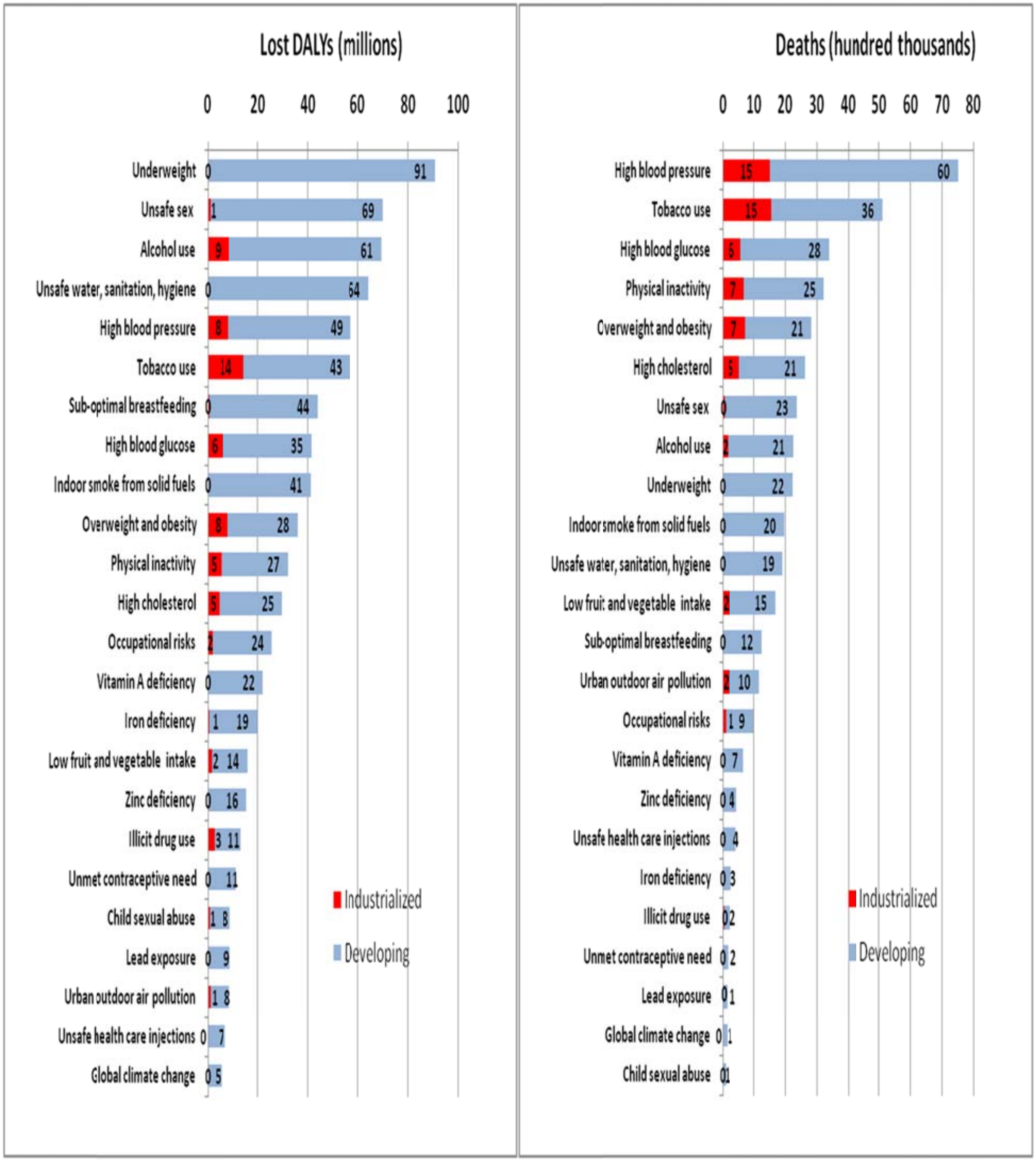


Figure 1: : Net GDP per capita, 1990-2200, after accounting for the upper bound estimates of losses due to global warming for four major IPCC emission and climate scenarios. For 2100 and 2200, the scenarios are arranged from the warmest (A1FI) on the left to the coolest (B1) on the right. The average global temperature increase from 1990 to 2085 for the scenarios are as follows: 4°C for AIFI, 3.3°C for A2, 2.4°C for B2, and 2.1°C for B1. For context, in 2006, GDP per capita for industrialized countries was $19,300; the United States, $30,100; and developing countries, $1,500. Source: Ref. 42.



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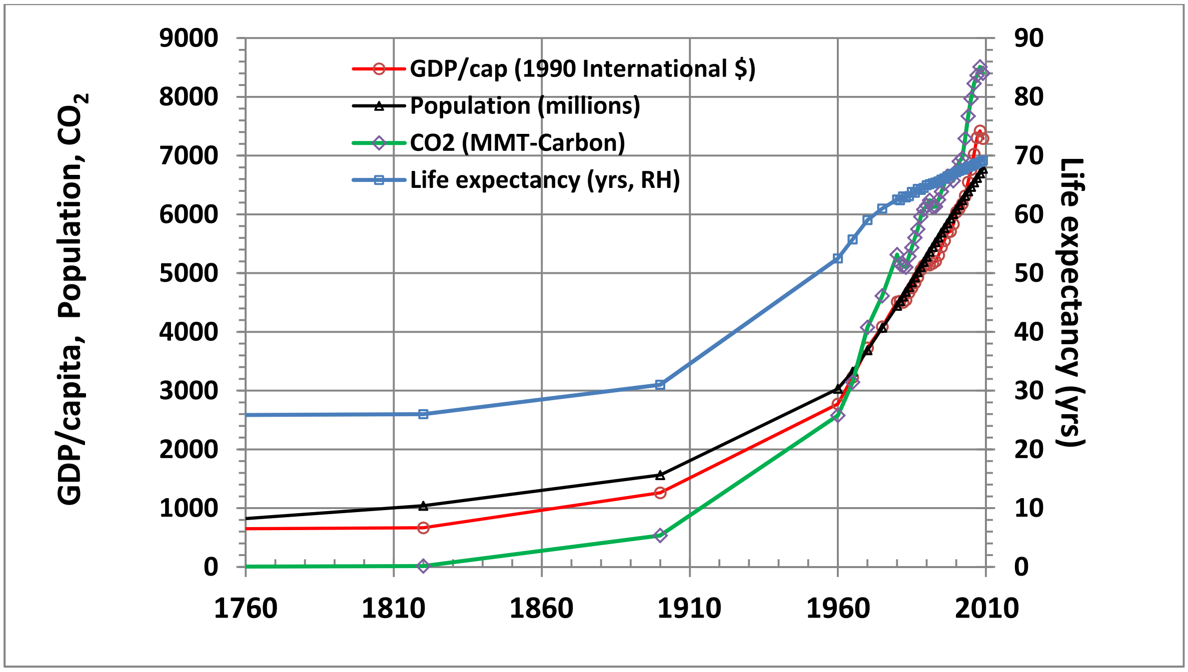

Figure 3: Global Carbon Dioxide Emissions from Fossil Fuels, GDP per Capita, and Life Expectancy, 1760–2009. Sources: Refs. 94–97.

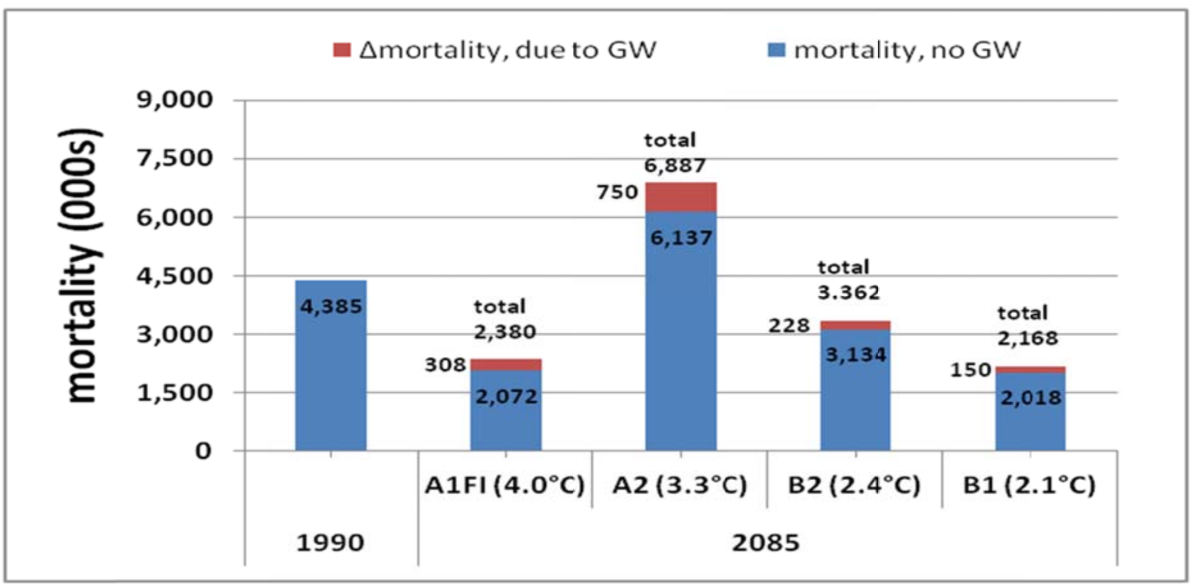

Figure 4. Deaths in 2085 Due to Hunger, Malaria and Extreme Events, with and without Global Warming. Only *upper bound* estimates are shown for mortality due to global warming. Average global temperature increase from 1990-2085 for each scenario is shown below the relevant bar. Source: Ref. 78.

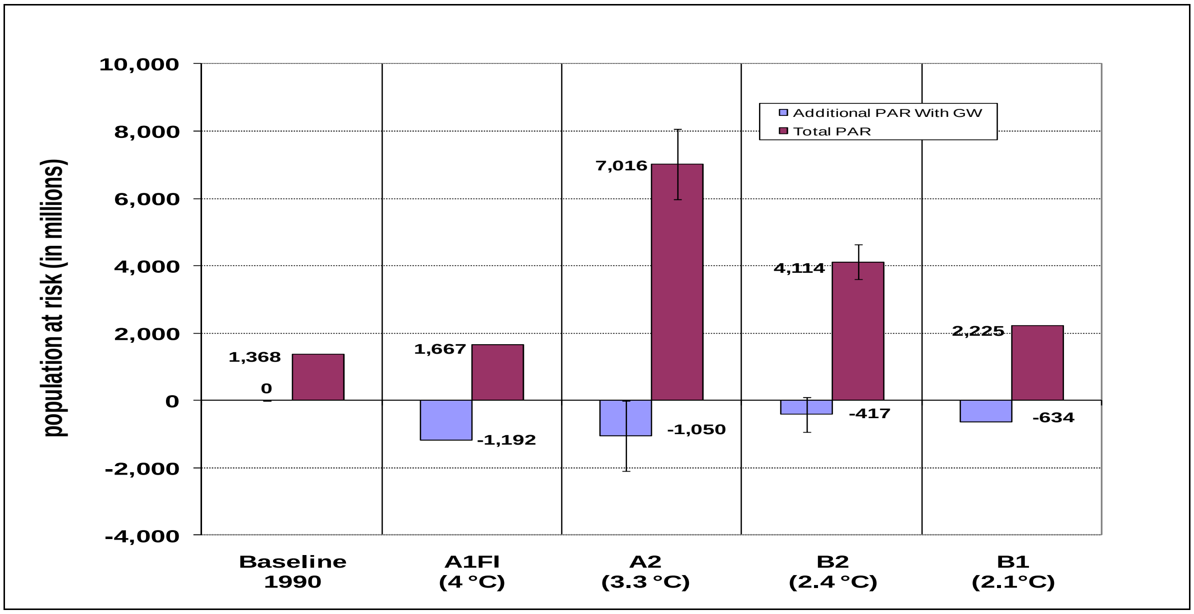

Figure 5. Population at Risk (PAR) from Water Stress in 2085, With and Without Global Warming. [20, 37] The vertical bars indicate the PARs based on the mid-point estimates of several model runs, while the vertical lines indicate the range of estimates. Source: Ref. 78.

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