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Improving Information for Policy Makers

Distributional Aspects of Climate Change Impacts

by

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FOREWORD

This paper was prepared for an OECD Workshop on the *Benefits of Climate Policy: Improving Information for Policy Makers*, held 12-13 December 2002. The aim of the Workshop and the underlying Project is to outline a conceptual framework to estimate the benefits of climate change policies, and to help organise information on this topic for policy makers. The Workshop covered both adaptation and mitigation policies, and related to different spatial and temporal scales for decision-making. However, particular emphasis was placed on understanding global benefits at different levels of mitigation -- in other words, on the incremental benefit of going from one level of climate change to another. Participants were also asked to identify gaps in existing information and to recommend areas for improvement, including topics requiring further policy-related research and testing. The Workshop brought representatives from governments together with researchers from a range of disciplines to address these issues. Further background on the workshop, its agenda and participants, can be found on the internet at: www.oecd.org/env/cc

The overall Project is overseen by the OECD Working Party on Global and Structural Policy (Environment Policy Committee). The Secretariat would like to thank the governments of Canada, Germany and the United States for providing extra-budgetary financial support for the work.

This paper is issued as an authored "working paper" -- one of a series emerging from the Project. The ideas expressed in the paper are those of the author alone and do not necessarily represent the views of the OECD or its Member Countries.

As a working paper, this document has received only limited peer review. Some authors will be further refining their papers, either to eventually appear in the peer-reviewed academic literature, or to become part of a forthcoming OECD publication on this Project. The objective of placing these papers on the internet at this stage is to widely disseminate the ideas contained in them, with a view toward facilitating the review process.

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1. INTRODUCTION

Climate change has always been seen as a problem of equity. By the 1980s, when climate change was beginning to be recognised as a policy problem and large-scale research was starting, it was clear where the problem originates (the carbon dioxide emissions of the rich) and where the effects would be felt hardest (the poor countries in the tropics). Ten or fifteen years of intensive research have not altered this basic notion, but have deepened the insight into causes and mechanisms. This paper gives a brief review about the state of knowledge on the distributional aspects of climate change impacts.

The paper is largely limited to the distribution of impacts between countries (in Section 2). Although there are virtually no estimates reported in the literature, the distribution of impacts within countries is also important, – but seethe US National Assessment (ref) for regional estimates. Impact estimates for different "sectors" (agriculture, health, sea level rise) provides little guidance for estimating differential impacts within countries. It is even harder to find estimates based on social classes.

The paper restricts itself to equity about the consequences of climate change. Equity issues about the consequences of emission reduction are ignored here, but should of course be part of a policy analysis. Equity issues about procedures for decision making are also ignored.

The paper is organised as follows. Section 2 reviews recent estimates of the regional impacts of climate change. Section 3 discusses alternative ways of aggregating regional impact estimates. Section 4 focusses on the vulnerability of the poor to climate change impacts, both with respect to exposure as well as to their limited capacity for adaptation. Section 5 discusses the impacts of economic development and other dynamic changes on vulnerability. The paper abstains from a discussion of aggregating climate change impacts over time, partly because the literature on that is too substantial to be reviewed here, and partly because, under virtually all scenarios,[1] the current generation is the poorest and therefore particularly worthy in equity considerations. In Section 6 we present salient conclusions.

[1] Almost all long-term scenarios for climate change analyses assume continuous economic growth and convergence of per capita incomes across the world. This is explained partly by a misplaced belief in outdated economic theory, and partly by the political constraints on scenario development. The last 50 years have seen both convergence and divergence of per capita income, the former within the OECD and between the OECD and east and southeast Asia, the latter between Africa and the rest of the world.

2. INTERNATIONAL ESTIMATES OF CLIMATE CHANGE IMPACTS

A number of studies have estimated the total damage cost or impact of climate change (disaggregated across sectors) in different regions of the world. Table 1 shows aggregate, monetised impact estimates[2] for a doubling of atmospheric carbon dioxide on the current economy and population from the three main studies undertaken since the IPCC Second Assessment Report (Pearce *et al.*, 1996), and summarises the ‘first generation’ of studies already reviewed in the Second Assessment Report for comparison (see also Fankhauser and Tol, 1996, 1997). The numerical results remain speculative, but they can provide insights on signs, orders of magnitude, and patterns of vulnerability. Results are difficult to compare because different studies assume different climate scenarios, make different assumptions about adaptation, use different regional disaggregation[3] and include different impacts. The Nordhaus and Boyer (1999) estimates, for example, are more negative than others, partly because they factor in the possibility of catastrophic impact. The Mendelsohn *et al.* (1998) and Tol (2002a) estimates, on the other hand, are driven by optimistic assumptions about adaptive capacity and, in Tol’s case, baseline development trends, which results in mostly beneficial impacts. In their review, Tol *et al.* (1998) conclude that 7-24% of the damage estimates are adaptation costs, the rest being true damages. Smith *et al.* (2001) provide a recent overview of the climate change impacts literature; see also Tol *et al.* (2000, 2001) and Yohe and Schlesinger (2002).

Table 1. Estimates of the regional impacts of climate change

	‚First Generation’	Mendelsohn et al.		Nordhaus / Boyer	Tol[b]
	2.5°C	1.5°C	2.5°C	2.5°C	1.0°C
North America	-1.5				3.4(1.2)
USA	-1.0 to -1.5		0.3	-0.5	
OECD Europe	-1.3				3.7 (2.2)
EU	-1.4			-2.8	
OECD Pacific	-1.4 to -2.8				1.0 (1.1)
Japan			-0.1	-0.5	
Eastern Europe & fUSSR	0.3				2.0 (3.8)
Eastern Europe				-0.7	
FUSSR	-0.7				
Russia			11.1	0.7	

[2] Other studies use alternative numerators for aggregating impacts. For example, the work reported by Parry *et al.* (1999, 2001) add up the number of people affected.

[3] The regional aggregation is based on either geographic or economic criteria. The UNFCCC groups nations in a different manner.

Middle East	-4.1			-2.0[c]	1.1 (2.2)
Latin America	-4.3				-0.1 (0.6)
Brazil			-1.4		
South & Southeast Asia	-8.6				-1.7 (1.1)
India			-2.0	-4.9	
China	-4.7 to -5.2		1.8	-0.2	2.1 (5.0)[d]
Africa	-8.7			-3.9	-4.1 (2.2)
DCs		0.12	0.03		
LDCs		0.05	-0.17		
World					
output weighed[e]	-1.5 to -2.0		0.1	-1.5	2.3 (1.0)
Population weighed[f]				-1.9	
at world average prices[g]					-2.7 (0.8)
equity weighted[h]					0.2 (1.3)

[a] Figures are expressed as impacts on a society with today's economic structure, population, laws etc. Mendelsohn *et al.*'s estimates denote impact on a future economy. Estimates are expressed as per cent of Gross Domestic Product. Positive numbers denote benefits, negative numbers denote costs.

[b] Figures in brackets denote standard deviations. They denote a lower bound to the real uncertainty

[c] high-income OPEC

[d] China, Laos, North Korea, Vietnam

[e] Regional monetary impact estimates are aggregated to world impacts without weighing.

[f] Regional monetary impact estimates are aggregated to world impacts using weights that reflect differences in population sizes.

[g] Regional impacts are evaluated at world average values and then aggregated, without weighing, to world impacts.

[h] Regional monetary impact estimates are aggregated to world impacts using "equity weights" that equal the ratio of global average per capita income to region average per capita income.

Source: Pearce et al. (1996); Mendelsohn *et al.* (1998); Nordhaus and Boyer (2000); Tol (2002a)

Standard deviations are rarely reported, but likely amount to several times the 'best guess'. They are larger for developing countries, where results are generally derived through extrapolation rather than direct estimation. This is illustrated by the standard deviations estimated by Tol (2002a), reproduced in Table 1. The Tol estimates probably still underestimate the true uncertainty, for example because they exclude omitted impacts and severe climate change scenarios (cf. Nordhaus, 1994; Tol, 1995, 1999b,d, 2003). Downing *et al*. (1996a,b) provide a much higher range of uncertainty, from nearly zero impact to almost 40% of world GDP, reflecting a much wider range of assumptions than are commonly included.

Overall, the current generation of aggregate estimates may understate the true cost of climate change because they tend to ignore extreme weather events; underestimate or ignore the compounding effect of multiple stresses (see Schneider 2003); and ignore the costs of transition and learning in adaptation. However, studies may also have overlooked positive impacts of climate change and not adequately accounted for how development could reduce impacts of climate change. Our current understanding of (future) adaptive capacity, particularly in developing countries, is too limited, and the inclusion of adaptation in current studies too varied to allow a firm conclusion about the direction, let alone the size of the effect on estimates of climate damages.

The uncertainties in the impact estimates shown in Table 1 are exacerbated by the shortcomings of the studies upon which they are based suffer from many shortcomings. We list the most important.

A major difficulty in impact assessment is our still incomplete understanding of climate change itself, in particular the regional details of climate change (Mahlman, 1997 Wigley, 2003). Impacts are local, and impacts are related to weather variability and extremes. Current climate change scenarios and current climate change impact studies use crude spatial and temporal resolutions, too crude to capture a number of essential details that determine the impacts. GCM-based scenarios are tailored to long-term climate forcing and may underrepresent potential climate change in the next several decades, which would result in relatively small estimates of damages in the near future. Near term damages are likely to be of greater concern for policy makers (and would be discounted less than longer term damges) and less amenable to adaptation.

Knowledge gaps continue at the level of impact analysis. Despite a growing number of country-level case studies (e.g., U.S. Country Studies Program, 1999), our knowledge of local impacts is still too uneven and incomplete for a careful, detailed comparison across regions, while methodological problems remain even with the best-assessed localities (Hahnemann, this volume). Furthermore, differences in assumptions often make it difficult to compare case studies across countries. Only a few studies try to provide a coherent global picture, based on a uniform set of assumptions. The basis of many such global impact assessments tend to be case studies with a more limited scope, often undertaken in the United States, which are then extrapolated to other regions. For instance, Fankhauser's (1995) global assessment of impacts on water resources is based on a single case study in northern California; earlier studies, such as Cline (1992) and Nordhaus (1991) are cruder still, and some later studies, such as Mendelsohn *et al.* (1998) are not much better. Such extrapolation is difficult – already between northern and southern California – and will be successful only if regional circumstances are carefully taken into account, including differences in geography, level of development, value systems and adaptive capacity. Not all analyses are equally careful in undertaking this task. While our understanding of the vulnerability of developed countries is improving – at least with respect to market impacts – good information about developing countries remains scarce.

Non-market damages, indirect effects (e.g., the effect of changed agricultural output on the food processing industry), horizontal interlinkages (e.g., the interplay between water supply and agriculture; or how the loss of ecosystem functions will affect GDP), and the socio-political implications of change are also still poorly understood. Uncertainty, transient effects (the impact of a changing rather than a changed and static climate), and the influence of change in climate variability are other factors deserving more attention in impact assessment.

Another key problem is adaptation (see Callaway 2003, Nicholls 2003, and Yohe 2003). Adaptation generally lowers negative impacts and increase positive ones. In some cases, adaptation may turn losses into gains. Rarely, adaptation would increase damages; this may happen, for instance, if competitors are better at adapting (cf. Tol *et al.* 1998). Adaptation will entail complex behavioural, technological and institutional adjustments at all levels of society, and not all population groups will be equally adept at adapting (Downing *et al.*, 1997). Adaptation is treated differently in different studies, but all approaches either underestimate or overestimate its effectiveness and costs. Impact studies are largely confined to autonomous adaptation, that is, adaptations that occur without explicit policy intervention from the government. Such studies ignore planned adaptation. But in many cases governments too will embark on adaptation policies to avoid certain impacts of climate change, and may start those policies well before critical climatic change occurs (cf. Fankhauser *et al.*, 1999) – for example, by linking climate change adaptation to other development and global change actions, such as on drought and desertification or biodiversity. Certainly, maladaptation will occur and could be expensive, exceeding potential damage costs.

The analysis is further complicated by the strong link between adaptation and other socio-economic trends. The world will substantially change in the future, and this will affect vulnerability to climate change. For example, the success of the WHO's target of eliminating malaria would reduce climate change impacts to zero. A less successful effort could introduce antibiotic-resistant parasites or pesticide-resistant mosquitoes, increasing vulnerability to climate change. The growing pressure on natural resources from unsustainable economic development is likely to exacerbate the impacts of climate change. However, if this pressure leads to improved management (e.g., water markets and demand management), vulnerability might decrease. Even without explicit adaptation, impact assessments therefore vary depending on the 'type' of socio-economic development expected in the future. The sensitivity of estimates to such baseline trends can in some cases be strong enough to reverse the sign, i.e., a potentially negative impact can become an opportunity for benefits under a suitable development path (Mendelsohn and Neumann, 1999).

3. AGGREGATION AND THE DISTRIBUTION OF REGIONAL IMPACTS

The need for synthesis and aggregation poses challenges with respect to the spatial and temporal comparison of impacts. Aggregating impacts requires an understanding of (or assumptions about) the relative importance of impacts in different sectors, in different regions and at different times. Developing this understanding implicitly involves value judgments. The task is simplified if impacts can be expressed in a common metric, but even then aggregation is not possible without value judgments. Aggregation across time, and the issue of discounting, is discussed by Arrow *et al.* (1996), Portney and Weyant (1999), Schneider (2003), Tol (1999e) and Yohe (2003). Discounting is particularly important for estimating the marginal costs of greenhouse gas emissions, an issue not discussed in this paper.

The value judgments underlying regional aggregation are discussed and made explicit in Azar (1999), Azar and Sterner (1996), Fankhauser *et al.* (1997, 1998) and Tol *et al.* (1996, 1999). We underline the importance of aggregation by using four alternative ways of computing world total impacts from regional impact estimates in Table 1. Monetary impact estimates of climate change do not estimate the impact of climate change on the economy – rather, they express climate change impacts as an equivalent income loss. The estimates in Table 1 are therefore welfare losses or rather approximate welfare losses. In order to aggregate welfare losses over countries, one first needs to transform the income equivalents back into welfare, then aggregate welfare, and finally transform the aggregated welfare back to income equivalents. In Table 1, this is done in the row “equity weighted”. The equity weights used are the ratio of world average per capita income to regional average per capita income. Fankhauser *et al.* (1997, 1998) show that these weights follow from assuming that individual utility is proportional to the natural logarithm of per capita consumption (a standard assumption), and that social welfare is the sum of individual utility (a standard but disputed assumption). In fact, as Fankhauser *et al.* also show, adding monetary impact estimates without equity weighting implicitly assumes the utility and welfare functions are linear; linear utility functions clearly violate all that is known about utility.

Table 2 shows aggregate damages for different utility and welfare functions. In general, a more curved utility function leads to higher aggregate impacts. (This is not necessarily the case though. For example, the middle income countries of the former Soviet Union may be less vulnerable than the richer countries of the OECD, as in Fankhauser’s estimates.) Welfare functions that put more emphasis on the plight of the poor also lead to higher aggregate damages, as illustrated by a comparison between the utilitarian welfare function (which adds utilities) and the Bernouilli-Nash welfare function (which multiplies utilities). This is not true in the extreme maximim, or Rawlsian welfare function, because in that case only the damage to the poorest region counts.

There is little empirical or ethical guidance with regard to the choice of utility and welfare functions. Although it is not up to the analyst to make such choices, it is clear that simply adding dollar values is plainly wrong. A conservative choice would be to use a utilitarian welfare function and a measure of risk aversion of unity.

Table 2. Global 2xCO2 Damages, Corrected for Inequality (annual damages, bn$)[a]

	Fankhauser	Tol
Uncorrected damages	322	364
Utilitarian Welfare Function		
risk aversion = 0.0	322	364
risk aversion = 0.5	316	411
risk aversion = 1.0	405	614
risk aversion = 1.5	622	1058
Bernoulli-Nash Welfare Function	405	614
Maximin Welfare Function		
risk aversion = 0.5	96	89
risk aversion = 1.0	181	172
risk aversion = 1.5	343	332

[a] A utilitarian welfare function is the sum of individual utility, that is, all count equally. A Bernoulli-Nash welfare function is the product of individual utility, that is, the poor count more than the rich, with relative weights proportional to relative incomes. A maximin welfare function is the minimum of individual utility, that is, only the poorest count. Risk aversion determines the curvature of the utility as a function of consumption.

Aggregation necessarily hides differences. For instance, Western Europe is commonly aggregated into one region, even though there are probably large differences between Scandinavia and Mediterranean Europe. For example, Downing *et al.* (1999) find that Southern Europe may well get drier whereas Northern Europe would get wetter under a doubling of atmospheric carbon dioxide. Agriculture may thus expand in the north, but would get into trouble in the already drought-prone south. In the aggregate, these differences roughly cancel. Unfortunately, most global economic impact studies do not have sufficient regional detail to further disaggregate Table 1.

One attempt to go beyond aggregated analyses is to look for common situations of vulnerability (Downing, 2003). A simple clustering groups countries by their exposure to climate change impacts and adaptive capacity (as measured by the Human Development Index):

- Vulnerable countries are those that expect high climate change impacts and have low adaptive capacity—Bangladesh is an extreme example, particularly exposed to sea level rise, cyclones and droughts, and a Least Developed County.

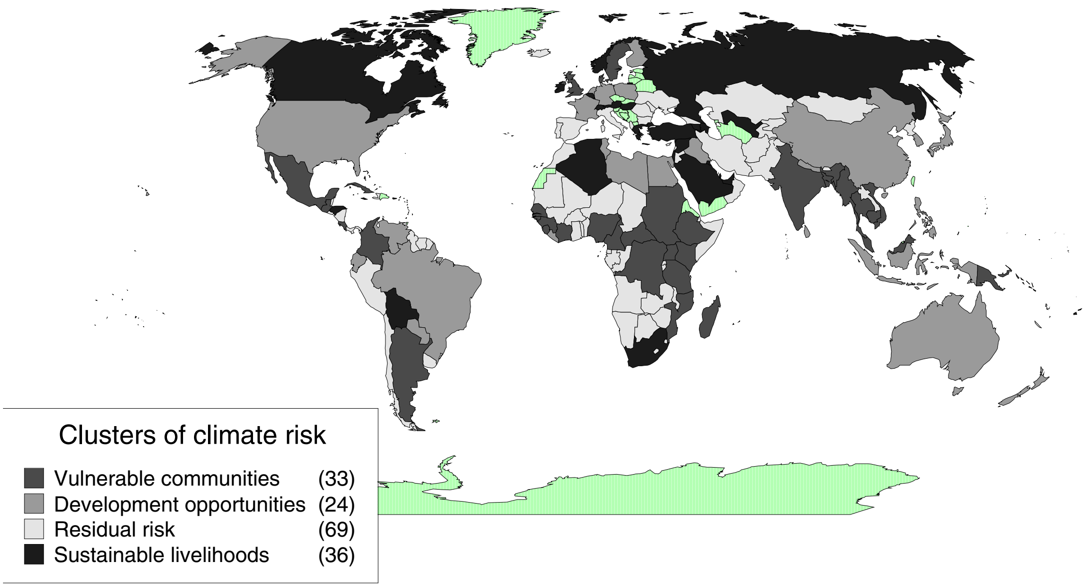
- Countries with residual risks might anticipate relatively low climate change impacts but also have a low adaptive capacity, so the risks could end up being significant. While uncertainty in projections of climate change impacts reduces our confidence in this cluster, Namibia might be a characteristic example, with relatively low exposure to sea level rise and storms.

- Opportunities for coping with impacts (perhaps in coastal zones and water resources) through development exist in countries where adaptive capacity is high, even though the impacts could be significant as well; The US is a good example.

- Countries with a high adaptive capacity and low expected impacts should be able to adapt effectively to climate change while sustaining economic growth and livelihoods; Canada and Norway might be typical examples.

Figure 1 classifies countries according to their potential impacts and their adaptive capacity. The qualitative result is suggestive of a much richer picture than Table 1 provides.

Figure 1. Clusters of climate risk



Countries are classified as either high or low in impacts, and either high or low in adaptive capacity. Countries in the top 40% of impacts on agriculture, water resource, sea level rise and biodiversity have high impacts; impacts were taken from Downing *et al.* (1996). Countries in the bottom 60% of the Human Development Index have low adaptive capacity. Vulnerable communities: high impacts, low adaptive capacity; Development opportunities: high impacts, high adaptive capacity; Residual risk: low impacts, low adaptive capacity; Sustainable livelihoods: low impacts, high adaptive capacity.

Of course, some insight into differences in impacts between regions can be gleaned from analysis of a single indicator. The Gini coefficient, a popular economic indicator, measures the area under the cumulative income curve, ranking people according to their income, relative to the cumulative income curve if everyone were to earn the same. The Gini coefficient is one if everybody has the same income; it is zero if all income is in the hands of a single person.[4] The Gini coefficient can be related to impacts, but only if we allow for both positive as well as negative values. In that case, the Gini coefficient lies between minus infinity and one, where lower numbers mean more inequality.

In Figure 2, we show the cumulative damages in 2025, measured in utils, a relative measure related to income[5]. World population is ranked in terms of falling vulnerability (on the x-axis). In 2025, as in most years, there are losers (the increasing part of the curve) as well as winners (the decreasing part) of climate change. The area under the cumulative impacts curve (C-A) is small, as losses cancel out gains--it is

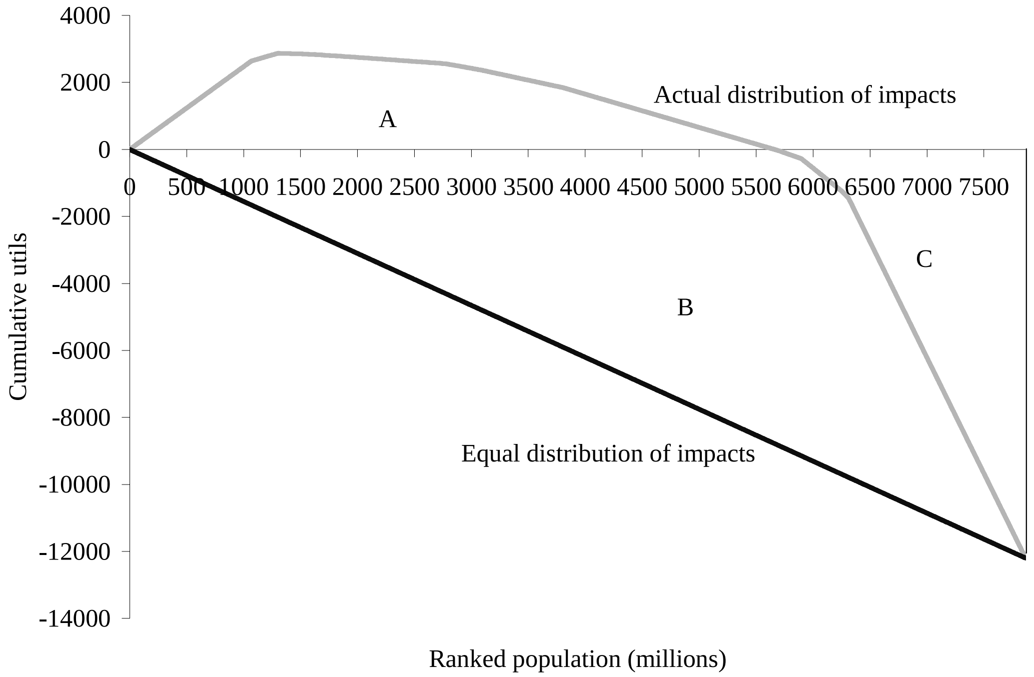
[4] Note that we in fact use one minus the Gini coefficient.

[5] Assuming a logarithmic utility function, this coincides with impacts expressed as a fraction of income.

slightly negative in this particular case. In contrast, the area under the equal distribution curve (B+C) is large and negative, as gains dominate losses. The Gini coefficient (C-A/B+C) is the ratio of a small and a large negative number, which is a positive number close to zero (0.02 to be exact). This corresponds to our intuition: a Gini coefficient close to zero implies a strongly skewed distribution of impacts.

One can easily imagine that the area under the cumulative impact curve of Figure 2 (C-A) is not negative but positive. Indeed, this is the case in 2030. There are still overall losses, but the losses are larger relative to the gains than in 2025. Then, the Gini coefficient is slightly negative, which again corresponds to our intuition: The distribution has worsened, so the Gini coefficient should fall.[6] If losses continue to increase relative to gains, the Gini coefficient continues to fall – to minus infinity at that point where average impacts are zero (B+C=0) but there are winners as well as losers. This corresponds to an intuitive definition of the "worst possible" distribution of impacts.

Figure 2. The cumulative damage curves, actual (light blue) and average (dark blue), in 2025, according to the FUND2.6 model



Note that impacts are measured as damages, that is, positive is bad and negative is good.

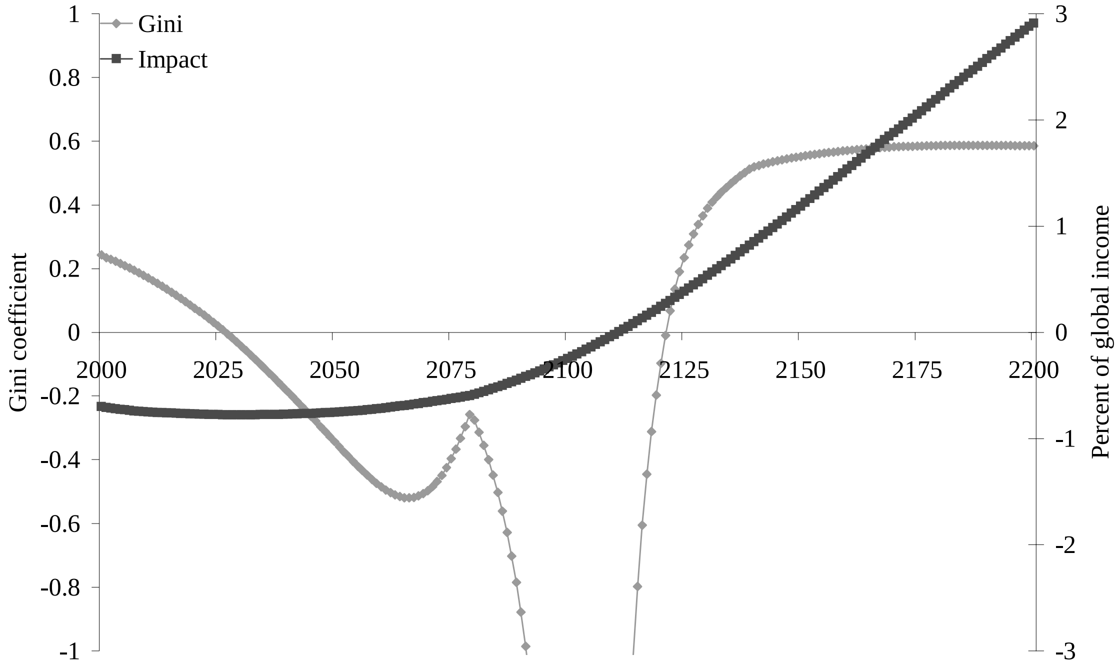
Figure 3 displays the evolution of the Gini coefficient over time, according to the outcomes of the FUND2.6 model (see Tol, 2002d).[7] The Gini coefficient starts low – as the average impact is positive, but some countries loose out – and falls – as the average impacts remain positive but the losses mount. Indeed, the Gini coefficient falls to minus infinity around 2100, but then it starts to rise rapidly as the average

[6] The fact that economists are used to thinking that the Gini coefficient should be greater than zero is because it is usually applied to the distribution of positive incomes. Note that, in this case, zero does not have a particular interpretation.

[7] The FUND model is an integrated assessment model of climate change, combining simple models of population, economy, energy, carbon cycle and climate and more extensive models of climate change impacts. See Tol (1997, 1998, 1999a-e, 2001, 2002c, 2003; Tol *et al.*, 2003).

impact is negative and most countries suffer negative impacts – a more egalitarian distribution of the gain. The Gini coefficient stabilizes around 0.6.[8]

Figure 3. The Gini coefficient of climate change damages (green) and the aggregate damages over the period 2000-2200, according to FUND2.6



[8] The stabilisation is due to the fact that the FUND model assumes a steady state towards the end of its time horizon. No meaning should be attached to this finding.

4. THE VULNERABILITY OF THE POOR

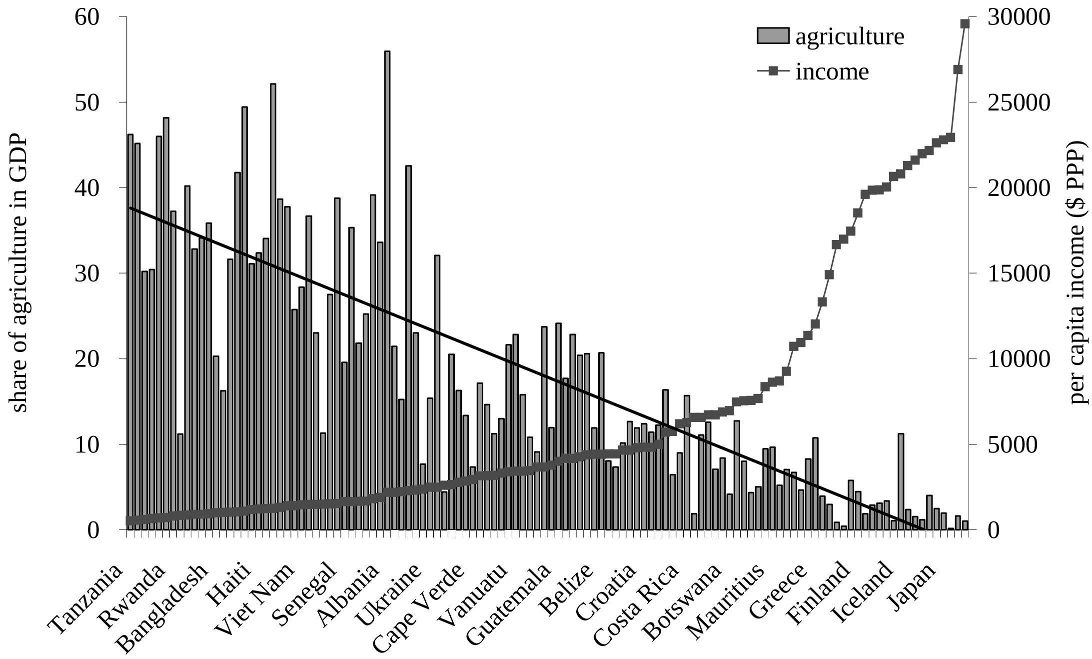
Differences in vulnerability are also apparent within regions and countries. Some individuals, sectors, and systems will be less affected, or may even benefit, while other individuals, sectors, and systems may suffer significant or even catastrophic losses. Poor people in general, wherever they live, may be more vulnerable to climate change than richer people. However, vulnerability and poverty are not synonymous—some environmental changes will affect wider populations and economies. A common construction of climate change vulnerability comprises:

- What is exposed to climate change?
- What are the risks of adverse impacts?
- What are the costs of adaptive measures
- What level of adaptive capacity is available to mitigate potential damages?

We illustrate these aspects of vulnerability by ranking per capita income. Some insight can be derived from analyses at the country level, although only a crude indication of the distribution of vulnerability within countries, as noted above. Comparisons are shown for agricultural share of GDP (exposure), temperature (a proxy of climate risks) and the costs of coastal protection (adaptive measures). The relative distribution of adaptive capacity is indicated above, using the Human Dimensions Index.

Developing countries tend to depend more directly on natural resources than do developed economies. Figure 4 illustrates this. It shows the contribution of agriculture to the gross domestic product and per capita income (1995 purchasing power parity dollars) in 1995. Clearly, poorer countries rely more on agriculture than do richer countries. Figure 4 actually understates the case, as subsistence agriculture is underrepresented in GDP estimates.

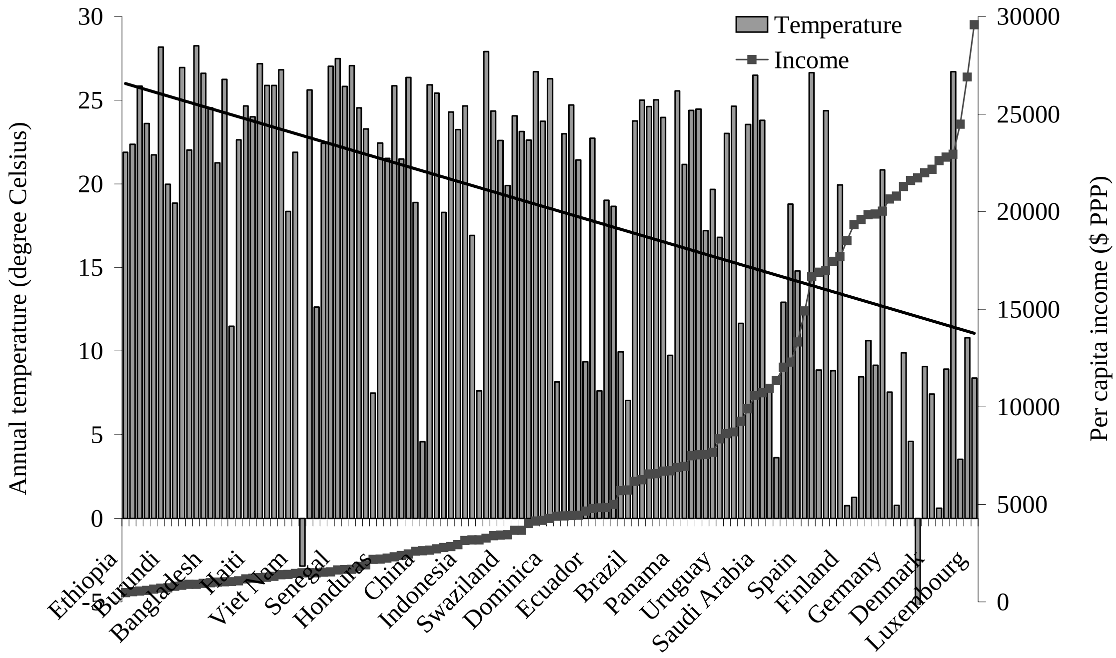
Figure 4. The share of agriculture in GDP and per capita income in 1995 for all countries for which such data is available. Countries are ranked by per capita income



Economic activities that rely on natural resources, such as land and water, are more susceptible to weather and climate than economic activities that rely on man-made resources, for the simple reason that the latter have more control over the environment than the former. (This argument does not hold for natural resources such as minerals and fossil fuels.)

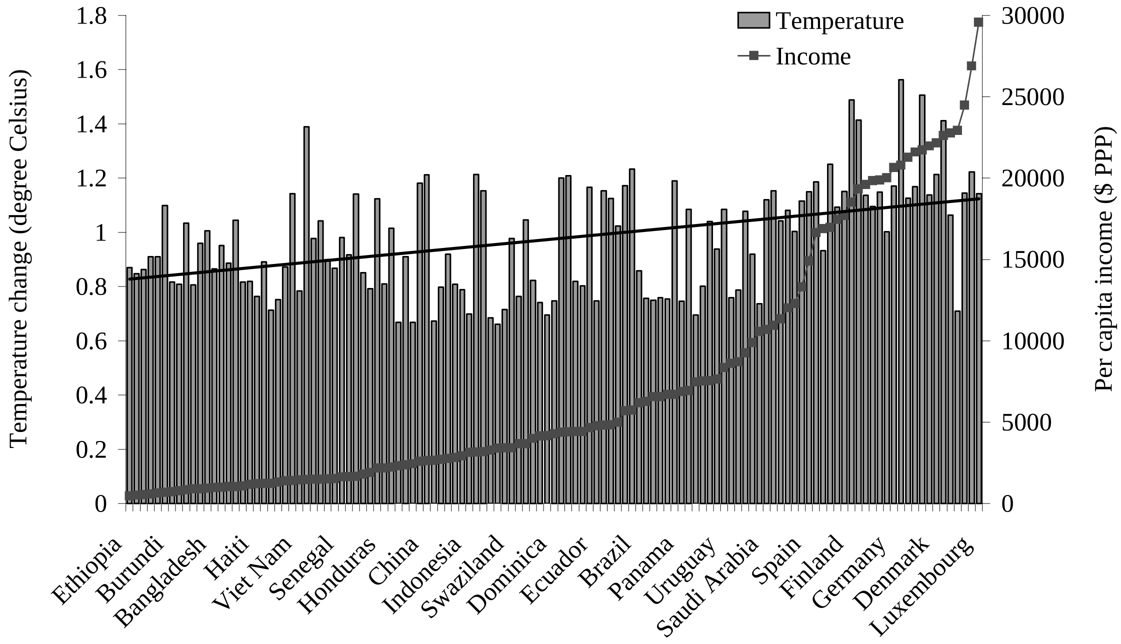
Poorer countries also tend to be hotter. Figure 5 illustrates this by showing per capita income and the annual mean temperature. In hotter countries, more activities are at or close to their upper temperature tolerance, and there are fewer technologies from still-hotter countries that can be employed should temperatures rise.

Figure 5. The annual mean temperature for the period 1961-1990 and per capita income in 1995 for all countries for which such data is available. Countries are ranked by per capita income



The fact that poorer countries tend to be hotter and therefore closer to their temperature tolerance limits is partly counteracted by the fact that climate models predict that temperatures would rise faster towards the pole than towards the equator. However, Figure 6 shows that this effect is small compared to the initial difference in temperatures. Warmer countries are also less likely to benefit from increases in temperature, as expected in the middle latitudes in some regions.

Figure 6. The change in the annual mean temperature for a one degree global warming as averaged over 14 GCMs and per capita income in 1995 for all countries for which such data is available

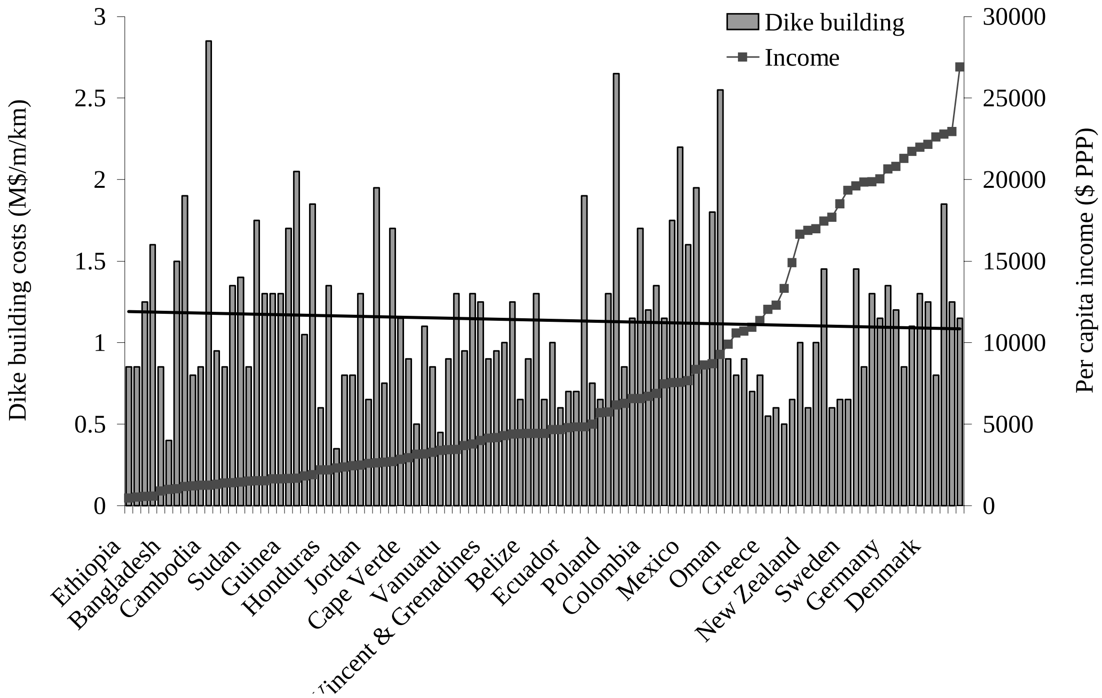


Countries are ranked by per capita income.

Besides having a larger part of their economies and livelihoods exposed to climate change and being closer to their upper temperature tolerance, poorer countries have a lower adaptive capacity. Adaptive capacity is the ability to ameliorate the negative consequences of climate change and take advantage of the positive changes. Adaptive capacity is thought to be determined by technological ability, economic resources and their distribution, and human, political and social capital. These matters are all better in richer countries. By implication, richer economics are better able to protect themselves against climate change.

Figure 7 illustrates this with the costs of dike building. Although wages and land prices are higher in richer countries, poorer countries would have to fly in foreign expertise to protect their coasts. As a result, dike building is as expensive – in absolute terms -- in poorer countries as it is in richer ones, but much more expensive as a fraction of income.

Figure 7. The cost of dike building and per capita income in 1995 for all countries for which such data is available



Countries are ranked by per capita income.

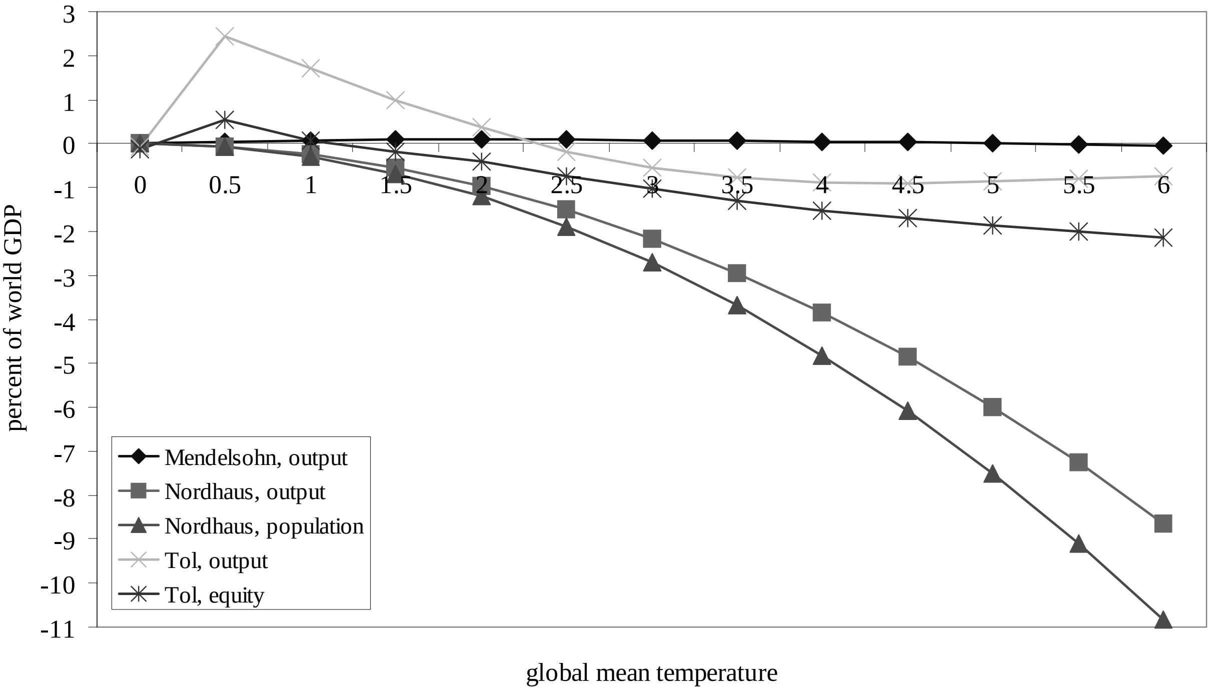
5. PATHWAYS OF ECONOMIC DEVELOPMENT

Global warming damages under the 2xCO_2 scenario are hypothetical damages on the *present* society. The real damages of global warming will occur in the future, and society will have changed in terms of population, economic size and structure, technology and socio-cultural and political factors. These changes will affect the vulnerability and adaptive capacity of society to global warming. If we are interested in the absolute size of damages (for example per ton of present CO_2 emissions) it is necessary to establish the future size of the population and the economic, natural, social and human capital stocks at risk. The timeframe of global warming damages is too long, however, to predict such future developments with any confidence, much less precision. Hence, scenarios are used that describe possible futures but do not claim to describe the most likely future. Because of the use of these scenarios, global warming damage assessments have a contingent nature: they are contingent upon the assumptions embedded in socio-economic scenarios, whether explicit or not.

One of the main challenges of impact assessments is to move from this static analysis to a dynamic representation of impacts as a function of shifting climate characteristics, adaptation measures and exogenous trends like economic and population growth. Our understanding of the time path aggregate impacts will follow under different warming and development scenarios, is still extremely limited. Among the few explicitly dynamic analyses are Sohngen and Mendelsohn (1999), Sohngen *et al.* (1998), Tol (2002b), Tol and Dowlatabadi (2001), Tol and Langen (2000) and Yohe *et al.* (1996). These studies are highly speculative, as the underlying models only provide a very rough reflection of real-world complexities. Figure 8 shows examples from three studies. While some analysts still work with relatively smooth impact functions (e.g. Nordhaus and Boyer, 2000), there is growing recognition (e.g., Tol, 1996, 2002b; Mendelsohn and Schlesinger, 1999) that the climate impact dynamics – the conjunction of climate change, societal change, impact, and adaptation – is certainly not linear, and might be quite complex (see below for two examples).

Impacts in different sectors may unfold along fundamentally different paths. Coastal impacts, for example, are expected to grow continuously over time, more or less in proportion to the rise in sea level. The prospects for agriculture, in contrast, are more diverse. While some models predict aggregate damages already for moderate warming, many studies suggest that under some (but not all) scenarios the impact curve might be hump-shaped, with short-term (aggregate) benefits under modest climate change turning into losses under more substantial change (e.g., Mendelsohn and Schlesinger, 1999, Smith and Hitz, 2003).

Figure 8. The impact of climate change as a function of the global mean temperature,

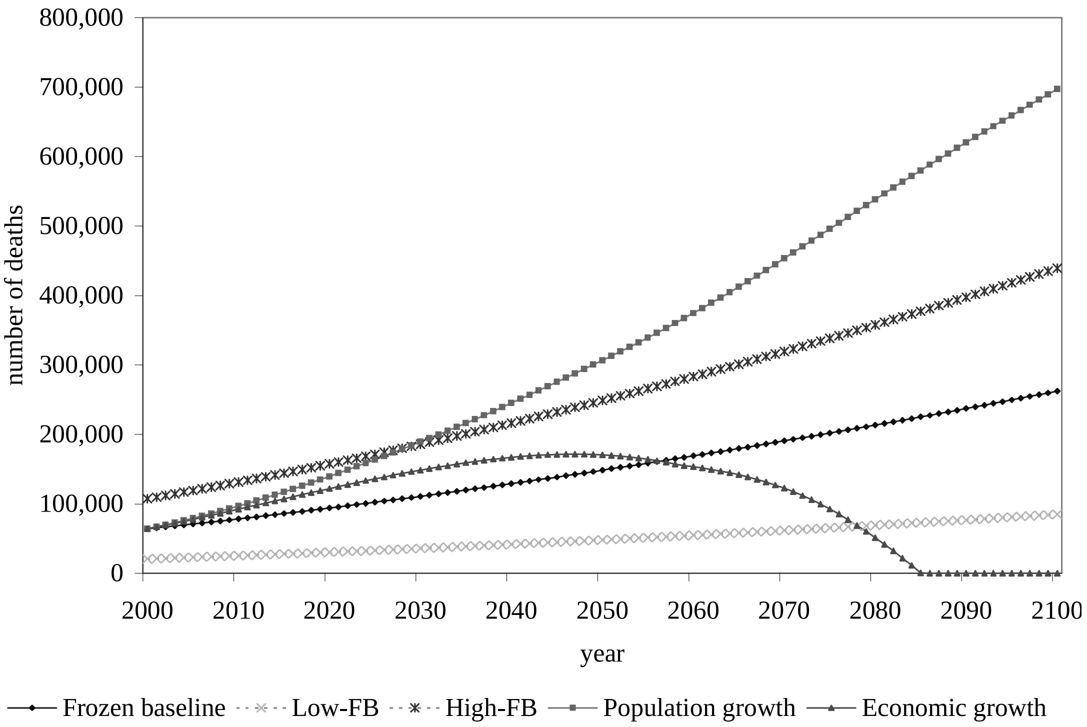


According to Mendelsohn *et al.* (1998), Nordhaus and Boyer (2000), and Tol (2002b). Mendelsohn *et al.* aggregate impacts across different regions weighted by regional output. Nordhaus and Boyer aggregate either weighted by regional output or weighted by regional population. Tol aggregates either by regional output or by equity, that is, by the ratio of world per capita income to regional per capita income.

The effect of development on vulnerability is perhaps best illustrated with malaria. First, we consider the impact of climate change alone. Figure 9 displays the additional number of deaths due to malaria, schistosomiasis, and dengue fever. Keeping the number of people and their income as at present, the impact is largely due to the geographic expansion of the area at risk. Our simulations suggest an expected increase in vector-borne disease mortality of about 250,000 per year. There is a high degree of uncertainty in this estimate as depicted by the range of future mortality (on the order of 100% higher or lower than the reference case).

Population growth increases the number of people at risk from vector-borne disease (even if their range is unchanged). Adding in the impact of population growth and geographic extension of potential outbreaks of vector-borne disease, the expected mortality is almost tripled to over 700,000 deaths per year. As noted earlier, economic growth – if assumed to improve (access to) public health services – can act to suppress the intensification of vector-borne disease and mortality even when the potential for their occurrence rises. Inclusion of the impact of economic growth (and its assumed positive effect on health services) on realised mortality due to vector-borne diseases would keep the annual death toll below 150,000 cases per year. If economic growth proceeds according to the scenarios explored here, there is a happy prospect that mortality from vector-borne diseases can be eradicated by about 2080, as all regions acquire a sufficient standard of living to afford effective health care and environmental management. Obviously, there is considerable uncertainty about the relationship between access to health services and economic development. When the assumed threshold of per capita income above which malaria mortality disappears is realised depends on the scenario of economic growth and differs between regions. A successful and cheap malaria vaccine would bring this date closer.

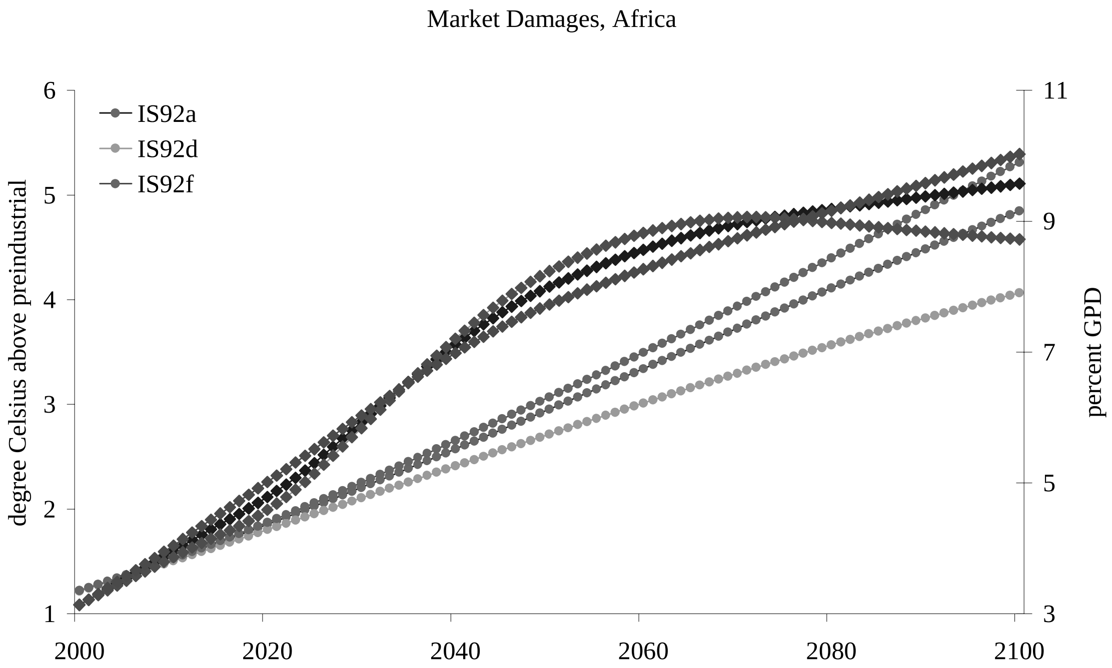
Figure 9. World-wide climate change induced vector borne mortality for five different cases. In 'frozen baseline', climate changes but economy and population are as in 1990



'Low-FB' and 'High-FB' use the same assumptions, but the sensitivity of vector-borne diseases to climatic change is set at its best guess minus or plus its standard deviation. In 'population growth', the scenario for demographic development is added. In 'economic growth', the scenario of increasing per capita income and consequent improvements of health care are also added.

Figure 10 further illustrates the dependence of climate change impacts on the business as usual scenario, again, the example is from Africa. Three scenarios are compared: IS92d, IS92a and IS92f, ordered by global emissions of carbon dioxide. IS92f has the fastest economic growth, followed by IS92a and IS92d; IS92d has the fastest improvements in energy- and carbon-intensity, followed by IS92a and IS92f. In the short run (up to 2035), the IS92f scenario has the largest global warming, and therefore also the largest impacts. Ather that, the situation reverses: IS92f has the greatest warming, but smallest impacts.. This is because IS92f also has the highest economic growth, and therefore the lowest dependence on agriculture. Despite greater warming, impacts are lower in IS92f than in IS92a. Later (after 2075), the situation reverses again. The explanation is not agriculture but energy demand. Towards the end of the 21^{st} century, Africa is rich enough to afford air conditioning – but the penetration of air conditioning is more pronounced under IS92f than under IS92d. Moreover, energy efficiency improvements are larger under IS92d than under IS92f.

Figure 10. Market damages (as a percent of GPD) in Africa for the IS92a, IS92d and IS92f scenarios (squares).



The global mean temperature is also displayed in the same but fainter colours (circles).

In the two examples above, vulnerability to climate change is largely driven by per capita income and the structure of the economy. The size and the structure of economies are routine components of long-term socio-economic scenarios.[9] However, Smit *et al.* (2001) postulate that adaptive capacity depends on a range of factors besides economics, a conjecture that is operationalised and measured by Yohe and Tol (2002). Unfortunately, examples of a more dynamic notion of adaptive capacity have not as yet been implemented in quantitative climate change impact literature.

[9] Scenarios used for climate change include, besides the size and structure of the economy, the size and structure of the energy sector, sometimes the size and structure of other activities that generate substantial emissions, and the size and composition of greenhouse gas emissions. These scenarios are very valuable for emissions and climate change, but less so for climate change impacts.

6. CONCLUSIONS

Our insight into the impact of climate change on human welfare is gradually increasing. However, some of the insights gained demonstrate the earlier naiveté of research into climate impacts. As a result, uncertainties may have increased, although quantitative assessments of the uncertainty are still rare.

We can be certain, however, that the impacts of climate change will not be uniform. Some will loose, others will benefit from climate change, and some will loose or gain a little whereas others will loose or gain a lot. It depends on what activities are analysed, when and where.

What is also certain is that the poor will loose most, at least relative to their income. The poor are more vulnerable both because their exposure is higher and because their adaptive capacity is lower.

If vulnerabilities are not uniform, one has to be very careful when aggregating impact estimates over countries or, for that matter, over economic sectors or income classes. Equity weights may be a solution, at least they acknowledge the importance of moral choices.

If vulnerability is not uniform between countries and sectors, then vulnerability will change over time. Research into the dynamics of vulnerability has only just begun, but the first results show that it is both complex and important. Although it can be said with a fair degree of confidence that economic growth would reduce vulnerability, it cannot be said that accelerating economic growth, and hence greenhouse gas emissions, would necessarily decrease impacts; nor whether reducing greenhouse gas emissions, and hence decelerating economic growth, would necessarily reduce impacts of climate change. It is equally impossible to say whether current policies for economic development are just what is needed for reducing vulnerability to climate change, or whether these policies need small or large adjustments.

The impacts of climate change are substantial but subtle, and more research is needed to guide mitigation and adaptation policies that live up to both the size and the complexity of the problem. Future research should include the richer notion of adaptive capacity that has emerged recently, and should build on a larger and richer set of socio-economic scenarios that embrace vulnerability, economic development and emissions. Such research will not only give us a better notion of who is vulnerable, but also how to reduce that vulnerability. Measures of the (in)equity of climate change impacts should be developed and reported. The inequities of climate change impacts should be compared to the inequities of greenhouse gas emission reduction.

The state-or-the-art in understanding climate vulnerability and adaptation is such that frameworks for optimising mitigation reductions against avoided damages are unlikely to be empirically based, grounded in well understood processes or reflecting a consensus on ethical issues.

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