INFECTIOUS DISEASE, DEVELOPMENT, AND CLIMATE CHANGE: A SCENARIO ANALYSIS

Richard S.J. Tol[a,b,c], Kristie L. Ebi[d] and Gary W. Yohe[e]

[a] *Research unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg, Germany*

[d] *Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands*

[c] *Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA*

[d] *ESS LLC, Alexandria, VA, USA*

[e] *Woodhouse/Sysco Professor of Economics, Wesleyan University, Middletown, CT, USA*

June 1, 2006

Working Paper FNU-109

Abstract

We study the effects of development and climate change on infectious disease in Sub-Saharan Africa. Infant mortality and infectious disease are close related, but there are better data for the former. In an international cross-section, per capita income, literacy, and absolute poverty significantly affect infant mortality. We use scenarios of these three determinants, and of climate change to project the future incidence of malaria, assuming it to change proportionally to infant mortality. Malaria deaths will first increase, because of population growth and climate change, but then fall, because of development. This pattern is robust to the choice of scenario, parameters, and starting conditions; and it holds for diarrhoea, schistosomiasis, and dengue fever as well. However, the time and level of the mortality peak is very sensitive to assumptions. Climate change is important in the medium term, but dominated in the long term by development. As climate can only be changed with a substantial delay, development is the preferred strategy to reduced infectious diseases, even if that is exacerbated by climate change.

Key words

Development, infectious disease, climate change, Sub-Saharan Africa, malaria

JEL Classification

I12, O13, Q54

1. Introduction

A cursory look at the geography and history of infectious diseases shows that they are prevalent in places where the weather is hot and wet and where the people are poor (e.g., WHO, 2005). Although closer study reveals a multitude of complexity and nuance (e.g., Casman and Dowlatabadi, 2002), climate determines the potential of many infectious diseases to flourish while health care[1] influences the actual incidence of disease. One would therefore expect that, in a scenario of economic growth, infectious diseases would fall as health care improves (Medlin *et al.*, 2006). Likewise, in a scenario of global warming, one would expect to see infectious diseases spread into new regions and perhaps intensify (McMichael *et al.*, 2001). In a scenario with both growth and warming, it is unclear what to expect, but projections of future disease incidence should take both into account. Indeed, given complex interactions between economic growth and exposure to disease, it is possible that reallocating development aid towards greenhouse gas emission reduction could actually increase the impacts of climate change on infectious diseases.

Previous studies that have looked into this issue (Tol and Dowlatabadi, 2001; Tol, 2005; Tol, forthcoming, a) suffer from the oversimplification of equating "development" with "economic growth". Here, we address this limitation by driving the evolution of a few of the statistically significant underlying determinants of adaptive capacity (in reducing vulnerability to infectious disease) into the future along economic growth scenarios and tracking the resulting vulnerability to two diseases – malaria and diarrhoea. Previous studies had considered malaria, of course, but none had extended even the simpler approach to a second disease. Moreover, previous work looked only at large regional aggregates, while this paper offers results for individual countries.

In Section 2, we report two empirical relationships. One relates vulnerability to infant mortality to three statistically significant determinants of adaptive capacity (per capital income, literacy, and absolute poverty, only, because other determinants were statistically insignificant). The second relates vulnerability to under-five mortality to two statistically significant determinants (literacy and absolute poverty). We use these relationships in Section 3 to produce alternative scenarios of the incidence of malaria and diarrhoea through 2100 along specific economic development pathways for a sample of developing countries where both diseases are currently a problem. Five different assumptions of the future evolution of incidence, some based on the empirical results from Section 2 and others drawn from earlier approaches, produce marketed different temporal profiles. It follows that assessments of the impacts of climate change that ignore the nuances in the relationships between the economic development and vulnerability can grossly misrepresent the risks of that change. Concluding remarks in Section 4 make this point.

2. Vulnerability to Infectious Disease

2.1. Adaptive capacity

The notion of adaptive capacity has proved useful in the study of the impacts of climate change. Essentially, adaptive capacity measures the ability of a society to respond, either to make the best of new opportunities opened by climate change, or to minimise negative consequences. Adaptive capacity for climate change is similar to adaptive capacity for any change. Indeed, adaptive capacity is closely linked to development, as a society that cannot

[1] Note that we interpret health care in its broadest sense, including hygiene, sanitation, primary health care, and public health infrastructure.

cope well with change cannot have developed. Vice versa, low development typically implies low adaptive capacity. Again, while these things are true in general, there are important exceptions as well. The impact of Hurricane Katrina on the USA, and health care in Cuba show that rich countries are not invulnerable, and poor countries may do well on reducing specific vulnerabilities.

Yohe and Tol (2002) suggested focusing attention on a list of underlying determinants for adaptive capacity:

1. the range of available technological options for adaptation;
2. the availability of resources and their distribution across the population;
3. the structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed;
4. the stock of human capital including education and personal security;
5. the stock of social capital including the definition of property rights;
6. the system's access to risk spreading processes;
7. the ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves; and
8. the public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

In fact, Yohe and Tol (2002) conjectured that the adaptive capacity of any system would, for all intents and purposes, be limited by the weakest of these underlying determinants; this is the so-called "weakest link" hypothesis with which they constructed an indexing scheme by which the relative vulnerabilities of wildly different systems could be judged. Albarini *et al.* (2006) test the framework of Yohe and Tol (2002) with a panel of experts and with objective data on natural disaster mortality. They find good accordance between experts and data and that the operationalisation of adaptive capacity has predictive skill. Tol and Yohe (2006) test the weakest link hypothesis of adaptive capacity by measuring vulnerability, the inverse of adaptive capacity. Statistical representations of the sensitivity of vulnerability to multiple determinants of adaptive capacity supported their tests; we will use their approach here to produce, for the first time, site-specific and (economically) path dependent trajectories of future vulnerability to two infectious diseases.

Following Tol and Yohe (2006), the vulnerability V of any country C to an external stress, for instance climate change, can be measured as

(1) $$\{1/V_C\} \equiv \{\sum \alpha_i A_i^{(1-\gamma)}\}^{1/(1-\gamma)}$$

where the A_i are indicators of n distinct determinants of adaptive capacity. The α_i and γ are parameters in the relationship that is motivated by the usual structure of constant elasticity of substitution production functions. In this regard, $(1/\gamma)$ is the "elasticity of substitution" between any two determinants in supporting the exercise of adaptive capacity in reducing vulnerability to the chosen stress. Note that

- $\gamma \rightarrow \infty$ would mean that $\{1/V_C\} \equiv \min\{\alpha_i A_i\}$. In this extreme case, the determinants of adaptive capacity would be perfect complements and overall vulnerability would be entirely determined by the "weakest link" in the sense that strengthening any but the weakest determinant would do nothing to reduce vulnerability.
- $\gamma = 1$ would means that $\{1/V_C\} \equiv \{\prod A_i^{\alpha_i}\}$. This is a threshold case because, as γ converges to unity from above, the "iso-vulnerability" loci do not intersect any of the

$A_i = 0$ axis. It follows that vulnerability would be infinite if any single determinant were not present. In all other cases, the determinants can substitute for one another to maintain the same level of vulnerability, but compensation would become increasingly expensive as strength in one or more determinants became weaker. This is nearly the functional form of the geometric mean employed by Brenkert and Malone (2005), although the geometric mean imposes the condition that all of the α_i coefficients are identical.

- $\gamma < 1$ would mean that the determinants can substitute for one another to maintain the same level of vulnerability and that compensation would become less expensive as strength in one or more determinants became weaker.
- $\gamma = 0$ would mean that $\{1/V_C\} \equiv \{\sum \alpha_i A_i\}$. In this case, the determinants of adaptive capacity would be perfect substitutes regardless of their individual levels. In words, the determinants can substitute for one another at constant rates to maintain the same level of vulnerability.

2.2. Data

Most of our data was taken from WRI (2005), a source that has internally consistency, quality checks, and global coverage. We used two alternative indicators for vulnerability to infectious disease. The first was infant (under-one) mortality. Infant mortality integrates a range of problems of poverty and health. Although disease-specific (infant) mortality would be more informative, data coverage is insufficient, particularly in poorer countries. The second indicator was under-five mortality. We would have preferred to use data on the diseases themselves, particularly malaria and diarrhoea. However, WHO country data omit these diseases for many countries, and crucially so for regions that the WHO regional data suggest are most vulnerable.

We grouped the indicators of adaptive capacity into five categories. Table 1 lists them all. Institutional indicators include the nature of government (democracy etc.), and the nature of government intervention in society (rule of law etc.). Cultural indicators include average attitudes (e.g., to risk). Related to that, we included a list of dummies giving the dominant religion in a country; note that a country may be labelled "Christian" even though most of its inhabitants are secular. Per capita income, income distribution, and poverty rates were employed as economic indicators. Finally, enrolment and literacy reflected education.

2.3. Results

We began by trying to explain infant mortality. Two problems with estimating (1) quickly became apparent. The first was model selection. There were many potential indicators of adaptive capacity, each with missing observations for different countries. Furthermore, the regressions were plagued by multicollinearity. One would preferably start with the model that includes all possible explanatory variables. Estimates could then be refined by eliminating variables that are neither individually nor jointly significant in a step-wise process. This procedure was not possible, however, because all of the variables were actually available for only a small number of countries. Indeed, this number was smaller than the number of potential explanatory variables. We were therefore forced to group the explanatory variables; Table 1 provides the details. A number of institutional variables had a significant effect on infant mortality: civil liberty (positive)[2], democracy (positive), economic freedom (negative), and political stability (positive). From the religion variables, only Christianity had a significant, positive influence. Individualism and long-term orientation were the only significant cultural variables, both with a positive effect. Secondary education and literacy had significant, positive effects on infant mortality. Absolute poverty, average per capita income, and the Gini coefficient had significant, positive effects on infant mortality.

Non-linearity was the second problem in estimating equation (1). Although non-linear estimators are now generally available, CES functions are complicated. We therefore linearly estimated equation (1) for specific γ's, and then conducted a grid search to produce both a maximum likelihood estimate for γ and the maximum likelihood function as well. The estimated function is:

$$V_c^{M1} = (1-\gamma)^{1-\gamma}\left(\underset{(2.1)}{20.6} - \underset{(0.04)}{0.15}\,Y^{1-\gamma} - \underset{(0.37)}{1.52}\,L^{1-\gamma} + \underset{(0.19)}{0.91}\,P^{1-\gamma}\right)^{1/(1-\gamma)} \qquad (2)$$

$$\gamma = \underset{(0.11)}{0.60};\ R^2 = 0.84;\ N = 49$$

where Y is per capita income, L is literacy, and P is absolute poverty. A modest version of the weakest link hypothesis is somewhat supported, but none of the indicators is essential (as would be the case if $\gamma > 1$).

We followed the same procedure for under-five mortality. Of the institutional variables, only the rule of law and political stability had a positive, significant influence. Christianity, individualism, and a long-term orientation had positive, significant effect. Both absolute and relative poverty significantly increase under-five mortality. Literacy and secondary education have a significant, positive effect.

Putting all explanatory variables together, only literacy and absolute poverty remained. The estimated function is:

$$V_c^{M5} = (1-\gamma)^{1-\gamma}\left(\underset{(2.4)}{21.8} - \underset{(0.60)}{4.55}\,L^{1-\gamma} + \underset{(0.27)}{1.92}\,P^{1-\gamma}\right)^{1/(1-\gamma)} \qquad (3)$$

$$\gamma = \underset{(0.10)}{0.28};\ R^2 = 0.81;\ N = 55$$

Even weaker support for a weakest link assumption was found.

3. Scenarios

Our empirical analysis highlighted three significant indicators of adaptive capacity: per capita income, literacy, and absolute poverty. Standard scenarios for climate change analysis do not project these variables. In fact, the SRES scenarios only have per capita income, measured in market exchange rates (MER). We measured income in purchasing power exchange rates (PPP), as this better reflects the true standard of living. Following Tol (forthcoming, b), we assumed that the ratio of PPP to MER falls by 0.28 (0.02) % for every 1% increase in per capita income (in MER). The data used in Section 2 show that literacy increases by 0.27 (0.03) % for every 1% increase in per capita income (in PPP), and that absolute poverty falls by 1.11 (0.13) % with the same 1% increase in per capita income (again in PPP). With these income elasticities in hand, it is easy to show that per capita income has to increase by a factor 1.9 to meet the Millennium Development Goal (MDG) of halving poverty in 2025; this is

[2] Note that we use "positive" and "negative" in the intuitive sense so, for example, increasing civil liberty reducing infant mortality is a positive effect.

equal to a 3.2% growth rate over 20 years. Given equation (2), infant mortality would fall by 14.6% (for a per capita income of $530, and a literacy rate of 56%, as in Nigeria).

Figure 1 shows scenario results for Nigeria. We use Nigeria in this initial discussion to represent a large but typical country in Sub-Saharan Africa, but we will report results for other countries below. Income per capita (MER) rises by a factor 120 over the course of the 21st century in West Africa for the SRES A1B scenario (IMAGE Team, 2002), but only by a factor 30 when measured in PPP. Five alternative projections, driven by this lower rate of change in income, are shown for malaria mortality. First, we assumed that the incidence of malaria is proportional to infant mortality and that future infinite mortality is driven by per capita income, literacy and absolute poverty according to equation (2). Second, we assumed that the incidence of malaria is proportional to under-five mortality, where under-five mortality is driven by literacy and absolute poverty according to equation (3). Third, we assumed that the incidence of malaria is proportional to infant mortality and that that infant mortality is driven by income only; this implies that the income elasticity of malaria is –0.85 (0.04)[3].[4] Fourth, we followed Tol and Heinzow (2003) and assumed an income elasticity of –2.65 (0.69); this is income elasticity of malaria estimated for the 14 WHO regions. Fifth, following Brenkert and Malone (2005), we assumed that changes in malaria are proportional to changes in the geometric mean of per capita income, literacy, and one minus the fraction of people in absolute poverty. For comparison, we also show the case in which malaria stays constant (relative to the population), as assumed by Martens et al. (1995, 1997) and van Lieshout *et al.* (2004).

The results are strikingly different across the various scenarios. In all, malaria mortality falls from the present 1.7 deaths per thousand per year, the rate reported by WHO for the poorest region of Africa. However, using the geometric mean as suggested by Brenkert and Malone (2005), malaria falls by a factor 4, while malaria disappears under the assumptions of Tol and Heinzow (2003). Incidence driven by the infant mortality and under-five mortality relationships reported in equations (2) and (3), respectively, behave similarly until 2050. After 2050, poverty is eradicated and literacy is universal, so malaria projected with under-five mortality stabilizes. Finally, the trajectory supported by the alternative model that drives infant mortality by a single determinant (income alone) lies somewhere in between “under five” and “infant”.

Figure 2 shows the implications for climate change impacts, again using Nigeria as an example with vulnerability driven by infant mortality per equation (2). We assumed that malaria mortality increases by 8% (6%) for every degree warming (Martens *et al.*, 1995, 1997; van Lieshout *et al.*, 2004). The middle trajectory shows that climate change alone would add some 40,000 malaria cases in 2100. If we add population growth,[5] then (as shown in the highest path), this estimate increases to almost 100,000. However, adding economic growth as described above, the number falls to slightly more than 1,000 excess deaths along the lowest path.

Figure 2 was constructed under that assumption that malaria follows infant mortality. Panel A of Figure 3 shows that the maximum number of climate-change induced malaria deaths over the next century could fall to only 22,000 cases per year even with Brenkert and Malone’s (2005) pessimistic assumptions about adaptive capacity. In a world described accurately by Tol and Heinzow (2003), there will be no malaria in 2100. Panel A shows malaria incidence

---

[3] Numbers in brackets are standard deviations.

[4] The income elasticity for under-five mortality is –0.90 (0.04), leading to practically the same projections.

[5] Population is assumed to increase by 2.2% per year in the first quarter century, 1.0% in the second quarter, 0.2% in the third, and -0.6% in the fourth. With these assumption, population doubles between 2000 and 2100. These assumptions are from IMAGE Team (2002).

stabilizing by the middle of the century under the assumption that malaria follows under-five mortality because literacy becomes universal and poverty is eradicated. It must be emphasized, though, that the Millennium Development Goal of cutting under-five mortality by 2/3 is never met, let alone in 2025.

The other panels of Figure 3 depict the results of other sensitivity analyses for Nigeria. After the assumptions about adaptive capacity, the rate of economic growth and its effect on adaptive capacity are most important for the number of malaria deaths in 2100. The assumed rate of climate change and the assumed sensitivity of malaria to climate change are most important in the medium run, but dominated by development and economic growth in the long run. The assumptions on population growth have little effect, as have the assumed income elasticities of purchasing power parity, literacy, and poverty.

Figure 4 shows the results for Nigeria, Botswana and Niger when climate change is cast against vulnerability calculated from the infant-mortality relationship of equation (2). The peak of climate-change-induced malaria is lowest and comes earliest in Botswana, and the disease is eradicated soonest. The peak is highest and comes latest in Niger, and is highest in 2100. Nonetheless, the qualitative pattern depicted here is typical of all countries in our sample. Table 2 offers some summary statistics for a selection of countries in Sub-Saharan countries. These are the only countries for which we have observations on infant mortality, per capita income, literacy, and absolute poverty with which to inform equation (2). In both Table 2 and Figure 4, we vary only the starting point from country to country (i.e., per capita income, literacy and absolute poverty). The scenario assumptions are otherwise the same as described above for Nigeria. The numbers are indexed to the year 2000, normalising for differences in baseline mortality and population size.

So far, we focussed on malaria. Tol (2002) postulates the same functional specification for dengue fever and schistosomiasis as for malaria. With that hypothesis, the qualitative behaviour is the same, although both diseases have much fewer victims than does malaria; and schistosomiasis may decrease with climate change. Diarrhoea is different, particularly since it increases with temperature to the power 1.14 (0.51); recall that we assume malaria to be proportional to warming. Figure 5 compares the evolution of malaria and diarrhoea for Nigeria for the A1B scenario. The number of diarrhoea deaths is an order of magnitude larger, but the pattern is much the same, with diarrhoea deaths peaking only slightly later. For completeness, we also show the results for the models of Link and Tol (2005) and Tol and Heinzow (2003). For both diseases, our projections based on infant mortality are much higher than their projections using simple income elasticities.

4. Discussion and conclusion

We show the impact of climate change and development on malaria in Sub-Saharan Africa for a range of scenarios and sensitivity analyses. In the medium term, the extent of climate change, the sensitivity of malaria to climate change, the initial conditions, development, and the relationship between development and health care are all important variables. In the long term, however, only the speed of development and how that affects health care matter – at least, under the range of assumptions used here. Climate change and its impact on malaria are important only if there is hardly any development over the 21st century. Other infectious diseases behave similar to malaria.

As climate change can only be affected in the long term but adaptive capacity can be improved in both the short and long term, this implies that development is a better response to climate-change-induced infectious disease than is greenhouse gas emission reduction. Tol and Dowlatabadi (2001) and Tol (2005) reach the same conclusion, but based on malaria only, using crude spatial aggregation and, most importantly, simplified relationships between infectious disease and development.

Our results show that development will reduce the burden of infectious disease. Progress is slow, however, and for the first few decades the effect of climate change dominates. This suggests that a policy that only focuses on development, assuming that improved health care would follow automatically, may not be advisable. Interventions specifically aimed at infectious diseases (e.g., bed nets and indoor spraying for malaria, see Breman *et al.*, 2006; breast-feeding and oral rehydration therapy for diarrhoea, see Keusch *et al.*, 2006) could save a substantial number of lives.

The most important caveat to our results is that we limit ourselves to the effect of development on infectious disease, ignoring the impact of infectious disease on development – through labour productivity, health care expenditures, education, and fertility. See Sachs (. Tol (forthcoming, a) shows that this is a minor error when considering climate-change-induced malaria, but the impact may be larger when all infectious disease is included.

An implicit assumption is that control of infectious disease in developing countries is analogous to control of infectious diseases in developed countries. This is unlikely to be true, as infectious disease in the tropics is not the same as infectious disease in the temperate zone. The burden of malaria in Sub-Saharan Africa is higher than the burden ever was in Europe or North America. Much effort and money has been spent trying to control malaria and diarrhoea but with limited and mixed success.

The results presented here do not carry over to other health impacts of climate change. Particularly, carbon dioxide emission reduction would be more effective for diseases related to air pollution, as both climate and air quality would improve. The effect of development on cardiovascular disease is ambiguous. Development would improve health care, but also longevity and obesity. The effect of climate change on development is also ambiguous, as both heat stress and cold stress affect people with cardiovascular disorders.

Our results are based on cross-sections between countries. As a result, we ignore the dynamics of the problem – even though health and education are stock variables. The analysis presented here should be repeated with a dynamic panel analysis, as soon as data allow. The findings should be complemented with studies of these effects within countries.

These caveats show the need and direction for further research. However, for now, our conclusion is that climate change is of subordinate importance for infectious disease, while development is crucial.

Acknowledgements

This paper would not have been possible without the series of Climate Change Impacts and Integrated Assessment meetings at Snowmass, masterly organised by Susan Sweeney and John Weyant of the Energy Modelling Forum. Financial support by the European Commission DG Research (ENSEMBLES), the Hamburg University Innovation Fund, and the Princeton Environmental Institute is gratefully acknowledged. All errors and opinions are ours.

References

Adherents.com (2003), *Nationally Predominant Religions*, http://www.adherents.com/adh_predom.html

Albarini, A., A. Chiabia and L. Muehlenbachs (2006), 'Using Expert Judgement to Assess Adaptive Capacity to Climate Change: Evidence from a Conjoint Choice Survey', *Global Environmental Change*, **16**, 123-144.

Breman, J.G., A. Mills, R.W. Snow, J.-O. Mulligan, C. Lengeler, K. Mendis, B. Sharp, C. Morel, P. Marchesini, N.J. White, R.W. Steketee and O.K. Duombo (2006), 'Conquering Malaria' in D.T. Jamison, J.G. Breman, A.R. Measham, G. Alleyne, M. Claeson, D.B. Evans, P. Jha, A. Mills and P. Musgrove (eds.), *Disease Control Priorities in Developing Countries*, 2nd ed., Oxford University Press, Oxford.

Brenkert, A.L. and Malone, E.L., 2005: 'Modeling Vulnerability and Resilience to Climate Change: A Case Study of India and Indian States', *Climatic Change* **72**: 57-102.

Casman, E.A. and H. Dowlatabadi (2002), *Contextual Determinants of Malaria*, RFF Press, Washington, D.C.

Freedom House (2003), *Freedom in the World – Annual Survey of Political Rights and Civil Liberties*, http://www.freedomhouse.org/

Gallup, J.L. and J.D. Sachs (1999), *Geography and Economic Development*, Center for International Development, Harvard University, Cambridge, MA. http://www.cid.harvard.edu/ciddata.html

Heritage Foundation (2003), *Index of Economic Freedom*, http://www.heritage.org/Research/TradeandForeignAid/

Hofstede, G. (2001), *Culture's Consequences - Comparing Values, Behaviors, Institutions, and Organizations Across Nations*, Sage Publications, London. http://www.geert-hofstede.com/

IMAGE Team (2002), The IMAGE 2.2 implementation of the SRES scenarios, RIVM CD-ROM Publication 481508018, RIVM, Bilthoven.

Kaufmann, D., A. Kraay and P. Zoido-Lobaton (1999), *Governance Matters*, World Bank Policy Research Working Paper **2196**, Worldbank, Washington, D.C.. http://www.worldbank.org/wbi/governance/data.html

Keusch, G.T., O. Fontaine, A. Bhargava, C. Boschi-Pinto, Z.A. Bhutta, E. Gotuzzo, J. Rivera, J. Chow, S.A. Shahid-Salles and R. Laxminarayan (2006), 'Diarrheal Diseases' in D.T. Jamison, J.G. Breman, A.R. Measham, G. Alleyne, M. Claeson, D.B. Evans, P. Jha, A. Mills and P. Musgrove (eds.), *Disease Control Priorities in Developing Countries*, 2nd ed., Oxford University Press, Oxford.

Link, P.M. and R.S.J. Tol (2004), 'Possible Economic Impacts of a Shutdown of the Thermohaline Circulation: An Application of *FUND*', *Portuguese Economic Journal*, **3**, 99-114.

Marshall, M.G. and K. Jaggers (2003), *Polity IV Project: Political Regime Characteristics and Transitions, 1800-2002*, Center for International Development and Conflict Management, University of Maryland, College Park. http://www.cidm.umd.edu/inscr/polity/

Martens, W.J.M., T.H.Jetten, J.Rotmans, and L.W.Niessen (1995), 'Climate Change and Vector-Borne Diseases -- A Global Modelling Perspective', *Global Environmental Change*, **5**, (3), 195-209.

Martens, W.J.M., T.H.Jetten, and D.A.Focks (1997), 'Sensitivity of Malaria, Schistosomiasis and Dengue to Global Warming', *Climatic Change*, **35**, 145-156.

McMichael, A., A. Githeko, R. Akhtar, P. Carcavallo, D. Gubler, A. Haines, R.S. Kovats, P. Martens, J. Patz and A. Sasaki (2001), 'Human Health' in J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White (eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability – Contribution of Working Group II to the Third*

Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.
Medlin, C.A., M. Chowdhury, D.T. Jamison and A.R. Measham (2006), 'Improving the Health of Populations: Lessons of Experience' in D.T. Jamison, J.G. Breman, A.R. Measham, G. Alleyne, M. Claeson, D.B. Evans, P. Jha, A. Mills and P. Musgrove (eds.), *Disease Control Priorities in Developing Countries*, 2nd ed., Oxford University Press, Oxford.
Sachs, J.D. (2005), *The End of Poverty – Economic Possibilities for Our Time*, Penguin, New York.
Tol, R.S.J. (2002), 'New Estimates of the Damage Costs of Climate Change, Part II: Dynamic Estimates', *Environmental and Resource Economics*, **21** (1), 135-160.
Tol, R.S.J. (2005), 'Emission Abatement versus Development as Strategies to Reduce Vulnerability to Climate Change: An Application of *FUND*', *Environment and Development Economics,* **10**, 615-629.
Tol, R.S.J. (forthcoming, a), 'Climate, Development and Malaria: An Application of *FUND*', *Climatic Change*.
Tol, R.S.J. (forthcoming, b), 'Exchange Rates and Climate Change: An Application of *FUND*', *Climatic Change*.
Tol, R.S.J. and H. Dowlatabadi (2001), 'Vector-borne Diseases, Climate Change, and Economic Growth', *Integrated Assessment*, **2**, 173-181.
Tol, R.S.J. and T. Heinzow (2003), *Estimates of the External and Sustainability Costs of Climate Change*, **FNU-32,** Centre for Marine and Climate Research, Hamburg University, Hamburg.
Tol, R.S.J. and G.W. Yohe (2006), *The Weakest Link Hypothesis for Adaptive Capacity: An Empirical Test*, Research unit Sustainability and Global Change **FNU-97**, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg.
van Lieshout, M., R.S.Kovats, M.T.J.Livermore, and P.Martens (2004), 'Climate change and malaria: analysis of the SRES climate and socio-economic scenarios', *Global Environmental Change*, **14**, 87-99.
WHO (2005), 'Malaria cases (per 100,000) by country', *Global Health Atlas*, World Health Organisation, http://gamapserver.who.int/mapLibrary/Files/Maps/global_cases.jpg
WRI, 2005: *EarthTrends – The Environmental Information Portal*, World Resource Institute, Washington, D.C. http://earthtrends.wri.org/
WVS (2003), *World Values Survey*. http://www.worldvaluessurvey.org/
Yohe, G. and Tol, R.S.J., 2002: "Indicators for Social and Economic Coping Capacity - Moving Toward a Working Definition of Adaptive Capacity", *Global Environmental Change* **12**: 25-40.

Table 1. Data used in the regression analysis.

Indicator	Description	Source
Institutions		
Accountability	Political, civil and human rights	Kaufmann et al. (1999)
Autocracy	Institutionalised autocracy	Marshall and Jaggers (2003)
Civil liberties	Freedom of expression, assembly, association, education and religion	Freedom House (2003)
Executive competition	Extent to which executives are chosen through competitive elections	Marshall and Jaggers (2003)
Corruption	Petty and grand corruption, and state capture	Kaufmann et al. (1999)
Democracy	Institutionalised democracy	Marshall and Jaggers (2003)
Economic freedom	Corruption, barriers to trade, fiscal burden, regulatory burden (health, safety, environment, banking, labour)	Heritage Foundation (2003)
Government effectiveness	Competence of bureaucracy and quality of public service	Kaufmann et al. (1999)
Government quality	Quality of public institutions	Gallup and Sachs (1999)
Rule of law	Contract enforcement, quality of policy and judiciary, and crime	Kaufmann et al. (1999)
Political rights	Free and fair elections, competitive politics, opposition power, minority protection	Freedom House (2003)
Executive recruitment	Institutionalised procedure for the transfer of executive power	Marshall and Jaggers (2003)
Extent of regulation	Incidence of market-unfriendly policies	Kaufmann et al. (1999)
Political stability	Violent threats or changes in government	Kaufmann et al. (1999)
Religion		
Buddhism	Predominantly Buddhist	Adherents.com (2003)
Christianity	Predominantly Christian	Adherents.com (2003)
Hinduism	Predominantly Hindu	Adherents.com (2003)
Islam	Predominantly Moslem	Adherents.com (2003)
Yorubaism	Predominantly Yoruba	Adherents.com (2003)
Animalism and spiritism	Predominantly Animist	Adherents.com (2003)
Culture		
Individualism	Reinforcement of individual achievement and interpersonal relationships	Hofstede (2001)
Masculinity	Degree of gender differentiation and male dominance	Hofstede (2001)
Uncertainty avoidance	Tolerance of uncertainty and ambiguity	Hofstede (2001)
Power distance	Degree of inequality in power	Hofstede (2001)

	and wealth	
Long-term orientation	Degree of orientation on the future	Hofstede (2001)
Trust	Degree of trust of others	WVS (2003)
Economics		
Gini coefficient	Degree of income inequality	WRI (2005)
Absolute poverty	Percentage of population living on less than $1/day	WRI (2005)
Relative poverty	Percentage of population below national poverty line	WRI (2005)
Per capita income	Per capita GDP, purchasing power parity exchange rate	WRI (2005)
Education		
Primary	Total enrolment relative to school-age population, primary education	WRI (2005)
Secondary	Total enrolment relative to school-age population, primary education	WRI (2005)
Tertiary	Total enrolment relative to school-age population, primary education	WRI (2005)
Literacy	Percentage of the population over 15 able to read and write	WRI (2005)

Table 2. Summary results for climate-change induced malaria and initial conditions for various countries.

Country	Infant mortality[a]	Income per capita[b]	Literacy[c]	Poverty[d]	Peak level[e]	Peak year[f]	2100 level[g]
Nigeria	81	986	56	31	807	2035	77
Botswana	56	6440	73	33	430	2020	2060*
Ethiopia	113	435	33	46	1153	2050	459
Kenya	74	1128	77	50	743	2040	55
Lesotho	96	1685	81	49	671	2035	2100*
Madagascar	96	1641	39	31	766	2035	127
Mauritania	97	1641	39	31	795	2035	2100*
Niger	121	825	14	61	1200	2030	493
Rwanda	134	770	60	46	814	2050	169
Senegal	73	1595	33	54	817	2035	11
South Africa	51	6789	83	24	398	2020	2060*
Uganda	98	973	62	69	752	2035	90
Zambia	111	853	73	85	763	2045	145
Zimbabwe	61	2025	85	41	654	2030	2090*

Notes:

[a] Measured in number per 1000 people.
[b] Per capita GDP measured in PPP$.
[c] Measured as percentage of people over 15 years of age who can read and write.
[d] Measured in percentage of people living on less than $1 per day.
[e] Peak incidence of climate-change-induced malaria indexed so that year 2000 levels = 100.
[f] Year when peak incidence of climate-change-induced malaria is felt.
[g] Incidence of climate-change-induced malaria in the year 2100 (indexed so that year 2000 levels = 100) or (given *) the year when incidence goes to zero.

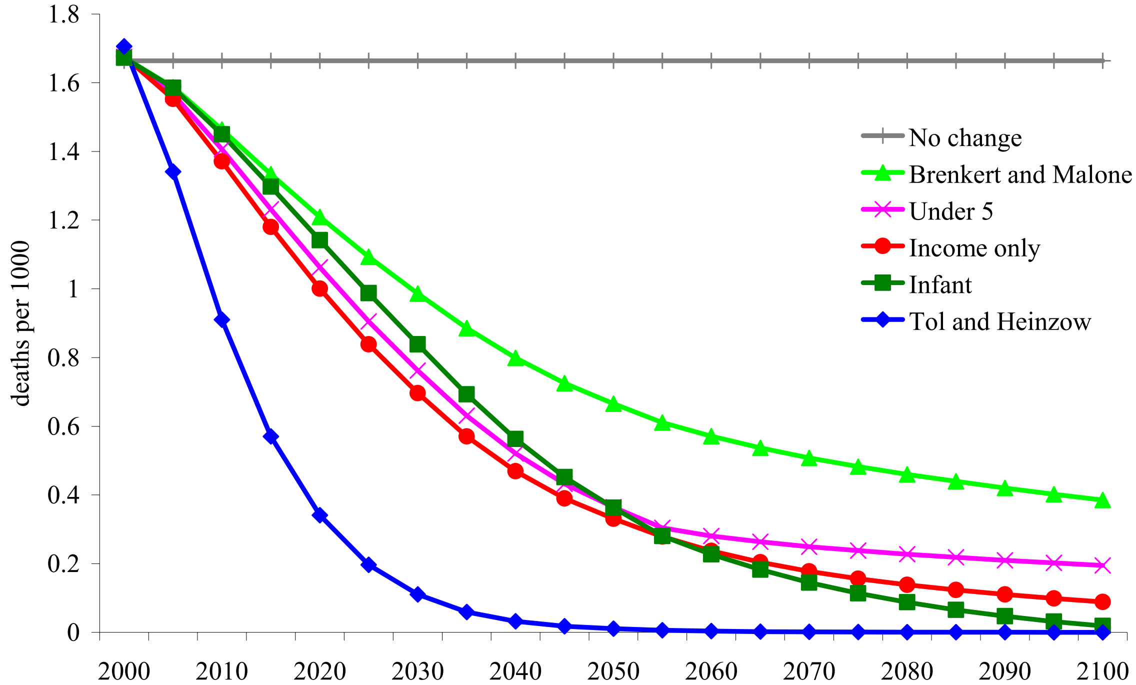

Figure 1. Malaria incidence (deaths per thousand) in Nigeria according to the SRES A1B scenario of development, with six alternative models of adaptive capacity.

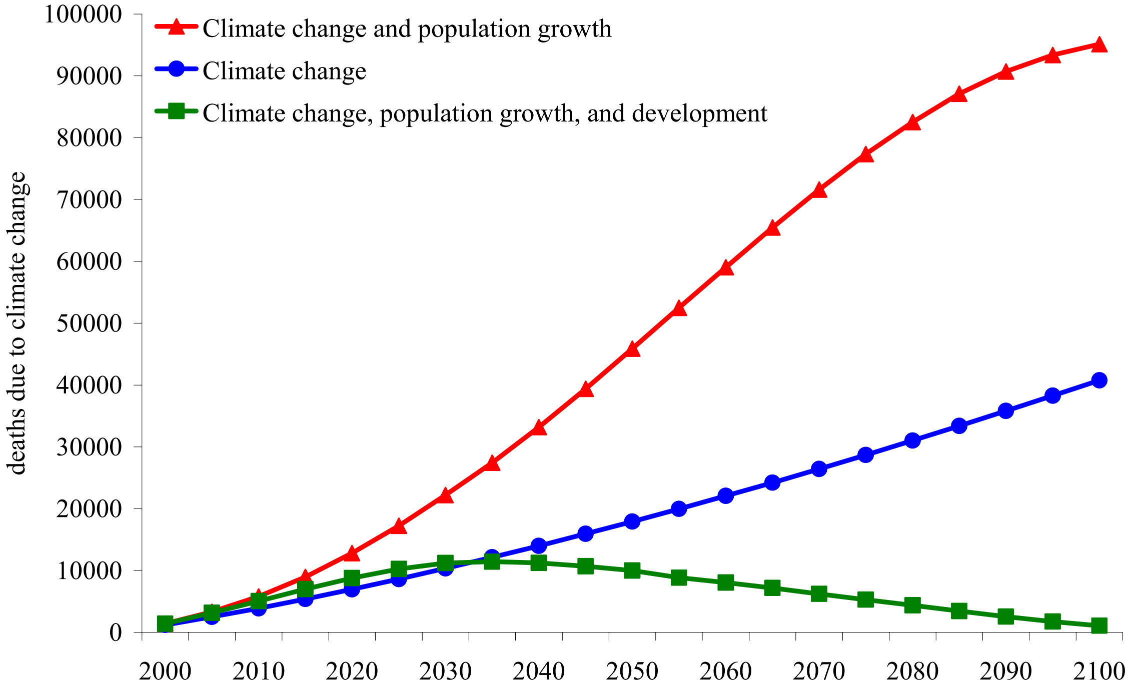

Figure 2. Number of climate-change-induced malaria deaths in Nigeria according to the three main components of the SRES A1B scenario.

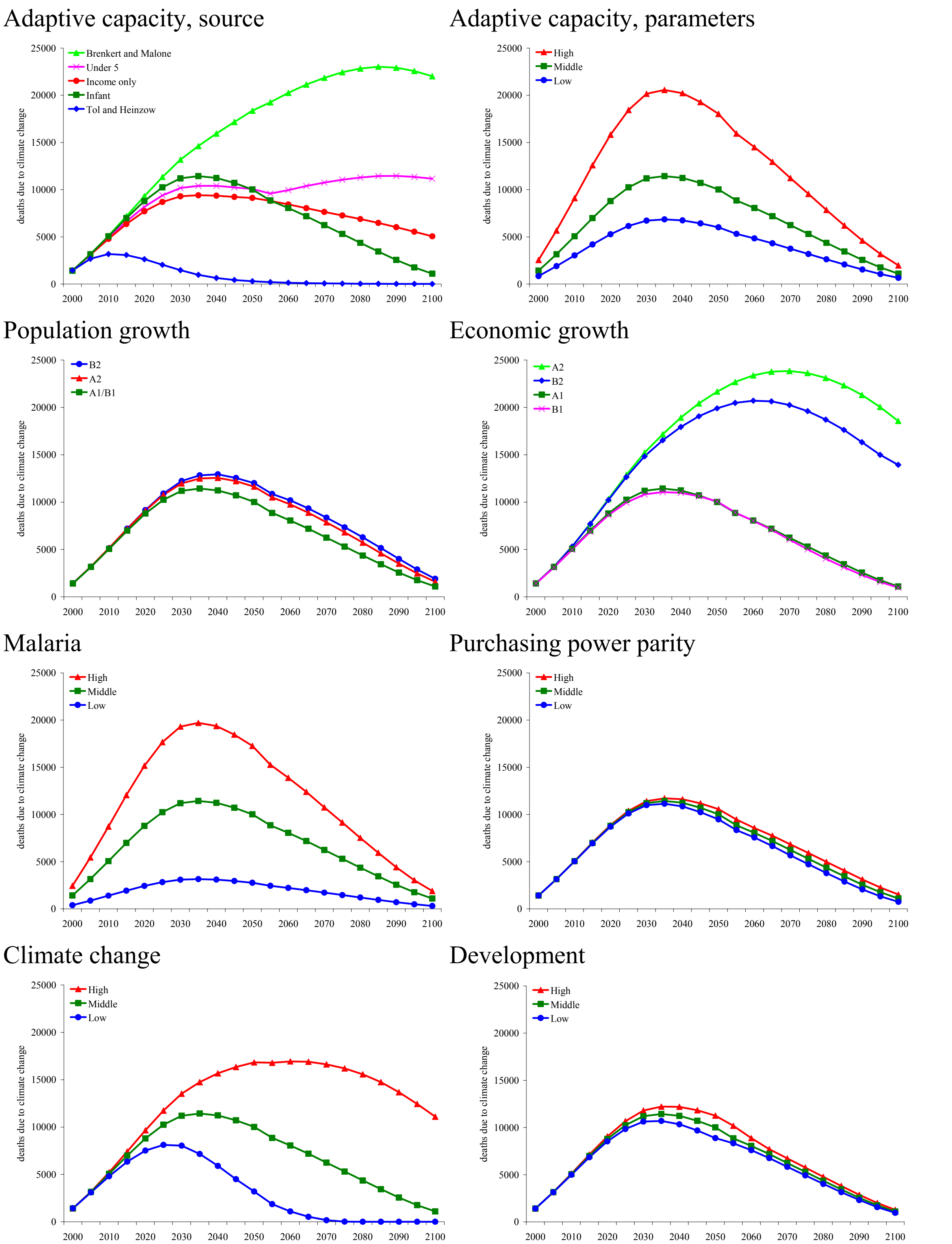

Figure 3. Number of climate-change-induced malaria deaths in Nigeria for a range of sensitivity analyses; in “adaptive capacity, source”, five alternative models are used (see text), with “infant mortality” as the base case; in “adaptive capacity, parameters”, the parameters of infant mortality are varied between their mean plus and minus their standard deviation; in “population”, three alternative projections of population growth are used; in “economic growth”, four alternative projections of economic growth are used, with “A1” as the base case; in “malaria”, the malaria sensitivity is varied between the mean plus and minus the standard deviation; in “purchasing power parity”, the income elasticity of purchasing power

parity is varied between its mean plus or minus its standard deviation; in “climate change”, the climate sensitivity is varied between 1.5ºC, 2.5ºC (the base case) and 4.5ºC; and in “development”, the income elasticities of literacy and poverty are varied between the mean plus and minus the standard deviation.

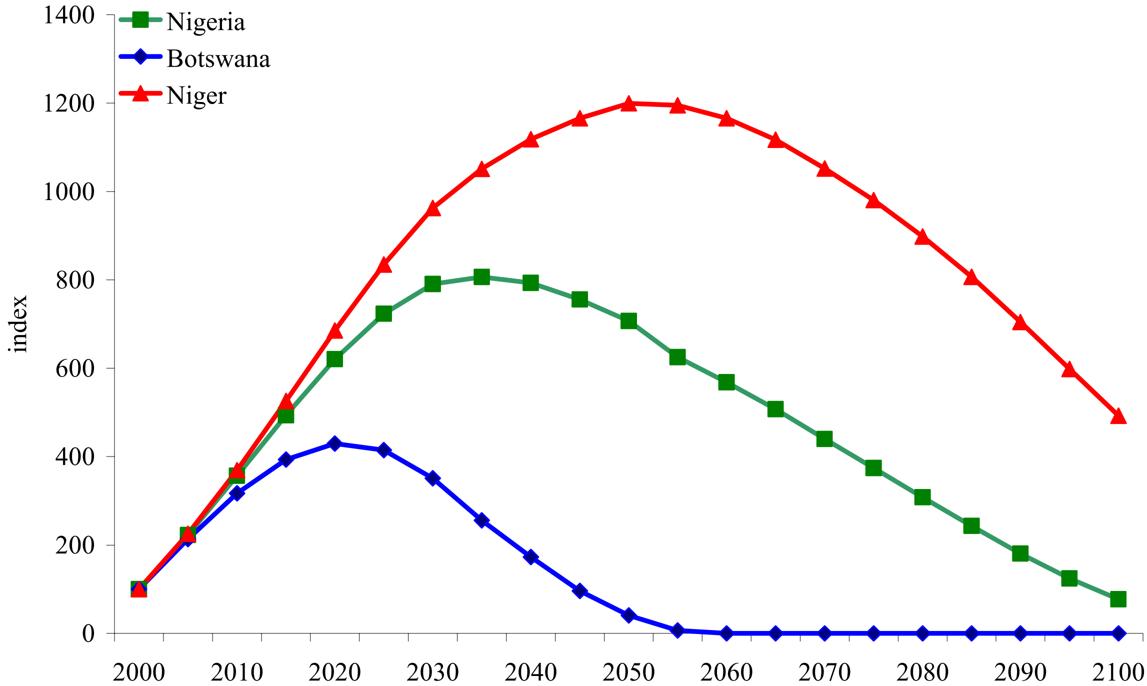

Figure 4. Index (2000=100) of climate-change-induced malaria deaths in Botswana, Niger, and Nigeria according to the SRES A1B scenario.

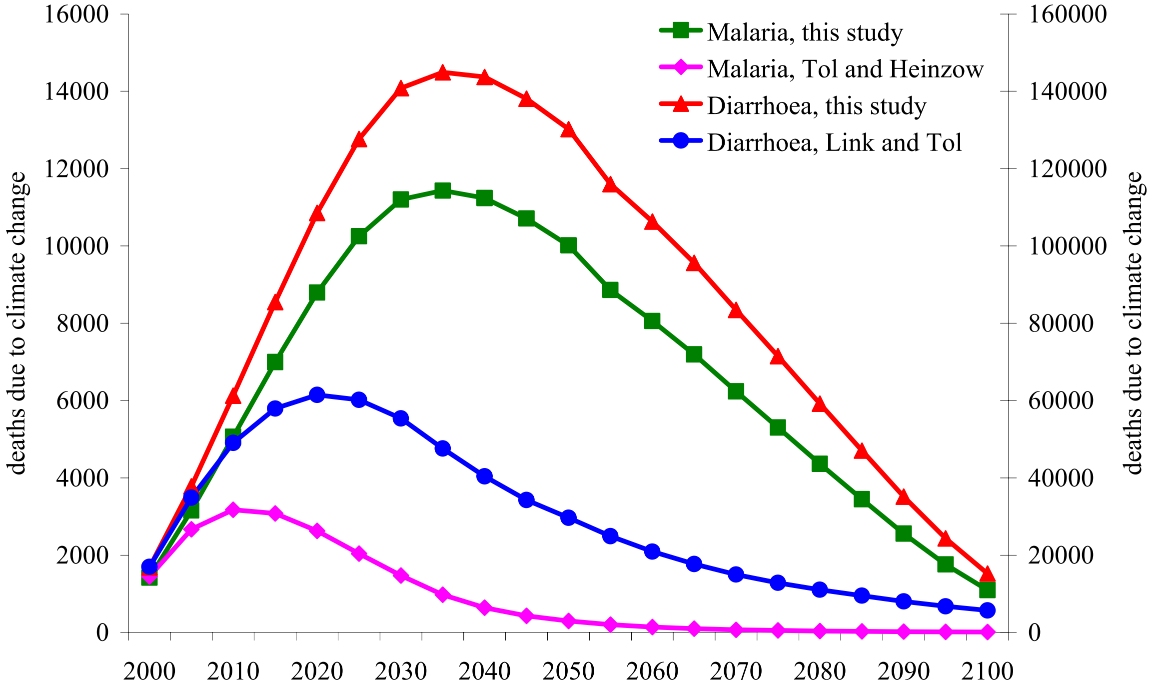

Figure 5. Number of climate-change-induced deaths due to malaria (left axis) and diarrhoea (right axis) in Nigeria according to the SRES A1B scenario and two alternative scenarios of adaptive capacity.

Working Papers

Research Unit Sustainability and Global Change

Hamburg University and Centre for Marine and Atmospheric Science

Tol, R.S.J., K.L. Ebi and G.W. Yohe (2006), *Infectious Disease, Development, and Climate Change: A Scenario Analysis*, **FNU-109** (submitted).

Lau, M.A. (2006), *An analysis of the travel motivation of tourists from the People's Republic of China,* **FNU-108** (submitted).

Lau, M.A. and R.S.J. Tol (2006), *The Chinese are coming – An analysis of the preferences of Chinese holiday makers at home and abroad*, **FNU-107** (submitted).

Röckmann, C., R.S.J. Tol, U.A. Schneider, and M.A. St.John (2006), *Rebuilding the Eastern Baltic cod stock under environmental change - Part II: The economic viability of a marine protected area.* **FNU-106** (submitted)

Ronneberger, K., M. Berrittella, F. Bosello and R.S.J. Tol (2006), *KLUM@GTAP: Introducing biophysical aspects of land-use decisions into a general equilibrium model. A coupling experiment,* **FNU-105** (submitted).

Link, P.M. and Tol, R.S.J. (2006), *Economic impacts on key Barents Sea fisheries arising from changes in the strength of the Atlantic thermohaline circulation*, **FNU-104** (submitted).

Link, P.M. and Tol, R.S.J. (2006), *The economic impact of a shutdown of the Thermohaline Circulation: an application of FUND*, **FNU-103** (submitted).

Tol, R.S.J. (2006), *Integrated Assessment Modelling*, **FNU-102** (submitted).

Tol, R.S.J. (2006), *Carbon Dioxide Emission Scenarios for the USA*, **FNU-101** (submitted).

Tol, R.S.J., S.W. Pacala and R.H. Socolow (2006), *Understanding Long-Term Energy Use and Carbon Dioxide Emissions in the USA*, **FNU-100** (submitted).

Sesabo, J.K, H. Lang and R.S.J. Tol (2006), *Perceived Attitude and Marine Protected Areas (MPAs) establishment: Why households' characteristics matters in Coastal resources conservation initiatives in Tanzania*, **FNU-99** (submitted).

Tol, R.S.J. (2006), *The Polluter Pays Principle and Cost-Benefit Analysis of Climate Change: An Application of* FUND, **FNU-98** (submitted)

Tol, R.S.J. and G.W. Yohe (2006), *The Weakest Link Hypothesis for Adaptive Capacity: An Empirical Test*, **FNU-97** (submitted, *Global Environmental Change*)

Berrittella, M., K. Rehdanz, R.Roson and R.S.J. Tol (2005), *The Economic Impact of Water Pricing: A Computable General Equilibrium Analysis*, **FNU-96** (submitted)

Sesabo, J.K. and R. S. J. Tol (2005), *Technical Efficiency and Small-scale Fishing Households in Tanzanian coastal Villages: An Empirical Analysis*, **FNU-95** (submitted)

Lau, M.A. (2005), *Adaptation to Sea-level Rise in the People's Republic of China – Assessing the Institutional Dimension of Alternative Organisational Frameworks*, **FNU-94** (submitted)

Berrittella, M., A.Y. Hoekstra, K. Rehdanz, R.Roson and R.S.J. Tol (2005), *The Economic Impact of Restricted Water Supply: A Computable General Equilibrium Analysis*, **FNU-93** (submitted)

Tol, R.S.J. (2005), *Europe's Long Term Climate Target: A Critical Evaluation*, **FNU-92** (forthcoming, *Energy Policy*)

Hamilton, J.M. (2005), *Coastal Landscape and the Hedonic Price of Accomodation*, **FNU-91** (submitted)

Hamilton, J.M., D.J. Maddison and R.S.J. Tol (2005), *Climate Preferences and Destination Choice: A Segmentation Approach*, **FNU-90** (submitted)

Zhou, Y. and R.S.J. Tol (2005), *Valuing the Health Impacts from Particulate Air Pollution in Tianjin*, **FNU-89** (submitted)

Röckmann, C. (2005), *International Cooperation for Sustainable Fisheries in the Baltic Sea,* **FNU-88** (forthcoming, in Ehlers,P./Lagoni,R. (Eds.): *International Maritime Organisations and their Contribution towards a Sustainable Marine Development.*)

Ceronsky, M., D. Anthoff, C. Hepburn and R.S.J. Tol (2005), *Checking the price tag on catastrophe: The social cost of carbon under non-linear climate response* **FNU-87** (submitted, *Climatic Change*)

Zandersen, M. and R.S.J. Tol (2005), *A Meta-analysis of Forest Recreation Values in Europe,* **FNU-86** (submitted, *Journal of Environmental Management*)

Heinzow, T., R.S.J. Tol and B. Brümmer (2005), Offshore-Windstromerzeugung in der Nordsee -eine ökonomische und ökologische Sackgasse? **FNU-85** (*Energiewirtschaftliche Tagesfragen*, **56** (3), 68-73)

Röckmann, C., U.A. Schneider, M.A. St.John, and R.S.J. Tol (2005), *Rebuilding the Eastern Baltic cod stock under environmental change - a preliminary approach using stock, environmental, and management constraints,* **FNU-84** (forthcoming, *Natural Resource Modeling*)

Tol, R.S.J. and G.W. Yohe (2005), *Infinite uncertainty, forgotten feedbacks, and cost-benefit analysis of climate policy,* **FNU-83** (submitted, *Climatic Change*)

Osmani, D. and R.S.J. Tol (2005), *The case of two self-enforcing international agreements for environmental protection*, **FNU-82** (submitted)

Schneider, U.A. and B.A. McCarl, (2005), *Appraising Agricultural Greenhouse Gas Mitigation Potentials: Effects of Alternative Assumptions*, **FNU-81** (submitted)

Zandersen, M., M. Termansen, and F.S. Jensen, (2005), *Valuing new forest sites over time: the case of afforestation and recreation in Denmark,* **FNU-80** (submitted)

Guillerminet, M.-L. and R.S.J. Tol (2005), *Decision making under catastrophic risk and learning: the case of the possible collapse of the West Antarctic Ice Sheet*, **FNU-79** (submitted, *Climatic Change*)

Nicholls, R.J., R.S.J. Tol and A.T. Vafeidis (2005), *Global estimates of the impact of a collapse of the West Antarctic Ice Sheet: An application of FUND,* **FNU-78** (submitted, *Climatic Change*)

Lonsdale, K., T.E. Downing, R.J. Nicholls, D. Parker, A.T. Vafeidis, R. Dawson and J.W. Hall (2005), *Plausible responses to the threat of rapid sea-level rise for the Thames Estuary,* **FNU-77** (submitted, *Climatic Change*)

Poumadère, M., C. Mays, G. Pfeifle with A.T. Vafeidis (2005), *Worst Case Scenario and Stakeholder Group Decision: A 5-6 Meter Sea Level Rise in the Rhone Delta, France,* **FNU-76** (submitted, *Climatic Change*)

Olsthoorn, A.A., P.E. van der Werff, L.M. Bouwer and D. Huitema (2005), *Neo-Atlantis: Dutch Responses to Five Meter Sea Level Rise,* **FNU-75** (submitted, *Climatic Change*)

Toth, F.L. and E. Hizsnyik (2005), *Managing the inconceivable: Participatory assessments of impacts and responses to extreme climate change*, **FNU-74** (submitted)

Kasperson, R.E. M.T. Bohn and R. Goble (2005), *Assessing the risks of a future rapid large sea level rise: A review,* **FNU-73** (submitted, *Climatic Change*)

Schleupner, C. (2005), *Evaluation of coastal squeeze and beach reduction and its consequences for the Caribbean island Martinique,* **FNU-72** (submitted)

Schleupner, C. (2005), *Spatial Analysis As Tool for Sensitivity Assessment of Sea Level Rise Impacts on Martinique,* **FNU-71** (submitted)

Sesabo, J.K. and R.S.J. Tol (2005), *Factors affecting Income Strategies among households in Tanzanian Coastal Villages: Implication for Development-Conservation Initiatives,* **FNU-70** (submitted)

Fisher, B.S., G. Jakeman, H.M. Pant, M. Schwoon. and R.S.J. Tol (2005), *CHIMP: A Simple Population Model for Use in Integrated Assessment of Global Environmental Change*, **FNU-69** (forthcoming, *Integrated Assessment Journal*)

Rehdanz, K. and R.S.J. Tol (2005), *A No Cap But Trade Proposal for Greenhouse Gas Emission Reduction Targets for Brazil, China and India*, **FNU-68** (submitted)

Zhou, Y. and R.S.J. Tol (2005), *Water Use in China's Domestic, Industrial and Agricultural Sectors: An Empirical Analysis*, **FNU-67** (*Water Science and Technoloy: Water Supply*, **5** (6), 85-93)

Rehdanz, K. (2005), *Determinants of Residential Space Heating Expenditures in Germany*, **FNU-66** (forthcoming, *Energy Economics*)

Ronneberger, K., R.S.J. Tol and U.A. Schneider (2005), *KLUM: A Simple Model of Global Agricultural Land Use as a Coupling Tool of Economy and Vegetation,* **FNU-65** (submitted, *Climatic Change*)

Tol, R.S.J. (2005), *The Benefits of Greenhouse Gas Emission Reduction: An Application of* FUND, **FNU-64** (submitted, *Global Environmental Change*)

Röckmann, C., M.A. St.John, U.A. Schneider, F.W. Köster, F.W. and R.S.J. Tol (2006), *Testing the implications of a permanent or seasonal marine reserve on the population dynamics of Eastern Baltic cod under varying environmental conditions,* **FNU-63-revised** (submitted)

Letsoalo, A., J. Blignaut, T. de Wet, M. de Wit, S. Hess, R.S.J. Tol and J. van Heerden (2005), *Triple Dividends of Water Consumption Charges in South Africa*, **FNU-62** (submitted, *Water Resources Research*)

Zandersen, M., Termansen, M., Jensen,F.S. (2005), *Benefit Transfer over Time of Ecosystem Values: the Case of Forest Recreation,* **FNU-61** (submitted)

Rehdanz, K., Jung, M., Tol, R.S.J. and Wetzel, P. (2005), *Ocean Carbon Sinks and International Climate Policy*, **FNU-60** (forthcoming, *Energy Policy*)

Schwoon, M. (2005), *Simulating the Adoption of Fuel Cell Vehicles*, **FNU-59** (submitted)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2005), *The Impact of Climate Change on Domestic and International Tourism: A Simulation Study*, **FNU-58** (submitted)

Bosello, F., R. Roson and R.S.J. Tol (2004), *Economy-wide estimates of the implications of climate change: Human health*, **FNU-57** (forthcoming, *Ecological Economics*)

Hamilton, J.M. and M.A. Lau (2004) *The role of climate information in tourist destination choice decision-making,* **FNU-56** (forthcoming, Gössling, S. and C.M. Hall (eds.), Tourism and Global Environmental Change. London: Routledge)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2004), *The impact of climate on holiday destination choice*, **FNU-55** (forthcoming, *Climatic Change*)

Bigano, A., J.M. Hamilton, M. Lau, R.S.J. Tol and Y. Zhou (2004), *A global database of domestic and international tourist numbers at national and subnational level*, **FNU-54** (submitted)

Susandi, A. and R.S.J. Tol (2004), *Impact of international emission reduction on energy and forestry sector of Indonesia*, **FNU-53** (submitted)

Hamilton, J.M. and R.S.J. Tol (2004), *The Impact of Climate Change on Tourism and Recreation*, **FNU-52** (forthcoming, Schlesinger et al. (eds.), Cambridge University Press)

Schneider, U.A. (2004), *Land Use Decision Modelling with Soil Status Dependent Emission Rates*, **FNU-51** (submitted)

Link, P.M., U.A. Schneider and R.S.J. Tol (2004), *Economic impacts of changes in fish population dynamics: the role of the fishermen's harvesting strategies*, **FNU-50** (submitted)

Berritella, M., A. Bigano, R. Roson and R.S.J. Tol (2004), *A General Equilibrium Analysis of Climate Change Impacts on Tourism*, **FNU-49** (forthcoming, *Tourism Management*)

Tol, R.S.J. (2004), *The Double Trade-Off between Adaptation and Mitigation for Sea Level Rise: An Application of* FUND, **FNU-48** (forthcoming, *Mitigation and Adaptation Strategies for Global Change*)

Erdil, Erkan and Yetkiner, I. Hakan (2004), *A Panel Data Approach for Income-Health Causality,* **FNU-47**

Tol, R.S.J. (2004), *Multi-Gas Emission Reduction for Climate Change Policy: An Application of* FUND, **FNU-46** (forthcoming, *Energy Journal*)

Tol, R.S.J. (2004), *Exchange Rates and Climate Change: An Application of* FUND*,* **FNU-45** (forthcoming, *Climatic Change*)

Gaitan, B., Tol, R.S.J, and Yetkiner, I. Hakan (2004), *The Hotelling's Rule Revisited in a Dynamic General Equilibrium Model*, **FNU-44** (submitted)

Rehdanz, K. and Tol, R.S.J (2004), *On Multi-Period Allocation of Tradable Emission Permits*, **FNU-43** (submitted)

Link, P.M. and Tol, R.S.J. (2004), *Possible Economic Impacts of a Shutdown of the Thermohaline Circulation: An Application of* FUND, **FNU-42** (*Portuguese Economic Journal*, **3**, 99-114)

Zhou, Y. and Tol, R.S.J. (2004), *Evaluating the costs of desalination and water transport,* **FNU-41** (f*Water Resources Research,* **41** (3), W03003)

Lau, M. (2004), *Küstenzonenmanagement in der Volksrepublik China und Anpassungsstrategien an den Meeresspiegelanstieg,***FNU-40** (*Coastline Reports*, Issue 1, pp.213-224.)

Rehdanz, K. and Maddison, D. (2004), *The Amenity Value of Climate to German Households*, **FNU-39** (submitted)

Bosello, F., Lazzarin, M., Roson, R. and Tol, R.S.J. (2004), *Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise*, **FNU-38** (submitted, *Environmental and Resource Economics*)

Schwoon, M. and Tol, R.S.J. (2004), *Optimal CO_2-abatement with socio-economic inertia and induced technological change*, **FNU-37** (submitted, *Energy Journal*)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2004), *The Effects of Climate Change on International Tourism,* **FNU-36** (*Climate Research*, **29**, 255-268)

Hansen, O. and R.S.J. Tol (2003), *A Refined Inglehart Index of Materialism and Postmaterialism*, **FNU-35** (submitted)

Heinzow, T. and R.S.J. Tol (2003), *Prediction of Crop Yields across four Climate Zones in Germany: An Artificial Neural Network Approach,* **FNU-34** (submitted, *Climate Research*)

Tol, R.S.J. (2003), *Adaptation and Mitigation: Trade-offs in Substance and Methods,* **FNU-33** (*Environmental Science and Policy*, **8** (6), 572-578)

Tol, R.S.J. and T. Heinzow (2003), *Estimates of the External and Sustainability Costs of Climate Change*, **FNU-32** (submitted)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2003), *Climate change and international tourism: a simulation study,* **FNU-31** (*Global Environmental Change,* **15** (3), 253-266)

Link, P.M. and R.S.J. Tol (2003), *Economic impacts of changes in population dynamics of fish on the fisheries in the Barents Sea*, **FNU-30** (*ICES Journal of Marine Science*, **63** (4), 611-625)

Link, P.M. (2003), *Auswirkungen populationsdynamischer Veränderungen in Fischbeständen auf die Fischereiwirtschaft in der Barentssee*, **FNU-29** (*Essener Geographische Arbeiten*, **35**, 179-202)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – An Assessment of Structural Impacts on Decision-making Processes*, **FNU-28** (*Ocean & Coastal Management*, No. 48 (2005), pp. 115-159.)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – A Unique Approach?*, **FNU-27** (*China Environment Series,* Issue 6, pp. 120-124; http://www.wilsoncenter.org/topics/pubs/7-commentaries.pdf)

Roson, R. and R.S.J. Tol (2003), *An Integrated Assessment Model of Economy-Energy-Climate – The Model Wiagem: A Comment*, **FNU-26** (*Integrated Assessment,* **6** (1), 75-82)

Yetkiner, I.H. (2003), *Is There An Indispensable Role For Government During Recovery From An Earthquake? A Theoretical Elaboration*, **FNU-25**

Yetkiner, I.H. (2003), *A Short Note On The Solution Procedure Of Barro And Sala-i-Martin for Restoring Constancy Conditions*, **FNU-24**

Schneider, U.A. and B.A. McCarl (2003), *Measuring Abatement Potentials When Multiple Change is Present: The Case of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry*, **FNU-23** (submitted)

Zhou, Y. and Tol, R.S.J. (2003), *The Implications of Desalination to Water Resources in China - an Economic Perspective*, **FNU-22** (*Desalination*, **163** (4), 225-240)

Yetkiner, I.H., de Vaal, A., and van Zon, A. (2003), *The Cyclical Advancement of Drastic Technologies*, **FNU-21**

Rehdanz, K. and Maddison, D. (2003) *Climate and Happiness*, **FNU-20** (*Ecological Economics,* **52** 111-125)

Tol, R.S.J., (2003), *The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties*, **FNU-19** (*Energy Policy,* **33** (16), 2064-2074).

Lee, H.C., B.A. McCarl, U.A. Schneider, and C.C. Chen (2003), *Leakage and Comparative Advantage Implications of Agricultural Participation in Greenhouse Gas Emission Mitigation*, **FNU-18** (submitted).

Schneider, U.A. and B.A. McCarl (2003), *Implications of a Carbon Based Energy Tax for U.S. Agriculture*, **FNU-17** (submitted).

Tol, R.S.J. (2002), *Climate, Development, and Malaria: An Application of* FUND, **FNU-16** (forthcoming, *Climatic Change*).

Hamilton, J.M. (2003), *Climate and the Destination Choice of German Tourists,* **FNU-15** (revised and submitted).

Tol, R.S.J. (2002), *Technology Protocols for Climate Change: An Application of* FUND, **FNU-14** (*Climate Policy,* **4**, 269-287).

Rehdanz, K (2002), *Hedonic Pricing of Climate Change Impacts to Households in Great Britain*, **FNU-13** (forthcoming, *Climatic Change*).

Tol, R.S.J. (2002), *Emission Abatement Versus Development As Strategies To Reduce Vulnerability To Climate Change: An Application Of* FUND, **FNU-12** (forthcoming, *Environment and Development Economics*).

Rehdanz, K. and Tol, R.S.J. (2002), *On National and International Trade in Greenhouse Gas Emission Permits*, **FNU-11** (*Ecological Economics*, **54**, 397-416).

Fankhauser, S. and Tol, R.S.J. (2001), *On Climate Change and Growth*, **FNU-10** (*Resource and Energy Economics*, **27**, 1-17).

Tol, R.S.J.and Verheyen, R. (2001), *Liability and Compensation for Climate Change Damages – A Legal and Economic Assessment*, **FNU-9** (*Energy Policy*, **32** (9), 1109-1130).

Yohe, G. and R.S.J. Tol (2001), *Indicators for Social and Economic Coping Capacity – Moving Toward a Working Definition of Adaptive Capacity*, **FNU-8** (*Global Environmental Change*, **12** (1), 25-40).

Kemfert, C., W. Lise and R.S.J. Tol (2001), *Games of Climate Change with International Trade*, **FNU-7** (*Environmental and Resource Economics*, **28**, 209-232).

Tol, R.S.J., W. Lise, B. Morel and B.C.C. van der Zwaan (2001), *Technology Development and Diffusion and Incentives to Abate Greenhouse Gas Emissions*, **FNU-6** (submitted).

Kemfert, C. and R.S.J. Tol (2001), *Equity, International Trade and Climate Policy*, **FNU-5** (*International Environmental Agreements*, **2**, 23-48).

Tol, R.S.J., Downing T.E., Fankhauser S., Richels R.G. and Smith J.B. (2001), *Progress in Estimating the Marginal Costs of Greenhouse Gas Emissions*, **FNU-4**. (*Pollution Atmosphérique – Numéro Spécial: Combien Vaut l'Air Propre?*, 155-179).

Tol, R.S.J. (2000), *How Large is the Uncertainty about Climate Change?*, **FNU-3** (*Climatic Change*, **56** (3), 265-289).

Tol, R.S.J., S. Fankhauser, R.G. Richels and J.B. Smith (2000), *How Much Damage Will Climate Change Do? Recent Estimates*, **FNU-2** (*World Economics,* **1** (4), 179-206)

Lise, W. and R.S.J. Tol (2000), *Impact of Climate on Tourism Demand*, **FNU-1** (*Climatic Change*, **55** (4), 429-449).