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Burden Sharing in the Context of Global Climate Change

A North-South Perspective

NERI Technical Report, No. 424

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Data sheet

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Abstract: This report explores some of the key issues related to distributional fairness and international burden sharing in the context of global climate change. A conceptual understanding of burdens going beyond costs of emission reductions and including damages of climate change and adaptation to climate change is suggested and aspects of adaptation measures, incentives to adapt, and barriers to adaptation discussed. Methods for regional differentiation of burdens and the inclusion of adaptation in vulnerability and integrated impact assessment are also explored.

Keywords: Climate change, burden sharing, vulnerability, adaptation, distributional fairness, integrated assessment models

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Abbreviations

CBA	Cost-benefit analysis
CDM	Clean Development Mechanism
CEA	Cost-effectiveness analysis
CETA	Carbon Emissions Trajectory Assessment
CGE	Computable general equilibrium model
CO_2	Carbon dioxide
COP-6	Sixth Conference of the Parties to the UNFCCC
CVI	Composite Vulnerability Index
EVI	Environmental Vulnerability Index
FARM	Future Agricultural Resource Model
FUND	Climate Framework for Uncertainty, Negotiation, and Distribution
GCM	General circulation model
GDP	Gross domestic product
GEF	Global Environment Facility
GHG	Greenhouse gases
GIS	Geographic information system
GIM	Global Impact Model
GNP	Gross national product
IAM	Integrated Assessment Model
ICAM	Integrated Climate Assessment Model
IPCC	Inter-governmental Panel on Climate Change
LDCs	Least developed countries
MARIA	Multiregional Approach for Resource and Industry Allocation Model
MERGE	Model for Evaluating Regional and Global Effects of GHG Reduction Policies
MiniCAM	Mini Change Assessment Model
OECD	Organization for Economic Co-Operation and Development
PAGE	Policy Analysis of the Greenhouse Effect
RICE	Regional Integrated Climate and Economy Model
SAR	Second Assessment Report
TAR	Third Assessment Report
UNFCCC	United Nations Framework Convention on Climate Change
VRIP	Vulnerability-Resilience Indicator Prototype
WTP	Willingness to pay

Preface

This report explores a concept of burdens that goes beyond costs of emission reductions and includes damages of climate change and adaptation to climate change. The report discusses adaptation meaures, incentives to adapt, and barriers to adaptation. Methods for regional differentiation of burdens and the inclusion of adaptation in vulnerability and integrated impact assessment are also explored.

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Summary

This report explores some of the key issues related to distributional fairness and international burden sharing in the context of global climate change. It is critical of the fact that climate change often is reduced to a question of lowering emissions of greenhouse gases, and by implication, that burden sharing and international cost allocation become a question of how to fairly distribute emission reductions and abatement costs among OECD countries. It is instead important to place burden sharing issues in an extended framework that includes damages of climate change and adaptation costs and better integrates the developing countries.

Some studies have identified a fairly large number of distributional fairness principles or norms. This report discusses four generally accepted norms of distributive fairness: responsibility, capacity, need, and contribution. The first norm states that those who have caused the problem are responsible for solving it. According to the second principle, countries that have greater capacity or ability to solve a joint problem should contribute more than countries with less capacity and ability. The third norm deals with the issue of basic human needs, the individual's 'right' to a certain minimum of social and economic welfare and thus a certain emission welfare. The norm of need would establish an equal level of greenhouse gas emissions per capacity in all countries, irrespective of the existing levels. According to the fourth norm, states should contribute in some proportion to the benefits of concerted collective action. The report further discusses how governments have addressed issues of fairness, differentiation, and burden sharing in the negotiations on the 1997 Kyoto Protocol and it is pointed out that these issues have until now almost exclusively been considered in the context of industrialized countries. There are thus few indications of which distributional fairness norms and burden sharing arrangements governments possibly could accept played a role in future attempts to bring developing countries into burden sharing arrangements under the UNFCCC.

Adaptation to climate change has been given some attention in the IPCC's *Third Assessment Report*. It is stressed that adaptive capacity is an important dimension in understanding countries' vulnerability to climate change. Vulnerability has also attracted attention as a way to approach the question of 'dangerous level' of climate change at the regional level. Vulnerability assessment is discussed in terms of its constitutive factors - which often are viewed as combinations of exposure, sensitivity, and adaptive capacity - and in terms of indicator development. Indicators of vulnerability to climate change are only in their infancy but experience from natural hazards and food security management is used to develop indicators further. The report also describes efforts to develop a vulnerability indicator with input from an impact assessment model.

Adaptation may take place autonomously by economic agents or may be induced by decision-makers responding to scenarios or

indications of climate change. The report examines some of the key issues with regard to possible adaptive responses. The inevitability of adaptation to climate change is underlined by recent studies showing that the Kyoto targets, even if fully implemented, will reduce global warming only slightly. The attractiveness of adaptive measures is discussed in the context of the inflicted costs due to climate change damages, cost of adaptation measures, actual criticality, adequacy of existing technologies, etc.

Integrated assessment models are examined from the perspective of including adaptive measures and efforts to address regional variation in impact assessment. Some progress has been made on these aspects since the IPCC's *Second Assessment Report*. Yet, climate models are still too coarse to provide regional and national scale input to more detailed impact modelling, and the uncertainties associated with impact models are discussed together with the problems of transferring models from developed to developing countries.

The question of which distributional fairness norms could be relevant from the perspective of climate damage costs and developing country eligibility to damage compensation or adaptation funding is finally discussed. The principles discussed in the context of international sharing of mitigation costs would seem to constitute a relevant set of starting points when considering who should pay for the economic losses due to climate change and for the costs of adaptation projects and programs. Regarding the question of the distribution of the means available for compensation and adaptation funding, four different approaches are discussed: equality, vulnerability to climate change, economic efficiency/cost-effectiveness, and contribution to mitigation efforts. It is noted that these principles would have quite different distributional implications for developing countries.

Dansk sammenfatning

Denne rapport diskuterer udvalgte emner vedrørende fordelingsretfærdighed og international byrdefordeling i relation til globale klimaforandringer. Det kritiseres i rapporten, at det globale opvarmningsproblem ofte reduceres til et spørgsmål om at reducere emissioner af drivhusgasser, og at byrdefordeling og international omkostningsfordeling udelukkende ses som et spørgsmål om opnåelse af en retfærdig fordeling af reduktionsomkostninger mellem OECD-lande. Det er i stedet vigtigt at analysere byrdefordeling indenfor en udvidet begrebsramme, som omfatter omkostninger ved skader som resultat af klimaforandringer og tilpasningsaktiviteter, og som inddrager udviklingslandene som centrale aktører.

En række studier har identificeret et rimeligt stort antal ganske specifikke principper for fordelingsretfærdighed i forhold til klimaforandring. Denne rapport fokuserer i stedet på fire generelle principper eller normer for fordelingsretfærdighed, nemlig ansvar, kapacitet, behov og bidrag. Ansvarsprincippet betyder, at det er dem som har forårsaget et problem, som er ansvarlig for at løse problemet. Ifølge kapacitetsprincippet skal lande, som har mere kapacitet eller 'evne' til at løse et fælles problem, bidrage proportionelt mere end lande med mindre kapacitet eller evne. Den tredje norm omhandler spørgsmål i forbindelse med basale behov, individets 'ret' til et vist minimum af social og økonomisk velfærd og, som følge heraf, et vist emissionsniveau. Behovsnormen vil sætte det samme emissionsniveau pr. indbygger i alle lande, uanset det eksisterende niveau. Ifølge den fjerde norm skal lande bidrage i forhold til gevinsterne opnået gennem kollektiv handlen. Rapporten diskuterer endvidere hvordan regeringer har forholdt sig til retfærdighed, differentiering, og byrdefordeling i forhandlingerne om Kyotoprotokollen, og det påpeges, at disse spørgsmål indtil videre næsten udelukkende er blevet rejst i forbindelse med industrilandenes aktiviteter. Der er derfor få indikationer på hvilke fordelingsretfærdighedsprincipper og byrdefordelingsarrangementer som regeringer ville finde relevante og eventuelt acceptable i forsøg på at inddrage udviklingslandene i fremtidige arrangementer udformet indenfor rammerne af UNFCCC.

Tilpasning til klimaforandringer er et emne, som er blevet givet stigende opmærksomhed, ikke mindst i IPCC's Tredje Vurderingsrapport. Denne understreger, at tilpasningskapacitet er en vigtig dimension af forskellige landes sårbarhed overfor klimaforandringer. Sårbarhedsvurderinger kan ses som en måde at nærme sig vurderinger af 'farlige niveauer' af klimaforandringer på regional skala. Rapporten redegør for de forhold, så som klimapåvirkning, følsomhed og tilpasningskapacitet, der inddrages i sårbarhedsvurderinger. Indikatorer for sårbarhed er indtil videre ikke veludviklede, men det er muligt at inddrage eksisterende erfaringer fra arbejde med naturkatastrofer og fødevaresikkerhed. Der redegøres for et forsøg på at udvikle en sårbarhedsindikator med input fra integrerede klimamodeller.

Tilpasning kan ske så at sige af sig selv gennem økonomiske aktørers spontane handlen, eller understøttet af regeringer som handler på baggrund af scenarier for klimaforandringer. Nyere beregninger understreger vigtigheden af at inddrage tilpasningsaktiviteter, idet det er stærkt sandsynligt, at en global klimaforandring vil indtræde. Til trods for fuld gennemførelse af Kyotoprotokollen og opnåelse af dens reduktionsmål vil fremtidige temperaturstigninger kun blive reduceret marginalt. På baggrund af omkostninger ved en given klimaskade, tilpasningsomkostninger, aktuel risiko, eksistensen af brugbare teknologier og andre forhold diskuteres det kort, hvornår det er mest favorabelt at igangsætte tilpasningsaktiviteter.

Den nyere udvikling indenfor integrerede modeller til vurdering af konsekvenser af klimaforandringer gennemgås med henblik på at vurdere inddragelse af tilpasningsaktiviteter samt den regionale skala. Det påpeges, at visse fremskridt er gjort indenfor disse to temaer, men at klimamodellerne i sig selv er for 'grove' til at levere brugbart input til regionale konsekvensmodeller. Herudover diskuteres nogle af de usikkerheder, der findes i modellerne samt de problemer, der vedrører overførsel af modeller til udviklingslandene, som er udviklet til at analysere forhold i vestlige lande.

Til slut diskuteres hvilke normer for fordelingsretfærdighed der kunne bringes i anvendelse indenfor et udvidet byrdefordelingskoncept, som også inddrager skader og tilpasning. Spørgsmålet om hvem der skulle yde midlerne til kompensation og finansiering af tilpasningsprogrammer kunne rimeligvis diskuteres indenfor samme ramme som for emissionsbegrænsninger. Spørgsmålet om hvem som er berettiget til kompensation eller klimatilpasningsstøtte diskuteres i forhold til fire tilgange med forskellige fordelingsmæssige implikationer: ligelighed, sårbarhed, økonomisk efficiens/omkostningseffek-tivitet, og bidrag til emissionsbegrænsninger.

1 Introduction

This report explores some of the key issues that arise in the context of fairness, international burden sharing and global climate change. The problem of climate change is often perceived as an issue of mitigation, i.e., GHG emissions control and reduction, and discussions on fairness and burden sharing have so far been almost exclusively concerned with the distribution of mitigation costs across the industrialized countries.

The United Nations Framework Convention on Climate Change (UNFCCC), which was signed in Rio de Janeiro in June 1992, is primarily concerned with a need for limiting and ultimately stabilizing future concentrations of greenhouse gases in Earth's atmosphere and the role of industrialized countries in GHG mitigation. While the issue of fairness is often being raised in the context of global climate change, including in the UNFCCC and the *Third Assessment Report* (TAR) prepared by the Intergovernmental Panel on Climate Change (IPCC), in most cases fairness refers to how the costs of GHG mitigation are distributed across countries.

But this report pays equally much attention to climate impacts, vulnerability, and adaptation to climate change. It is suggested that any consistent framework for exploring issues related to fairness and burden sharing should include the adaptation costs and the costs of residual climate damages. Fairness and global burden sharing concern the international distribution of the total costs of climate change, not just how mitigation costs are distributed.

As a result of a growing international confidence in the estimates from general circulation models, it is increasingly widely accepted that the Kyoto Protocol, even if fully implemented, will not prevent the occurrence of negative impacts due to a warmer climate. It seems also certain that climate damages will be very unevenly distributed between the North and the South: the South will be hit hardest by global climate change. Scientific predictions and model estimates have repeatedly concluded that the developing countries are particularly vulnerable to a rise in atmospheric greenhouse gas (GHG) concentrations. The debate on fairness of global climate policy thus should take into account the potentially significant economic, social, and environmental losses in developing countries due to adverse climate effects and extreme climatic events.

The studies and assessments reviewed in this report indicate increasing interest in monetary and other quantitative assessments of the potential climate impacts and the regional distribution hereof, as well as the integration of adaptation in these assessments. The need to give more weight to these issues is also mirrored in the recently published TAR from the IPCC.

The report discusses notions of vulnerability and adaptive capacity and presents an overview of impact types. Tools and methods for quantitative assessment of the geographical distribution of damage cost and vulnerability are discussed, including the development and potential policy use of indicators and indices of vulnerability and the distributed impact assessment models. In order to understand the magnitude and severity of climate impacts, it is also necessary to take into account the opportunities for adaptation to climate change. A taxonomy of adaptation measures is presented that indicates that a number of measures for mitigating negative climate effects are potentially available.

It is obvious that adaptive measures could reduce the damages caused by climate change, at least to some extent. It is equally obvious, however, that the capacity to implement them will depend on the economic and social capabilities of actors, sectors, regions, and countries. It was suggested at the Sixth Meeting of the Conference of the Parties (COP-6) to establish several mechanisms for funding of adaptation under the UNFCCC and the Kyoto Protocol. But the question of how such resources should be divided among vulnerable countries has not yet been explicitly addressed. Moreover, it seems plausible that these funds would be insufficient to meet future funding needs for adaptation.

The following chapters explore some key issues and conceptual and methodological frameworks. Chapter 2 outlines a framework for burden sharing that includes both the mitigation costs and the costs associated with the impact side of climate change - the so-called Second Fairness Framework. Chapter 3 presents an overview of the most prominent fairness principles explored in the academic literature and examines a number of proposals for burden sharing among the industrialized countries. Furthermore it identifies three fairness principles or norms that seem particularly important when assessing the fairness of international distributions of mitigation costs - i.e. responsibility, capacity, and need.

Chapter 4 introduces the concept of vulnerability and presents an overview of existing approaches to the development of vulnerability indices and indicators. Adaptation measures, their incentives and underlying motivation, and timing are discussed in chapter 5. Although the monetary valuation of climate impacts is a disputed issue, both improved spatial detail and adaptation measures are increasingly included in economic modelling approaches. Chapter 6 summarizes the recent developments and indicative results from impact assessments and integrated assessment models (IAMs). The impact modules of these IAMs are based on benchmark estimates from impact studies, and an overview of recent impact studies, modelling approaches, and results is also presented. Chapter 7 suggests some general principles for international allocation of resources for climate adaptation and compensation of ‘victims’ of climate change. Consistent conceptual frameworks and concrete tools are clearly needed in this area as well. The concluding chapter summarizes the different trends and makes recommendations for further research.

2 Two Frameworks for Assessment of Fairness of Climate Change

2.1 First Fairness Framework

Burden sharing should focus on the costs and the benefits both of GHG mitigation projects for reducing global emissions and adaptation for offsetting the local effects of climate change. However, climate change and burden sharing is often perceived as solely a problem of mitigation. For instance, this view has largely framed the climate change issue in the UNFCCC context and it implies that climate change should primarily be solved at 'the source', i.e. through mitigation activities. As a result, little systematic attention is paid to climate damages and adaptation to climate change.

When adopting this view, which is illustrated by the First Fairness Framework (Figure 2.1), the essential fairness issue becomes how to develop and implement a fair and just arrangement for sharing GHG mitigation costs. Thus, fairness and global burden sharing become an issue of sharing mitigation costs and making proportional (however defined) country contributions (A_{con},B_{con},C_{con}, etc.) to global climate protection. However, the value of the local damages caused by climate change and the costs of adaptation to climate change at national and local levels are not seen as being part of global burden sharing.

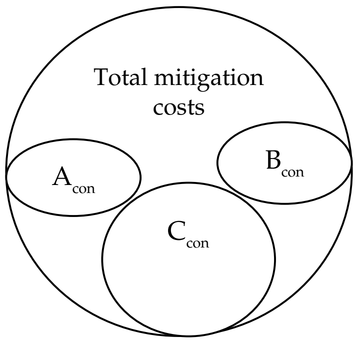

Figure 2.1: First Fairness Framework: total mitigation costs

This conception of global equity raises two major questions of distributional fairness: Which actors 'ought to' incur mitigation costs? And what contributions would be considered 'fair shares' to the total burden? The UNFCCC is explicit on the first question and emphasizes that the industrialized countries should 'go first' in reducing GHG emissions and that the developing countries should only later begin to reduce, or at least limit, their GHG emissions. With regard to the second question, the UNFCCC states implicitly that the mitigation costs should be shared equitably within the group of industrialized countries. It could be interpreted to mean that the OECD countries should incur the same economic loss as a result of their GHG mitigation activities, as measured by the percent loss in gross domestic product (GDP). Although this interpretation may seem intuitively fair to many, the UNFCCC does not identify which fairness principle(s) should constitute the normative basis of international burden sharing arrangements.[1]

2.2 Second Fairness Framework

As witnessed at COP-6, held in the Haag in November 2000, the issue of adaptation to climate change has recently moved up the global climate agenda, even though the main focus of the climate negotiators is still on GHG mitigation. One implication of adopting a broader view of climate change is that the total costs and benefits of mitigation and adaptation, the economic value of the local damages due to GHG emissions, and the distribution of these costs and benefits may be considered and estimated within a single framework. This view has significant implications for how international and global equity is interpreted, as illustrated by Figure 2.2.

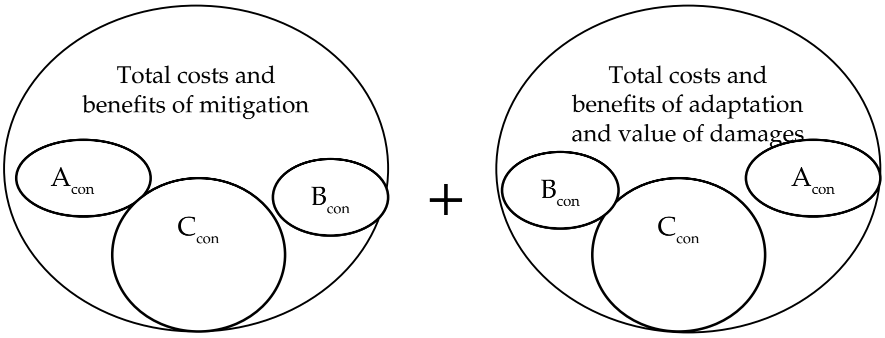

Figure 2.2: Second Fairness Framework: Sum of total costs and benefits of litigation plus total costs and benefits of adaptation and value of residual damages

The total costs in the Second Fairness Framework consist of three types of costs: mitigation, damage, and adaptation costs. This raises complex questions about the estimation of the magnitude of the total costs of climate change and about comparison of mitigation costs and adaptation costs (and benefits) and damage costs. This framework also raises two major issues: Which actors 'ought to' shoulder the mitigation, adaptation, and damage costs? What would constitute their 'fair share' of the total burden?

2.3 Summary

The costs of adaptation to climate change and the value of local climate damages have traditionally been ignored in discussions of international equity and global burden sharing in the climate change context. In this chapter a framework was put forward that accommodates policy development and development of methods for assessment of fairness in burden sharing. This framework integrates mitigation, damage, and adaptation costs – it does not simply focus on mitigation costs at the expense of all other cost types.

[1] For a discussion of the fairness principles underlying government proposals submitted during the negotiations on the (differentiated) Kyoto Protocol, see Ringius et al. (2002).

3 Equity Principles and Burden sharing Rules

Discussions of fairness and burden sharing have primarily been concerned with the distribution of the mitigation costs across the main ‘polluters’, i.e. the industrialized countries. Although no generally accepted definition of fairness exists, it is possible to identify a few notions of distributional fairness, which seem particularly influential in international climate policy.

3.1 Introduction

Equity is a critical issue in human interactions. Thus, it should come as no surprise that the issue of equity figures prominently in international discussions and negotiations on global climate change. Because both abatement costs and damage costs of climate change are likely to be high, equity and fairness are salient issues when countries hammer out the international distribution of the burdens and benefits of global climate protection. Many find it almost self-evident that coping with climate change will depend on the development and implementation of perceived equitable national and international solutions. National obligations and international bargains that are seen as unfair will not generate the collective action that is necessary to solve this long-term global environmental problem.

But equity is sometimes addressed only indirectly, defined imprecisely, seems invested with different meanings, or even overlaps with other concepts. The second section therefore discusses prominent fairness norms and equity principles, and distinguishes equity from related concepts. As the third section documents, the two main global agreements addressing climate change, namely the UNFCCC and the Kyoto Protocol, repeatedly emphasize equity. Both analysts and governments have proposed a number of arrangements for equitable burden sharing, and the most prominent approaches and their international distributional implications are summarized in the fourth section.

3.2 Equity Principles and Burden sharing Rules

Burden sharing refers to the way in which a group of countries benefiting from an international common good agrees to share the costs (and benefits) of providing the good. Yet there exists no commonly accepted definition of equity and fairness. It is nonetheless possible to identify four more widely accepted norms of distributive fairness that underlie and sometimes even shape international environmental affairs, including global climate policy to some extent. These four norms emphasize responsibility, capacity, need, and contribution to a common good, respectively.[2] They follow two

[2] For a more through discussion, see Ringius et al. (2002).

different approaches to the question of what constitutes an equitable distribution of costs among actors. The norms of responsibility and capacity focus on the distribution of the costs (burdens) of providing a common good, whereas the norms of need and contribution, which likewise are concerned with fair and just cost distribution, take into account the distribution of the benefits (goods) flowing from a common good.

The first norm is concerned with the responsibility for a common problem. Focusing attention on the question of responsibility, this norm states that those who have caused the problem are responsible for solving it. It is undoubtedly a generally accepted norm in international environmental affairs. Thus, according to Principle 21 of the Stockholm Declaration on the Human Environment (1972): 'States have the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States'. Essentially, this norm implies that countries should contribute to the solution to a common problem in proportion to their share of responsibility for causing the problem. In the context of climate change, this would mean that responsibility for coping with this problem rests with those countries that emit the largest amounts of greenhouse gases per capita, namely the developed countries. Developing countries with high total emissions should, despite modest emissions per capita, also contribute relatively more, especially if their future total emissions increase significantly.

A second widely accepted norm of international environmental affairs is concerned with the individual role of countries in providing a common good. According to the norm of capacity, countries that have greater capacity or ability to solve a joint problem, and thus provide a common good, should contribute more than countries with less capacity and ability. This norm says, in essence, that countries should contribute to a common good in proportion to their capacity to do so. Gross domestic product (GDP) per capita is often used as a rough indicator of a country's capacity to contribute to the solution to an international common problem. Also this norm places the main share of the burden of coping with climate change on developed countries.

A third widely accepted norm deals with the issue of basic human needs, the individual's 'right' to a certain minimum of social and economic welfare and, by implication, a certain emission level. Interpreted in the context of climate change, this norm would imply that individuals have the right to emit an equal amount of greenhouse gases. Individuals should therefore receive an identical amount of permits, allowances, or quotas to emit greenhouse gases. The norm of need would establish an equal level of greenhouse gas emissions per capita in all countries, irrespective of the existing emission levels. Because per capita emissions generally are low in developing countries, this norm would be relatively more burdensome on developed countries.

According to the fourth generally accepted norm, states should contribute in (some) proportion to the benefits of concerted, collective action. Similar to the norm of need, it focuses attention on the distribution of the benefits of solving a common problem, particularly on those actors who would receive disproportionally larger gains from collective efforts to mitigate a problem. But unlike the norms concerned with responsibility, capacity, and need, this norm generally attracts little attention in international discussions and negotiations on global climate change. It seems that the primary reason for this is that it potentially would shift the costs and burdens of climate protection from developed to developing countries. Scientists and decision-makers generally expect the most severe economic, environmental, and social damages due to climate change to be inflicted on developing countries, so this group of countries stands to gain more than developed countries from climate control. But many would probably find it immoral to demand that poor developing countries should contribute proportionally more than rich developed countries to the solution to climate change. Because of its 'perverse' distributional implications in the climate change context, the norm of contribution conflicts with the first three norms, and they seem to completely overrule it. The norms of responsibility, capacity, and need evidently influence international discussions and negotiations on the issue much more.

Table 3.1 Selected equity principles and related burden sharing rules.

Equity principle	Interpretation	Example of implied burden sharing rule
Egalitarian	Every individual has an equal right to pollute or to be protected from pollution	Allow or reduce emissions in proportion to population.
Sovereignty	All nations have an equal right to pollute or to be protected from pollution; current level of emissions constitutes a status quo right	Allow or reduce emissions proportionally across all countries to maintain relative emission levels between them.
Horizontal	Countries with similar economic circumstances have similar emission rights and burden sharing responsibilities	Equalize net welfare change across countries (net cost of abatement as a proportion of GDP is equal for each country).
Vertical	The greater the ability to pay, the greater the economic burden	Net cost of abatement is directly correlated with per capita GDP.
Polluter pays	The economic burden is proportional to emissions (eventually including historical emissions)	Share abatement costs across countries in proportion to emission levels.

The three norms of responsibility, capacity, and need together create the deeper normative structure in which global climate policy is embedded. Thus, those equity principles that are proposed most frequently by analysts and governments fit well with this normative structure (for an overview of the most prominent equity principles, see Table 3.1). It is quite evident that responsibility creates the underlying rationale and justification for the polluter pays principle; that the norm concerned with capacity and ability is paralleled by the principles of horizontal equity (the equal treatment of equals) and vertical equity (a progressive distribution of burdens); and that the egalitarian principle echoes the norm of need. Sovereignty, which takes a different approach to proportionality, is often justified by claiming so-called acquired rights.

Sovereignty reflects a frequently observed practice of international negotiations, namely that identical and equal obligations should be imposed on all countries, in other words the fairness norm of equality. It is almost routine to follow an across-the-board, symmetrical approach in international environmental negotiations; at least, this approach often serves as the starting point of negotiations on how costs and obligations should be distributed among countries. In climate change policy, a prominent across-the-board measure would be to simply reduce greenhouse gas emissions by the same percentage, relative to a specified base year. Due to different national situations and starting points, however, symmetrical agreements may often distribute burdens unevenly across countries. Countries might therefore attempt to differentiate obligations.

Burden sharing rules or formulae should be conceived of as potentially useful conceptual tools in international climate negotiations. While they cannot take the place of political negotiation, they can help countries develop the overall formula that forms the basis for agreement and perhaps even identify a sufficiently equitable formula for burden sharing. Differentiation will in the end be decided through a political process, not a technical one, involving pressures and offers. But this should not overshadow that equity principles and burden sharing rules can play an important role in creating a conceptual framework and choosing criteria for comparison of country obligations. Norms of fairness and justice can provide focal points around which international negotiations and discussions can be structured and bargains made.

Equity principles should be distinguished from specific burden sharing rules and formulae as well as from indicators and criteria. Equity principles refer to more general norms of justice and fairness and, by linking them to rules (formulae), can be operationalized. Burden sharing rules are operational functions generating a specific scheme for reducing greenhouse gas emissions or bearing the abatement costs. Rules are based on input from one or more indicators (criteria). They must specify both the relevant indicators and how these should be combined. Indicators provide the 'hard' data, for example CO_2 (carbon dioxide) emissions per capita and GDP per capita. It should be stressed that some equity principles could be consistent with more than one type of burden sharing rules, and particular rules could be consistent with more than one particular equity principle. Thus, there exists no simple one-to-one relationship between equity principles and burden sharing rules.

To illustrate, in the course of the negotiations on the Kyoto Protocol, which took place in the period 1995–1997, one country suggested a burden sharing rule that combines CO_2 equivalent emissions per unit of GDP, GDP per capita, and CO_2 equivalent emissions per capita.[3]

[3] For an analysis of this rule, see Ringius et al. (1998).

These were thought to indicate how energy efficiency, ability to pay (capacity), and emission entitlement and contribution of pollution vary among countries. According to this rule, developed countries with above average values would receive a percentage target above the average target, whereas countries with below average values would receive a target below the average target. The rule is

$$\mathbf{Y_i=A[x(B_i/B)+y(C_i/C)+z(D_i/D)]}$$[4]

As discussed in section 3.4, governments and analysts are suggesting many alternative types of burden sharing rules and arrangements.

3.3 Equity in the UNFCCC and the Kyoto Protocol

The UNFCCC repeatedly stresses equity and fair burden sharing among countries, and the Kyoto Protocol concluded in Kyoto, Japan, in December 1997, identifies several equity principles. Both distinguish explicitly between developed and developing countries, and Article 3.2 of UNFCCC in particular underlines that full consideration should be given to 'the specific needs and special circumstances' of the latter group of countries. It is also stressed in Article 3.2 of UNFCCC that full consideration should be given to 'those Parties, especially developing country Parties that would have to bear a disproportionate or abnormal burden under the Convention'.

These two agreements refer not to one but several equity principles and more general fairness norms that should guide global cooperation. According to Article 3.1 of UNFCCC: 'The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities'. Thus, countries shall take into account intergenerational equity. Moreover, and more concretely, because of obvious dissimilarities and asymmetries across countries with respect to the responsibility for climate change, as well as the capacity to deal with it, the signatory countries have agreed in the same article that 'the developed country Parties should take the lead in combating climate change and the adverse effects thereof'. As discussed already, the norms of responsibility and capacity imply that developed countries should bear the brunt of the burden of climate control.

The Kyoto Protocol differentiates the obligations of the developed countries and those of countries with former centrally planned economies. Iceland may increase its emissions by 10 per cent, Australia may increase emissions by eight per cent, and Norway by one per cent, but Japan shall reduce its emissions by six per cent, the

[4] Y_i is percentage reduction of emissions from country i. B_i is CO_2 equivalent emissions per unit of GDP for country i and B is the equivalent average for the developed countries; C_i and C are GDP per capita for country i and the average of the group; and D_i and D are CO_2 equivalent emissions per capita for country i and the average of the group. x, y and z are weights that add up to one. A is a scaling factor that ensures that the desired overall emissions reductions for the group of countries is achieved.

United States shall reduce by seven per cent, and the EU and a number of Eastern European countries by eight per cent by 2008-2012, compared to 1990 emission levels. Developing countries are under no obligation to control greenhouse gas emissions under the Kyoto Protocol. This differentiation of targets evidences the need for fairness and justice in global climate policy, although it also reflects differences in bargaining power among countries.

3.4 Government Proposals for Burden sharing and Differentiation

Countries proposed many different types of burden sharing arrangements in the course of the negotiations on the Kyoto Protocol. Many countries followed an across-the-board or symmetrical approach and opted for a flat-rate target, i.e. the same percentage target for all countries. Some 15 countries, however, suggested differentiating obligations of countries. Their approaches to differentiation varied widely. We summarize now the most prominent approaches.[5]

One prominent approach aims at a convergence of per capita emissions of greenhouse gases in all countries over time. Its explicit objective is stabilization of atmospheric concentrations of greenhouse gases at an acceptable level at some future point in time – according to one proposal, for instance, the atmospheric concentration of CO_2 should be less than 550 parts per million by volume (ppmv) by year 2100. The approach often implies a significant reduction of per capita emissions in developed countries while emissions in developing countries may be increased until they reach a certain level. Countries with high per capita emission levels need to reduce more compared to countries with lower emission levels.

The idea of historic responsibility provides the normative underpinning of burden sharing arrangements that highlight the differences in contributions of greenhouse gases from individual countries aggregated over time. These arrangements usually include the amounts of greenhouse gas emitted by developed countries in the past, such as the 1950-1990 period, or perhaps even periods preceding 1950. Responsibility is the key equity parameter in these proposals. But it will presumably not be considered fair and equitable to use past emissions as the main criterion for determining climate obligations as it has only recently been widely acknowledged that the accumulation of anthropogenic greenhouse gases in the atmosphere has negative implications for the global climate system. Nevertheless, the issue of how the industrial development of the developed countries has produced the bulk of the anthropogenic greenhouse gases accumulated in the atmosphere is often raised by developing countries in international climate negotiations.

Proposals for multi-criteria formulae (one example was given above in section 3.2) combine several indicators and might be linked explicitly to particular fairness norms and equity principles. Some of

[5] This section draws heavily on Torvanger and Godal (1999).

the most frequently suggested indicators are CO_2 (equivalent) emissions per unit of GDP, GDP per capita, and CO_2 equivalent emissions per capita.

Yet another type of arrangement focuses on GDP per capita when distributing obligations among countries. GDP per capita seems often to serve as an indicator for ability to pay or capacity in these proposals. It is sometimes suggested to include additional input about national conditions and circumstances, for example greenhouse gas emissions per capita, in this type of arrangement.

Still another type of proposal emphasizes cost-effectiveness. These proposals imply that national obligations should be distributed so as to equalize marginal abatement costs across countries. This means that emission reductions in principle are achieved at the global least cost.

Finally, in the internal negotiations prior to Kyoto on differentiation of targets of member states the EU followed a so-called Triptique Approach (Blok et al., 1997; Ringius, 1999). This bottom-up approach separates the economies of the member countries into three broad economic sectors – domestic sector, heavy industry, and electricity generation. The obligations of the member states are calculated by adding up individual allowances for each sector and by taking into account economic growth, population changes, and climate-adjusted energy use. But the sectoral allowances themselves are not regarded as sectoral targets. A per capita approach is used to calculate emission allowances in the domestic sector. The Triptique Approach assumes that the emissions from the domestic sector converge at the same level in the member states in year 2030, and that emissions allowances per capita are identical in all EU member states in 2030. Energy efficiency improvement targets are established for the heavy industry. Because of large differences in the EU electricity sector, a tailor-made approach is followed. It is assumed that the poorer member countries should carry lesser burdens. It should be noted that, rather than choosing a single indicator at the level of individual members, the approach combines several energy indicators at the sectoral level. In this way it shifts attention away from comparing contributions and fairness among members to comparing sectoral contributions and fairness across sectors in the EU.

3.5 Summary and conclusions

The UNFCCC and the Kyoto Protocol view fair burden sharing as a critically important issue. They separate equity between developed and developing countries from equity among developed countries. Several specific equity principles and more general fairness norms stressing responsibility and capacity are referred to in the treaties identified. It is stressed that developed countries need to ‘go first’ in the climate change area. There seems to be broad support for horizontal equity in the context of the rich OECD countries, but neither this nor any other principle is operationalized in the form of specific burden sharing rules. The UNFCCC and the Kyoto Protocol lack specific rules and mechanisms for achievement of equity.

Despite their many differences, the proposals reviewed in this chapter indicate that governments consider three principles to be the most attractive and relevant in fair burden sharing: egalitarianism, the polluter pays principle (responsibility), and ability to pay (capacity). Regarding single-principle arrangements, if climate burdens should be distributed in accordance with the most widely supported equity principle, then burden sharing should be based on egalitarianism. There would probably be much less political support for a single-principle arrangement based on the polluter pays principle and seemingly little or no support for a single-principle arrangement based on ability to pay. Regarding multi-principle arrangements, the most relevant and acceptable principles are ability to pay, egalitarianism, and the polluter pays principle. Among these three, ability to pay would probably receive more political support than egalitarianism and the polluter pays principle. Regarding indicators, governments mainly favor three indicators, namely CO_2 equivalent emissions per capita, CO_2 equivalent emissions per GDP unit, and GDP per capita.

Because governments have so far been focusing primarily on obligations of developed countries and countries with former centrally planned economies, the negotiations on the Kyoto Protocol give less indication about which fairness norms and burden sharing rules governments consider relevant and attractive with respect to developing countries. That said, it seems very likely that developing countries, and developed countries as well, would argue that responsibility, capacity, and need should constitute the normative foundation of any arrangement establishing fair and just climate targets for developing countries. As to indicators, it is quite plausible that governments would select historical emissions as an indicator of responsibility, GDP per capita as an indicator of wealth, and (a certain minimum level of) GDP per capita as an indicator of need.

4 Impacts and Vulnerability

4.1 'Burdens' in a climate change context

As described in chapters 2 and 3, the burden sharing issue in climate change has until now mainly dealt with the distribution of the costs of emission reductions related to the Kyoto protocol. However, other issues with relevance to burden sharing are emerging. As the evidence of climate change builds up, so do considerations of likely impacts/damages and adaptation options, their costs, and the policy options concerning these issues. It is particularly relevant to examine how the burdens related to damages and the costs of adaptation are likely to be distributed. To what extent tools for quantifying and comparing burdens exist, and how they could assist in establishing burden sharing rules, is equally relevant.

In the aftermath of the publishing of the IPCC Second Assessment Report, it was decided that the IPCC Third Assessment Report (TAR) should put greater emphasis on impacts and adaptation. TARs analytical framework for integration of impacts and adaptation considerations in climate change is presented in Figure 4.1.

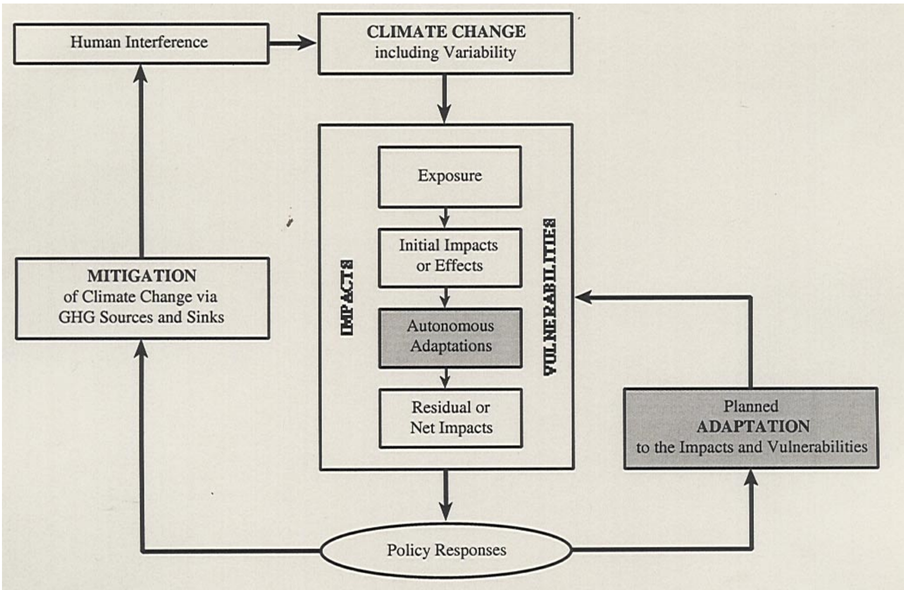

Figure 4.1: Climate change framework as used in IPCC Third Assessment Report (McCarthy et al., 2001).

The figure illustrates that, as climate change proceeds, autonomous adaptations and planned adaptation are expected to take place within systems and sectors as well as by individual decision-makers, thus giving rise to the concept of net or residual impact/damage. Autonomous adaptation refers to the actions that decision-makers carry out as climate change impacts are recognized, without directed intervention by a public agency (McCarthy et al., 2001). Planned adaptation, in contrast, refers to adaptive measures carried out or initiated at societal level. As the figure indicates, planned adaptation may be initiated as anticipatory policy related to climate predictions and the vulnerability of the system under concern, or as reactive measures related to experienced change.

When figure 4.1 is viewed in the perspective of burden assessment, it can be argued that the burdens of climate change consist of the costs of mitigation and the costs of damages and adaptation. Thus the concept of 'burdens' of climate change is here broadly conceived, as in the Second Fairness Framework presented in chapter 2. If these burdens are assessed in monetary terms, they include not only the costs related to politically defined levels of emission reduction, but additionally the costs from climate change impacts as well as the costs (and benefits) related to adaptation policies.

Two different approaches to the assessment of impacts exist. One approach is the development of integrated assessment models and the valuation of impacts. The recent development of these models, especially their attention to adaptation and regional detail, is examined in chapter 6. The other approach is the development of quantitative local and regional indicators for vulnerability to climate change.

This chapter introduces recent assessments of impact types and vulnerability of sectors. Concepts and approaches that are relevant to vulnerability are briefly explained, and the general understanding of the concept of vulnerability in the climate change context is presented. Recent developments in indicators and indices of vulnerability and their potential use are also discussed.

4.2 Distribution of climate change impact

The IPCC has carried out two major efforts to summarize and review existing knowledge about regional impact and vulnerability to climate change. The first is published in the report*: The Regional Impacts of Climate Change: An Assessment of Vulnerability* (Watson et al., 1998); the second is volume 2 of the IPCC TAR: *Climate Change 2001: Impact, Adaptation and Vulnerability* (McCarthy et al., 2001). Moreover a number of recent global impact assessment studies also produce estimates at a regional level (Parry et al., 1999a).

Climate change impacts can be differentiated in a number of ways with respect to sectors, themes/areas, etc. Figure 4.2 below presents one categorization that divides the categories into market and non-market damages. The most studied sectors are agriculture and sea-level rise (Nordhaus and Boyer, 2000), while other, equally important areas, such as health impacts, ecosystem losses and catastrophic impacts, are not studied to the same extent. In general, knowledge of potential impact becomes sparser when moving from the left hand to the right hand categories in the figure.

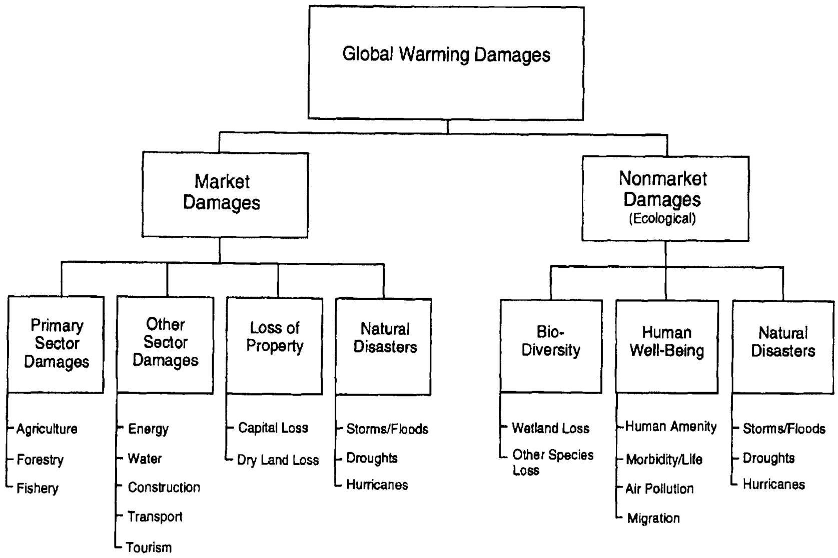

Figure 4.2: Overview of global warming impacts (Manne et al., 1995).

The IPCC report on regional impacts focuses on the most vulnerable sectors and areas, including ecosystems, hydrology and water resources, food and fiber production, coastal systems, human settlements, and human health. These sectors are assessed for each of 10 regions encompassing the land surface of the Earth. Depending on the availability of studies, quantitative estimates are presented for a number of areas, but the overall assessment is qualitative. The assessments build on published studies that use a variety of methods and models and they do not allow for conclusions regarding the relative vulnerability among regions.

In the Third Assessment Report impact assessments focus first on themes or sectors and secondly on regions. In a final chapter summarizing vulnerability, five central themes are selected, with the purpose of collecting and organizing information in a way that could help policy makers reach their own conclusions as to what is a 'dangerous' climate change. Each of these themes is discussed in terms of the impact that an increase in global mean temperature would have on the theme. The five themes are (McCarthy et al., 2001):

- Damage to, or irreversible loss of, unique and threatened systems,
- Distribution of impacts. This covers the differential impacts expected in regions, countries, islands, cultures etc.,
- Globally aggregated impacts,
- Probability of extreme weather events, and
- Probability of large-scale single events (e.g. collapse of West Antarctic ice sheet or shutdown of North Atlantic thermohaline circulation).

(McCarthy et al., 2001)

The third source of information is a number of impact assessments that employ the same climate change scenarios and adopt consistent assumptions on population and economic development in the future (Parry et al., 1999a). They cover water, food, coastal, and health aspects.

In the following examples of major regional differences are given concerning especially sensitive sectors/resources – either in a North-South perspective or in a regional detail. The examples are selected so as to represent some of the most vulnerable areas and sectors, as well as areas that have been covered by recent attempts to assess impacts at regional scales.

Agricultural production
The agricultural sector is highly sensitive to climate change, due to the dependence on water availability, length of growing season, drought etc. Regional projections of climate parameters diverge quite strongly and confidence in regional scenarios remains low (Watson et al., 1998).

Regions that are highly dependent on their agricultural sector, that mainly rely on rainfed agriculture, and have limited adaptive capacity are especially vulnerable to climate change. This is the case for Africa, probably part of arid Western Asia, Tropical Asia, and Latin America. Projected changes in crop yields for Temperate Asia vary widely. The studies, on which the latter assessments build generally does not take into consideration improvements in management, crop changes etc. (Watson et al., 1998).

It is uncertain whether the global supply of food will decrease or increase, and if food supply can meet demand in 2025 (Döös and Shaw, 1999). But there is general agreement that yields are likely to increase at the higher latitudes and decrease at the lower latitudes. Moreover it is unlikely that the demand for cereals can be met in the less-developed countries (Döös and Shaw, 1999), as recent modelling results show that cereal productivity decrease about 12% in Africa and 23% for South East Asia (Parry et al., 1999b). Strongly negative effects are expected for populations poorly connected to the market (McCarthy et al., 2001), as well as for arid and sub-humid regions where climate may already constrain production and where adaptive capacity is low (Parry et al., 1999). Some argue, however, that the gap between potential and actual productivity in smallholder agriculture in Africa may be even more important for food supply than impacts of climate change (Watson et al., 1998). Likewise it is argued that policy measures addressing direct human factors such as improved agricultural management and increased use of fertilisers is a more robust response in relation to the food security of the least developed countries than indirect policy measures directed towards other issues such as adaptation to climate change. This is based on analyses of predictions of future food production, which show that the greatest uncertainties are associated with management and fertilisers, rather than climatic change, irrigation, salinization, waterlogging, or pests (Döös and Shaw, 1999).

Water resources
Water stress and access to water resources has long been seen as an increasingly conflict-laden area, and a number of developing countries are currently water-stressed. The fundamental link between climate and water resources indicates that this situation could worsen in some regions. Impacts of changes in hydrological regimes vary over the regions, but in general arid and semi-arid areas are

particularly vulnerable to changes in water availability. In some regions, like arid Western Asia, some river systems may experience higher flow for some decades – while glaciers melt – followed by a reduction in flow. Latin America is highly heterogeneous. In some areas hydropower generation and grain and livestock production are particularly vulnerable to changes in water supply. In Austral-Asia possible reductions in water availability would sharpen competition among uses, while in Europe reduced flood protection and decrease in water quality are possible impacts. Small island states may experience freshwater shortages (Watson et al., 1998).

One study of climate change and global water resources estimates that by 2025 around 5 billion people out of 8 billion in total will live in countries experiencing water stress[6] (Arnell, 1999). This does not take into account intra-regional access to water. Thus it is noted that several countries in semi-arid regions have sufficient resources, but much of the water is highly localised to major rivers. The two climate scenarios used in the study differ to some extent in their regional predictions of precipitation. This means that differences exist in modelled runoff, especially in the Amazon basin and over much of the United States, and with opposite effect on the Indian subcontinent. The result from this model shows that by 2025 water resource stress will increase in the Middle East, around the Mediterranean, in parts of Europe and in Southern Africa, while results differ over the two scenarios for Southern Asia.

As noted by the IPCC (Watson et al., 1998), hydrological parameters indicating the sensitivity of river systems are also relevant for assessing the vulnerability of water resources to climate change. Studies indicate that e.g. the Nile and to a lesser extent the Zambesi are extremely sensitive to changes in temperature.

Coastal zones

The impact of sea-level rise is one of the better-studied areas of climate change. Coastal zones are especially susceptible to extreme events, like floods and storms, and impacts include changes in ecosystems of importance for economic activities (e.g. mangroves, coral reefs), fresh water resources as well as impacts on settlement and protective structures, and loss of land. The development of coastal settlement and economic activity has reduced resilience and adaptability in the developed countries, where especially low-lying urban areas and coastal ecosystems are vulnerable. Measures to contain the impacts of climate change in such areas may require substantial investments (Watson et al., 1998).

Models of flooding and wetland losses due to global sea-level rise show that the areas most vulnerable to flooding are the southern Mediterranean, Africa, and the low-lying populated deltas in South and South East Asia. The reason for this is that the largest number of people susceptible to flooding according to the model live in these regions. In relative terms, however, the small island states may experience a steeper increase in the percentage of people flooded. The

[6] Water stress is defined as using more than 20% of available water resources (Arnell, 1999).

biggest wetland losses due to sea-level rise are estimated to occur around the Mediterranean and the Baltic (Nicholls et al., 1999).

Health impacts
A range of health-related issues might be influenced by climate change, including changing habitats for disease bearing vectors, local food production and nutrition, heat and cold-related illnesses, and impacts of economic disruption and relocation. It is expected that the geographic range and seasonality of vector-borne infectious diseases will increase, as will the proportion of people living in areas of potential transmission (McCarthy et al., 2001).

Most regions expect an increase in vector-borne diseases, particularly tropical areas in Africa and South and South East Asia. For Africa reduced nutrition is expected to be an additional risk parameter (Watson et al., 1998).

Estimates of the potential impact of climate change on malaria transmission show that the greatest proportional changes may happen in the temperate zones, where temperature is currently too low for transmission. Moreover tropical zone highlands may be more at risk of seasonal transmission. However, estimates of future population at risk of malaria differ significantly between regions and between climate scenarios (Martens et al., 1999).

Based on the findings in the impact assessments, Parry and co-workers conclude that climate change impacts should be a cause of deep concern, as negative impacts were significant in all sectors (Parry et al., 1999a). Moreover the studies confirm that the most negative impacts are expected to occur in less developed countries, due to the regional distribution of climate change as well as the lower adaptation capacity inherent in these regions.

4.3 What is Vulnerability?

Perceived increasing evidence of climate change occurring in spite of mitigation activities is leading to a change in the view of climate change. National and international government agencies are slowly beginning to realise that some societies and ecological systems are particularly vulnerable to the potential effects of climate change.

Vulnerability is intuitively related to the potential harm that a region, sector, or group of people can be expected to suffer from the exposure to a given hazard – ‘the capacity to be harmed’ (Moss et al., 2001). The concept of vulnerability has been used to characterise ecosystems as well as human systems. In the context of human systems, approaches to vulnerability differ in the way they treat exposure. Either the hazard (exposure) is included in the vulnerability concept, or vulnerability is exclusively used for the sensitivity and ability to adapt to the changes (Kelly and Adger, 2000). It may be argued that hazard should be excluded from the concept, as exposure will not necessarily lead to negative outcomes (Moss et al., 2001)[7].

Recent approaches to understanding the vulnerability of people and social systems build to a large extent on the entitlement concept, as developed by Amarthya Sen (Downing et al., 2001). He ascribed peoples' food entitlements to their ability to command food through various sources including production, market and transfers. A large body of literature has later used this approach for more general analyses of the relations between access to and commands over resources and vulnerability of social groups. The box below illustrates basic ideas of social vulnerability found in this literature.

Box 1:
Key Concepts of Vulnerability

Vulnerability is a relative measure - critical levels of vulnerability must be defined by the analyst, whether the vulnerable themselves, external aid worker, or various societies that include the vulnerable and interventionists.

Everyone is vulnerable, although their vulnerability differs in its causal structure, evolution, and the severity of the likely consequences.

The locus of vulnerability is the individual related to social structures of households, community, society and world-system. Places can only be ascribed a vulnerability ranking in the context of the people who occupy them.

Vulnerability relates to the consequences of a perturbation, rather than its agent. Thus people are vulnerable to loss of life, livelihood, assets and income, rather than to specific agents of disaster, such as floods, windstorms, or technical hazards. This focuses vulnerability on the social systems rather than the nature of the hazard itself.
Source: (Downing et al. 2001):

In a recent UNEP publication on vulnerability to climate change, it is recommended to view vulnerability as embodying three domains (Downing et al., 2001):

- present criticality (present distribution of vulnerable groups and the relative level of human development),
- adaptive capacity (prospects for adapting to climate change over the coming decades),
- climate change hazard (risk of adverse climate impacts).

This is very close to the approach taken by the IPCC in TAR, where the three dimensions of exposure, sensitivity towards climate change, and adaptive capacity define vulnerability. These approaches includes exposure in their vulnerability concept, and vulnerability levels can thus be described as combinations of exposure, system sensitivity to climate change, and characteristics related to a range of factors describing the adaptability of the societal system. Figure 4.2 illustrates that for areas with high risk of exposure, vulnerability can be understood as combinations of high sensitivity and low adaptive capacity (creating 'hotspots').

[7] For extended discussions and reviews of the concept see e.g. (Smit et al., 1999; Kelly and Adger, 2000; Downing et al., 2001).

Vulnerable systems/resources		
Sensitivity	Capacity to respond	
	Low	High
High	Vulnerable system	Adaptive system
Low	Robust, inflexible system	Resilient system

Figure 4.2: Vulnerability as contingent on sensitivity and adaptive capacity, in areas of high risk of exposure.

Sensitivity is, strictly speaking, only a measure of the extent to which a system is positively and negatively affected, or responsive, to climate stimuli. For the purpose of identifying attributes of vulnerability, however, it is only the detrimental or damage related parts of the sensitivity that determine the vulnerable systems or regions.

Dependence on primary sectors has been seen as a determinant of sensitivity, as these sectors – like agriculture and water resources (Ringius et al., 1996) – are especially sensitive to climate change. Regions that are already producing food and fibre under drought prone conditions can be seen as an example of this. These usually exhibit a present criticality due to a large variability in agroclimate, with succeeding instability in production, income, and food security. The agricultural potential is highly sensitive to climate change as small changes in climatic parameters - such as the length of growing season or rainfall changes - may increase incidence of harvest failures dramatically. Thus food security as well as earnings from marketed produce may be affected. Coastal zones, like the southern coast of West Africa, are sensitive to sea-level rise and extreme events when densely settled or due to the socio-economic activities related to the zone, like fishery. Human health is sensitive to changes in vector-borne diseases, insect breeding sites, heat- and cold related diseases, and mortality. Ecosystems are sensitive to various degrees. In general, climate change is expected to occur at a rapid rate relative to the adaptability of ecosystems (Watson et al., 1998), and forest-, montane- and coral reef ecosystems are considered to be most sensitive, due to their relatively slow rate of reestablishment or their isolation.

Adaptive capacity describes characteristics of the system that relate to its capabilities to adapt. It is defined as the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. It represents a policy option for enhancement. The adaptability or adaptation capacity of a system is related to its capability to respond to information and experience of climate change, and to command resources for turning this knowledge into active strategies and ways of handling these challenges or opportunities.

The determinants of adaptation capacity span a number of issues. Those that are put forward in TAR include:

- technology,
- information and skills,
- infrastructure,
- institutions, and
- equity.[8]

Others have focussed on the availability of resources and their distribution across the population, and the stock of social capital, including the social definition of property rights.

This very general list to some extent accommodates any stresses placed on a system or society. But the issues listed illustrate that introducing adaptation and the adaptive capacity of societies into the perspective of climate change, may give rise to questions of possible links and complementarity between climate policies and general development policies, including sustainable development.

Adaptive capacity has been the focus of a number of case-studies. A study by Kelly and Adger (2000) of vulnerability of coastal Vietnam argue that the concern about short-term hazards (case studies on cyclone impact) are also relevant for long-term changes, as the primary linkages between social, economic, and political characteristics that they explore will also determine the capacity to react to environmental stress manifest over longer time-scales. They find that capacity to adapt of individuals, households, or communities is closely related to issues of poverty, inequality, and capability of institutions (the latter are broadly defined as the 'rules of the game').

Issues of poverty and inequality are also discussed elsewhere. One study finds that knowledge on adaptation processes, their economic and social costs, and their distribution is generally lacking, especially in developing countries (Kates, 2000). Based on hazards research and the method of analogies, a large number of studies from developing countries that focus on adaptation by the poor are reviewed. These studies are grouped in five themes: adaptation to extreme weather and climate; adaptation to drought; adaptation of food production to population growth; adaptation to population pressure in African high density areas; and adaptation to interactive stresses of population, economy, and environment. Based on these studies it is argued that the ability to adapt and the access to adaptation options is contingent on existing divisions between rich and poor countries and rich and poor people.

One example is based on reviews of 10 case studies of adaptation to population pressure in high density areas in Africa. Here it is shown that while there is considerable capacity of poor people to adjust to prolonged and extended change - similar to what some expect from global warming - the capacity to move beyond mere subsistence is

[8] See McCarthy et al. (2001).

low in the absence of external inputs, markets, and new technology. A similar conclusion was reached from reviews of the Sahel literature on drought and famine prevention. While it has taken two decades of drought to develop some capability in the international and national communities to respond to the drought and to prevent famine and save lives, there was still little success in adjusting the livelihood systems to persistent drought.

Another example is drawn from 30 case studies linking changes in population, economy, and environment. These studies demonstrated cycles of displacement, division of land and degradation linked to the resources of poor people, and often initiated by the very activities intended for development. Kates (2000) argues that the development-commercialisation activities that initially displaced poor people were precisely those that would constitute adaptive strategies to climate change, like large-scale agriculture, irrigation, hydroelectric development, forestry, and wildlife preservation. He finds that the benefits of adaptation are not distributed evenly and that the very process of adaptation, even if beneficial for some groups or for a nation as a whole, may marginalize other groups whose adaptation capacity is low, due to lack of access to economic and social resources.

In summary, vulnerability to climate change is a complex attribute, which can be approached by assessing sensitivity and adaptation capacity to a given exposure. In general poor people are particularly vulnerable as they lack the means and resources for adaptation even in circumstances where changes may be foreseen. Benefits of adaptation may be unevenly distributed within a region or society.

4.4 Approaches to assessment of regional vulnerability

As shown in the section above, vulnerability is a complex issue and is difficult to assess. Yet, there are a number of reasons why it is necessary to find ways and methods for assessment. With reference to the UNFCCC's article 2, the IPCC has been requested to help policy-makers to precisely define what should be considered 'dangerous' impacts of climate change[9]. Improved approaches for comparing and aggregating impacts across sectors and populations are needed.

Moreover a focus on system capabilities to cope or to adapt and on adaptation processes could be relevant for national or sub-national policy development. Given the emphasis placed on the Kyoto protocol's adaptation fund in the recent negotiations, it may become relevant to suggest recommendations in relation to adaptation funding. Vulnerability indicators have been proposed, not only as assisting in the determination of 'dangerous levels' of climate change, but also for allocation of such funding (Moss et al., 2001). Increased

[9] Article 2 states that 'the ultimate objective of this Convention... is to achieve... stabilization of greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system...(McCarthy, et al. 2001).

knowledge of these issues could serve to illustrate and clarify the linkages between climate adaptation and the general promotion of sustainable development

In an attempt to conceptualise adaptation (Smit et al., 2000), three ways of approaching the issue is mentioned: conceptual studies, numerical studies (development of impact assessment models including adaptation) and empirical studies (focussing on past adaptations to climate or other stimuli). These complementary and interacting approaches are also used for the study of vulnerability. The following sections will take a closer look at some of the suggestions for vulnerability assessment. The focus will be on the possibilities of assessing regional vulnerability, an important issue from the perspective of fairness and burden sharing among countries.

Approaches to vulnerability assessment

Efforts to assess and compare potential regional impacts of climate change or vulnerability of regions or nations are quite recent and available methods need further refinement. For comparative purposes it is necessary to synthesise a large amount of complex information and present it in some comparable format or unit, such as in monetary values, in an aggregate index, or in indicator sets. Unfortunately there are few studies and little knowledge about criteria and variables by which vulnerability and adaptive capacity can be quantitatively compared within and between regions.

Methods for the assessment of vulnerability to or impact of climate change have mainly developed along two lines:

Predictions of net damage is one way of approaching the difficult area of identifying 'dangerous' levels of climate change, and the relative vulnerability of regions and sectors can be related to the outcome of such predictions (Kelly and Adger, 2000). Climatic models are still quite weak when it comes to prediction of regional changes in climatic stimuli. Moreover integrated impact assessment models are encumbered with uncertainties, difficulties in modelling effects of adaptation, and a number of other complexities (McCarthy et al., 2001). In chapter 6 a review of integrated assessment models is presented.

As discussed above vulnerability of regions can also be approached by focussing more on the system characteristics, such as sensitivity and resilience, and how they may affect adaptive processes (Moss et al., 2001). This approach is based on research traditions within natural hazard research on behaviour as response to environmental stress, decision-making, institutional capacity, and flexibility. While the exposure sets the context of the analyses, the focus is on pre-existing constraints on the capacity to respond (Kelly and Adger, 2000). This approach includes a quantitative path, which focuses on the development of vulnerability indices.

Table 4.2 presents a list of indicators and measures that initially has been used for conceptual modelling or indication of vulnerability. Physical and monetary measures result from integrated modelling, while other indicators are constructed from the attributes of vulnerability. The first two rows are specifically related to vulnerability to climate change. The third row - the aggregated indices - is partly developed for more general purposes, partly for the specific issue of climate change.

Table 4.2: Possible vulnerability indicators.

Indicator type	Examples	Sources
Physical measure, e.g. water stress, food security, sea-level rise, hydrological regions	Number of people affected, Number of systems affected, Change in net primary productivity	(Arnell, 1999), (Parry et al., 1999b), (Mendoza et al., 1997)
Monetary measure	Value of damages caused by climate change	A number of sources – see chapter 6
Aggregated indices	Environmental Vulnerability Index (EVI), Composite Vulnerability Index (CVI) Vulnerability-resilience-indicator-prototype (VRIP)	(Kaly et al., 1999) (Atkins and Mazzi, 1999) (Moss et al., 2001)

The World Bank has initiated work on the development of a vulnerability index for small island states (Atkins and Mazzi, 1999). Often GDP per capita is used as a criterion for various kinds of development support, but it has been argued that conditions like high economic exposure, remoteness and isolation, and proneness to natural disasters have a debilitating effect on small economies, in spite of relatively high per capita incomes. Complementary criteria may need to be developed for decisions on differential treatment, e.g. in the designation of less developed countries (LDCs). Vulnerability is linked to (1) the incidence and intensity of risk and threat, (2) to the ability to withstand risks and threats (resistance), and (3) to bounce back from their consequences (resilience). Behind the Composite Vulnerability Index is a model that statistically links a measure named 'output volatility'[10] to number of people exposed to natural disasters in a given period, to export diversification and to export dependence. These were selected from a large number of tested variables (Atkins and Mazzi, 1999).

Indices of present and future vulnerability related to a number of issues have been constructed, including water resource risk and food security. Moreover attempts to link vulnerability indices to global change assessment models have been initiated (Downing et al., 2001).

A vulnerability index for climate change (Moss et al., 2001)

One example of such an attempt is a study that aims at building an aggregated vulnerability index at the national level, using an integrated assessment model to forecast input parameters for sector analyses of sensitivity and adaptive capacity. The structure of the

[10] Output volatility is the standard deviation of annual rates of growth of constant price GDP per capita – a measure that is used by Atkins and Mazzi as vulnerability indicator.

prototype index developed is presented in figure 4.3. Sensitivity is assessed for the food, settlement, health, water, and ecosystems sectors, while adaptive capacity is linked to economics, human resources, and environment.

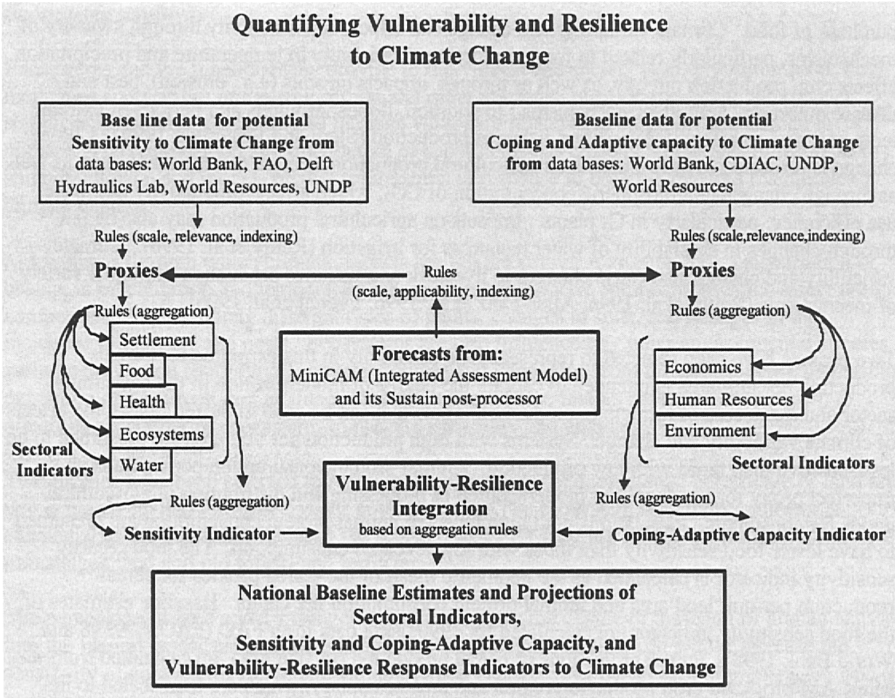

Figure 4.3: A framework for a vulnerability-resilience indicator prototype (VRIP). (Moss et al., 2001).

The approach to vulnerability taken in this work is closely related to the vulnerability concept adopted by IPCC. But the concrete development of an index of vulnerability creates a number of problems. Basically it must be questioned whether it covers the conditions creating vulnerability. The development of VRIP draws on a wide range of knowledge on determinants of sensitivity and adaptive capacity and includes proxy variables covering a range of functional relationships. One problem is however, that institutional issues are not included, while considerable attention is paid to both formal and informal institutions in most adaptation approaches. This aspect is mentioned in the report, and it is suggested to include civic resources[11] in further work on the index (Moss et al., 2001). Moreover the aggregation level is extremely high in the final vulnerability index – a number – and should be considered in the light of the complex conditions that it covers. The present index is however transparent and facilitates analyses of the various sector sensitivities.

Pathways for index development

Suggestions for further development in the application of indices to adaptation priorities have been put forward (Downing et al., 2001). One suggestion is to develop a problem-oriented approach,

[11] Civic resources includes resources related to social relations, networks, associations among individuals or other, where kinship relations, civic associations, etc. are associated with obligations to help those who are negatively affected by climate change.

acknowledging that potential impacts differ fundamentally and cannot be easily compared; an example is how to compare and prioritise between food security in Mali versus coastal hazards in Bangladesh. In this approach sectoral vulnerability might with advantage be related to the specific threats of climate change, thereby defining domains or themes of vulnerability, as exemplified in figure 4.4. Within such domains specific indices could be developed for characterisation of regional vulnerability. Funding could then be allocated to domains –problem fields - and prioritised within the domains using indices and other information.

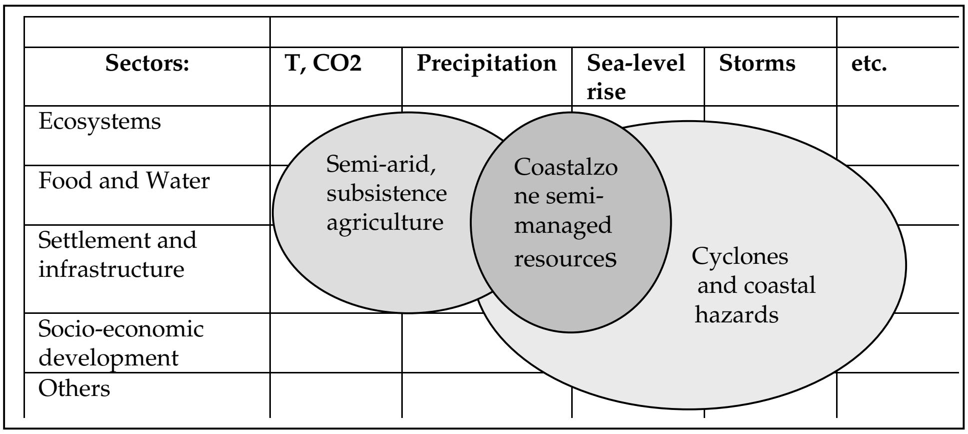

Figure 4.4: Examples of vulnerability domains (after Downing, 2001).

As pointed out by Kates (2000), vulnerability to climate change is to a high degree linked to the global poor for whom adaptation only may happen with tremendous social costs. He argues that 'if the global poor are to adapt to global change, it will be critical to focus on poor people, and not on poor countries as does the prevailing North-South dialog'.

By taking a thematic approach to problem fields, like drought in semi-arid areas, this point would to some extent be acknowledged. A problem for this approach would however be that data on subnational levels are often lacking or difficult to obtain.

Other more simple approaches seek to link sectoral vulnerabilities to present adaptability represented by the Human Development Index.

4.5 Summary

There is general agreement that the developing countries are more vulnerable to climate change than the developed countries. This is due to their greater reliance on primary sectors, which are susceptible to climate change, and their insufficient adaptive capacity due to economic and institutional weaknesses. There is less knowledge about regional distributions of future climate damages and comparisons across regions and composite indices for robust international comparison are in their infancy. Calls for more refined criteria for decision-making have recently been made by international bodies and governments. Researchers have taken initiatives towards these ends and some suggestions for relevant research have been made, including development of indicators on impact, sensitivity, and adaptive capacity across regions and socio-economic groups.

5 Adaptation to Climate Change

In the climate change context, adaptation refers to the adjustment of social, economic or ecological systems to climatic stimuli, i.e. not only to changes in mean values of climatic variables, but also to the rate of change of these variables, climate variability and extreme climate events. As was illustrated in figure 4.1, it is common to differentiate between autonomous and planned adaptation. In unmanaged biophysical systems adaptations are autonomous and reactive processes, which are the way in which species and habitats respond to changing conditions. In the following section only adaptation in social systems are addressed.

It has been argued that adaptation to changes in the mean condition mostly fall within the coping range of human systems and communities, while these systems are usually much more vulnerable to changes in occurrence of extreme events (McCarthy et al., 2001). Adaptation to climate change has moved up the climate change agenda as scientific confidence in climate change has increased. At an earlier stage, adaptation was seen as being a politically incorrect issue, as it could be interpreted as a reluctance to carry out mitigation measures (Burton, in: Pielke, 1998). But, as it has become evident that mitigation efforts will not prevent substantial impacts, the need to take significant adaptive measures has become more evident (Parry et al., 1999b).

Political interest in adaptation stems from several areas of concern. Firstly from an interest in which adaptations are likely to occur autonomously (Smit et al., 2000). Secondly from a concern that the rate of climate change could outpace the adaptive mechanisms inherent in social and natural systems, and that adaptations should therefore be supported (see figure 4.1).

Table 5.1 illustrates how adaptation can be viewed in a policy context. For the purpose of predicting 'dangerous' levels of impacts, adaptation analysis must be included in impact assessment, as was indicated in figure 4.1. Moreover adaptation is relevant for policy evaluation, i.e., in relation to questions of which adaptations to undertake according to criteria such as cost-benefits, economic efficiency, equity, and implementability.

Table 5.1: The role of adaptation *(Source: Smit et al., 1999).*

	Adaptation as part of IMPACT ASSESSMENT	Adaptation as part of POLICY EVALUATION
Analytical Function	Positive	Normative
Purpose	Predict, Estimate Likelihood	Evaluate, Prescribe
Central Question	What Adaptations are Likely?	What Adaptations are Recommended?
UNFCCC Article	Art. 2. are the impacts likely to be dangerous for ecosystems, food production and sustainable economic development?	Art. 4. which measures should be formulated and implemented to facilitate adequate adaptation?

It should be pointed out that autonomous adaptation is included in both columns in Table 5.1. Instead of being undertaken by governments, autonomous adaptation is carried out by economic agents in the course of making their decisions about allocating resources to production, consumption, and investment.

5.1 Why adaptation?

Through the Kyoto Protocol the international society has agreed on a first round of mitigation targets. Recent studies find, however, that full implementation of the Kyoto targets will only reduce global warming slightly and will have little effect on the impacts of climate change (Parry et al., 1998a; Parry et al., 1998b; Wigley, 1998). The main reasons for this are the anticipated growth of GHG emissions from developing countries (the developing countries are not committed to emission limitation under Kyoto) and that, due to their slow decay rates in the atmosphere, GHGs emitted in the past that already have entered the atmosphere over recent decades commit us to further global warming.[12] As figure 5.1 illustrates, the implications of full implementation of Kyoto in terms of reduced increase in temperature, 0.05 ^{O}C, are almost negligible by 2050. In IPCC's 'best estimate' scenario, the temperature increase by 2100 is about 2.4 ^{O}C (Houghton et al., 1996). Wigley estimates that even with a 1% reduction per year after 2012, the global mean warming reductions by 2100 are small, and climate stabilization will not be approached (Wigley, 1998).

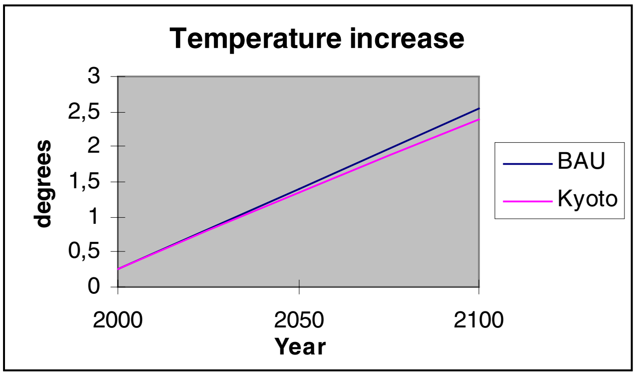

Figure 5.1: Expected temperature increase with and without Kyoto. (BAU is Business as Usual) *Source*: Based on (Parry et al., 1998b).

Parry and co-workers have estimated climate impacts by 2050 without any autonomous adaptation in three areas – water shortage, coastal flooding, and hunger. They examined the consequences of global warming under four different scenarios. The first scenario is a business-as-usual scenario (i.e. no mitigation); the second is full implementation of Kyoto; the third is a more-ambitious-than-Kyoto

[12] As the warming in 2050 occurs for a large part due to emissions that have already entered the atmosphere, the impact of the Kyoto reduction targets will be relatively larger in the longer term. The reduction in relative warming by 2100 for the four scenarios shown in Table 5.2 are 2.54^{O}C, 2.39^{O}C, 2.19^{O}C, and 2.08^{O}C respectively, i.e. a reduction of 0.15^{0}C for the implementation of the Kyoto targets. (Parry et al., 1998b).

scenario implying a 20% reduction; and the fourth scenario implies a 30% reduction relative to the unmitigated base case (see Table 5.2). Kyoto would reduce global warming by only 0.06 °C by 2050, and the considerably more stringent target of 20% reduction would only achieve a further reduction of 0.1 °C.[13]

Table 5.2 Impacts estimated for 2050.

	Impacts estimated for 2050			
Emissions scenarios	Global warming (°C) w.r.t. 1961-90	Million of people at additional risk of:		
		Water shortage	Coastal flooding	Hunger
Unmitigated	1.39	1053	23	22
Kyoto	1.33	1053	22	20
20% reduction	1.22	909	21	17
30% reduction	1.19	891	20	16

Source: (Parry et al., 1998b).

As seen in Table 5.2, Parry et al. find that full implementation of the Kyoto agreement would not affect the number of people without access to adequate water, and those prone to coastal flooding and hunger would only be affected to a minor degree. Even an ambitious 30% reduction would only reduce the numbers affected by water shortage by a few percent, while the impact on hunger would be somewhat more substantial. This strongly indicates that efforts to remedy climate change will not have a large impact on the key problems facing developing countries.

The study by Parry et al. does not estimate the economic value of the avoided climate damages or the mitigation costs of the three emission reduction scenarios. But it shows that even very deep cuts in GHG emissions from the industrialized countries would have relatively little effect on groups that are vulnerable to climate change. It is also evident that reduction of GHG emissions from developing countries will be necessary in order to halt climate change; the developed countries are unable to solve this problem alone. It is furthermore evident that adaptation to climate change probably will be inevitable and should be an integral part of any comprehensive, multifaceted climate change strategy.

5.2 Timing of adaptation

Some have concluded that it is better to delay adaptation to climate change until later (Ausubel, 1995). It is argued that many key issues in climate change research are uncertain, better and cheaper technology will be available in the future, and future generations will have greater wealth that can be used for adaptive purposes. In the extreme version of this argument, there is no need for an adaptation

[13] Numbers are rounded.

policy response to climate change. But it seems most doubtful that purely market-based approaches to adaptation will alone be sufficient and much less be optimal, especially in developing countries.

Arguments for the postponement of adaptation to climate change are often based on the assumption that climate change is likely to happen gradually. However, in 1990 the IPPC concluded that the rate of future climate change was uncertain. Evidence indicates that the climate in earlier times has changed considerably within decades (Dansgaar, 1993; Overpeck, 1996), and irregular behaviour is accepted as a major aspect of the dynamics of complex systems (McCarthy et al., 2001). The IPCC Second Assessment Report emphasises the occurrence of non-gradual changes: 'Future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve 'surprises'. In particular these arise from the non-linear nature of the climate system. When rapidly forced, non-linear systems are especially subject to unexpected behavior' (Houghton et al., 1996). The IPCC Third Assessment Report emphasises climatic variability and extremes as the main challenges for adaptation (McCarthy et al., 2001).

Box 2:
Why Adapt to Climate Change Today: Main Arguments for and against

Arguments for:
- the atmospheric concentrations of GHGs will increase during the 21st century
- considerable uncertainty about climate change
- non-gradual changes likely to occur
- already committed to some climate change
- need for precaution
- possibility of significant irreversible impacts
- loss of inexpensive opportunities if adaptation is postponed to later

Arguments against:
- better adaptation options and technologies become available in the future
- more knowledge in the future
- more wealth in the future
- climate change is characterized by long lead times and cumulative changes
- mitigation should be the primary policy response
- climate change impacts will be insignificant
- spontaneous, autonomous adaptation will generally be more effective than planned, anticipatory adaptation.

Anticipatory adaptation options are those that a) would be taken for reasons other than climate change but have climate change benefits, b) those that involve modifying planned measures just a little (i.e. at low cost) to adapt to climate change. It might also include building flexibility into new 'systems' such that they can operate effectively under a variety of alternative climate scenarios (including existing climate), even though they do not provide the highest net benefits under current climate.

Adaptation is not advisable in all cases, however, and the need for adaptation may be assessed best in each single case and at the sectoral level. Whether adaptation is advisable depends on the constraints on and opportunities for adaptation as well as on the cost and benefits associated with an adaptive response. Moreover, climate impacts on regional and national levels presently cannot be predicted with accuracy. However, despite the current uncertainties of climate change, in some cases it is clearly preferable to develop and implement anticipatory adaptation policies (Smit, 1993; Burton, 1996). An U.S. Office of Technology Assessment Report in particular points to the costs of possible climate impacts, cases where there exist a need to react well in advance of any climate change, and when anticipation today is less expensive or more successful compared with a response made at a later stage. As the report concludes:

> 'Waiting to react to climate change may be unsatisfactory if it is possible that climate change impacts will be very costly. Of greatest concern may be those systems where there is the possibility of surprise–of facing the potential for high costs without time to react–or where the climate impacts will be irreversible. Such impacts seem more likely if long-lived structures or slow-to-adapt natural systems are affected, if adaptive measures require time to device or implement, or if current trends and actions make adaptation less likely to succeed or more costly in the future. In these cases, anticipating climate change by taking steps now to smooth the path of adaptation may be appropriate' (Smith and Mueller-Vollmer, 1993).[14]

All these are important reasons why it would be advisable to react earlier rather than later. In some cases and situations there might be several such reasons for deciding not to postpone adaptation. First, it seems justified to react at an early stage when the costs of climate change impacts potentially are very high, but could be avoided, or at least reduced, by anticipatory adaptation. Climate change causing storms and floods could result in loss of human lives and property, but costs and losses could be reduced through improved contingency planning. In general, it is necessary to take into account varying lead-times of human interventions and the lead-time of ecological and socio-economic systems when examining the need for anticipatory adaptation. Some species may be unable to migrate to a more favourable location before the climate changes, for example, and government intervention to make markets favour more climate-robust products may take years and even decades to accomplish.

Decisions of a long-term nature made today may be affected by future climate change. For example, some types of trees that are planted today may not survive under altered climate conditions that increase temperatures and change precipitation patterns. Similarly, the design of long-lived structures, such as bridges and dams, should take into account possible climate change. Another example, coastal-zone development in climate-sensitive areas in Africa may contribute

[14] Examples of irreversible changes are loss of species or loss of valuable ecosystems.

to future losses due to climate changes if no adjustments to climate change are made.[15] Moreover, in some cases reacting to climate change may already be warranted. Adaptation is therefore advisable in areas (e.g. floods and droughts) where action already is needed but has not yet been taken. Such anticipatory steps would bring benefits even in the absence of climate change. They should be considered examples of so-called 'no regrets' options.

Action should be considered in situations such as those just described. However, there is no need for immediate adaptation when adequate technologies and responses to climate change already exist and can be readily implemented. Some adaptation responses may have short lead times and could easily be implemented by existing institutions. They could therefore be implemented as the effects of global warming unfold. For example, it might be relatively easy to switch to heat-tolerant crops as warming increases. Moreover, by postponing adaptation until later, it is possible to increase knowledge of the magnitude and severity of impacts and accordingly respond in a more adequate manner. Also important, feasible and effective adaptation responses may be available today but inexpensive and even more effective responses could become available in the future. If adaptive responses and policies are implemented prematurely, future opportunities for inexpensive and effective adaptations could be lost.

In some cases, industrialised countries already have the technology, wealth, know-how, and institutional capacity necessary to protect themselves when the climate changes. Developing countries are more vulnerable than industrialised countries to adverse effects of climate change while in general they lack the capacity and resources needed to protect themselves against negative climate effects. TAR identifies the main barriers to adaptation in these countries as:

- financial/market (uncertain pricing, availability of capital, lack of credit)
- institutional/legal (weak institutional structure, institutional instability)
- social/cultural (rigidity in land use practises, social conflicts)
- technological (existence, access)
- informational/educational (lack of information, trained personnel)

(McCarthy et al., 2001).

High priority should be given to the enhancement of sustainable economic growth in developing countries because this will increase their wealth, resources, and options available for adaptation (see e.g., (Goklany, 1995). In this respect it should be noted that the UNFCCC stresses that the achievement of sustainable social and economic development and eradication of poverty are priority goals for the developing countries. Moreover, this underlines the importance of integrating adaptation with other immediate, medium, and long-term goals and with broader societal goals of the developing countries. Additionally, the threat of climate change is yet another significant

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[15] A World Bank report identifies global warming and vulnerability of sea-level rise as an important area for regional cooperation deserving GEF support (World Bank, 1995).

environmental issue, which should justify that further strengthening of indigenous institutional capacity to protect the environmental and ecological resources of developing countries is undertaken. Finally, solutions to adapt to climate change may presently be unavailable or unknown. In those cases, it is necessary to develop solutions and society must engage in and stimulate research in order to improve the capacity to adapt.

5.3 Four types of strategic adaptation responses

Table 5.3 shows four types of strategic adaptation responses to climate change. They represent four generic response types. They are not listed according to priority, urgency, or cost. In case of the first group, adaptation costs will often be incurred at the early stage, whereas for other types of policies costs will be incurred either later or over the entire life of a project or a policy. Some adaptive policies may fit more than one generic policy type. It will be important to identify those policies and measures that are better taken soon, otherwise opportunities for inexpensive adaptation options will be missed.

Table 5.3 Four generic types of strategic adaptation responses to climate change

(1) *Project-based activities*.
Included in this group of adaptation policies are:
a. modifications of projects with long life spans (e.g. dams, bridges, forests). The policy is to modify projects so that they can perform satisfactorily for the entire range of likely climate changes;
b. projects that bring benefits and achieve their goals irrespective of occurrence of climate change (‘no regrets’ options). The policy is to realize ‘no regrets’ options to the extent possible, e.g. improvement in the capability to adjust to existing climate variability;
c. projects for which adaptation to climate change is inexpensive. Where inexpensive opportunities exist, projects should be modified so that they are able to perform satisfactorily for the entire range of likely climate changes, e.g. sewage systems may be modified inexpensively to prepare for future changes in ground water level;
d. projects that increase protection against extreme events (e.g. floods, storms, drought). Projects should reduce the vulnerability to extreme events when it can be achieved with no or few additional costs, e.g. by increasing drought early warning and preparedness;
e. projects which prevent irreversible impacts (e.g. preservation of biological diversity). Projects should help to preserve valuable biological resources, e.g. by protecting against sea-level rise threatening valuable coastal resources.

(2) *Institutional and regulatory adaptation.*
Included in this group of adaptation policies are:
a. projects that aim to correct developments that otherwise would increase vulnerability to climate change in the future (e.g. infrastructure, coastal-zone development, land use). By using regulatory measures, projects aim to reduce future social and economic vulnerability to climate change, for example, by removing economic incentives that stimulate population increase in coastal areas that are endangered by rising sea-level, or adopting land-use regulations;
b. projects that correct institutions in order to reduce vulnerability (existing institutions may produce ‘perverse effects’). Policy should correct economic institutions when they increase vulnerability to climate change, e.g. removing economic subsidies that create an economic disincentive for shifting to drought-resistant crops (e.g. from maize to millet).

(3) *Research and education.*
Included in this group of adaptation policies are:
a. projects aiming at developing solutions when adaptive solutions currently are unavailable and time is needed for their development. When costs are modest, projects might, for example, contribute to the development of drought-resistant crops and cultivars;
b. projects that stimulate behavioral changes needed to accommodate to climate change. Projects might help to raise awareness of climate change and opportunities for adaptation, e.g. by supporting relevant activities of government agencies and NGOs.

(4) *Development assistance for capacity building.*
Included in this group of adaptation policies are:
a. projects enhancing the productivity of sectors, especially natural resource sectors. Projects should aim to increase the productivity of sectors because this will increase wealth, resources and options available for adaptation in developing countries;
b. projects that strengthen the overall institutional capacity of developing countries. Projects should aim to strengthen the institutional capacity of developing countries because this increases their capabilities to develop and implement adaptive responses to adverse climate change effects;
c. projects that reduce pollution levels and improve environmental quality. By reducing non-climate environmental stresses, projects contribute to making natural and socio-economic systems more robust and less vulnerable to climate-related stresses.

Source: Ringius et. al, 1996.

5.4 Summary

Adaptation attracts increasing interest today, and it was recently agreed to fund adaptation projects in vulnerable developing countries. Most research addressing adaptation argues for anticipatory adaptation sustained by public policy. There is still a lack of knowledge on adaptation forms and processes, of the costs of adaptation projects and programs, and of the comparability between alleviating present criticality and adaptation to future impacts.

Developed countries will in general have the necessary capacity for initiating adaptation measures. But many developing countries, which are expected to be negatively affected by impacts of climate change, lack this capacity. While it recently was decided to establish adaptation funding for the most vulnerable regions in the context of the UNFCCC, the means available for such funding are expected to be relatively modest. TAR recognises that the enhancement of adaptive capacity in many ways is compatible with and would complement those development efforts that are promoted under the rubric of sustainable development. There is therefore a need to explore further how general development efforts towards sustainability could reinforce adaptive capacity in the context of climate change, and *vice versa*.

6 Determining the Impacts from a Changing Climate: IAMs and Impact Studies

In the past the term 'costs of climate change' has primarily been associated with mitigation activities, i.e. the reduction of CO_2 or other greenhouse gas (GHG) emissions from the industry, energy, agriculture, and residential sector. In accordance with this emphasis on the mitigation side of the climate change problem, the equity literature (see chapter 3) has mainly been concerned with evaluating the distribution of mitigation costs among industrialised countries from the perspective of different equity criteria and fairness principles.

The costs of the potential impact of climate change have been a more neglected subject in the global climate negotiations. The subject has generally been considered 'politically incorrect' because it was seen as a distraction from the more urgent mitigation actions. Lately, however, together with growing evidence of an uneven North-South distribution of costs and benefits associated with a changing climate and little progress since the Kyoto Protocol agreement in 1997, impact assessment is receiving more attention. As pointed out by (Parikh and Parikh, 1998), by focussing attention on the impact side of climate change, the risk to poor countries becomes a salient issue.

Different tools are available to analyze and describe regional impacts from climate change. Chapter 4 has concentrated on two instruments, namely vulnerability indices and indicators, while chapter 5 focused on adaptation measures, their motivation and timing, and the opportunity for reducing impacts on a regional and local level. The main aim of this chapter is to present a third tool available to inform climate change policymaking, namely monetary impact assessment and its inclusion in Integrated Assessment Models.

Early attempts to monetize climate change impacts on a country and global scale have been summarized in the IPCC's Second Assessment Report and its Working Group III (Pearce et al., 1996). Since then, most models employed and their impact estimates have been improved.

Opinions in the scientific community diverge with regard to the usefulness of cost-benefit analysis (CBA) as a tool for evaluating policy options in the area of climate change. Opposition to the application of CBA is often founded in the inherent difficulties associated with determining the actual impact resulting from climate change and its measurement in monetary values, including the choice of the discount rate (Bolin, 1998; Tietenberg, 1998). Costing the impact on market goods and services (e.g. reduction in agricultural output, increased energy needs for cooling) is often relatively easy. On the other hand, the costs connected with changes in the supply of non-market goods, especially those that do not result in changes in human behavior (e.g. loss of biodiversity) are much more difficult to determine. Although there are methods available to elicit willingness-to-pay for non-market services (e.g. contingent valuation or contingent ranking methods) their credibility is questioned by a number of scientists. Some members of the scientific community question whether the environment should at all be priced. However, other scientists advocate the need for a global cost-benefit assessment to provide policy makers with some numbers, however crude, about the costs and benefits associated with mitigation actions (or the lack thereof), and their likely distribution (Pearce, 1998). This more pragmatic approach is based on the argument that uncertainty about the actual value of environmental damages should not lead to their value being treated as 'zero' as could be the case if no range of values is available.

The mitigation costs associated with different emission levels have been analyzed and summarized in a number of publications, the most comprehensive one being the summary of the Stanford Energy Modeling Forum (Weyant et al., 1999). In line with the Second Fairness Framework presented in chapter 2, this chapter concentrates on the impact site of climate change and presents an overview of Integrated Assessment Models (IAMs) and describes a number of impact studies. The emphasis is on the regional diversity and the treatment and integration of adaptation in the models and impact studies. The main focus of these studies is on the monetisation of impacts. Equity issues are only touched briefly, mostly by pointing to the uneven regional distribution of impacts and in some cases calculating worldwide impacts using weights that account for income differences between regions. The following overview includes therefore a brief summary of a recent attempt to approach the equity issue by proposing a compensation scheme based on shares of contribution to the climate problem and shares of potential damages resulting from it (Panayotou et al., 2001).

6.1 Representation of Impact and Adaptation in Integrated Assessment Models of Climate Change

The following chapter provides a short introduction to the representation of impact and adaptation in IAMs. Based on the overview given in (Tol and Fankhauser, 1998) ten IAMs are selected and presented in Table 6-1. In the next section, four different impact studies (three of them are the most recent ones available) are summarized and their indicative results are discussed. Making rational and informed policy decisions on climate change issues requires the integrated assessment of a large number of interrelated processes. The climate change system is defined by human activities that determine the greenhouse gas emissions that in turn, together with atmospheric, biological and oceanic processes, link emissions to atmospheric concentrations. Based on those emissions levels, climate and radiative processes influence the global and regional climate, which again affects ecological, economic and socio-political processes, where final impact can be assessed in physical, monetary, or other units. Most of the current attempts of assessing climate change processes in an integrated fashion are pursued in the form of models, the so-called Integrated Assessment Models (IAMs). Figure 6.1 shows the main elements of such a full-scale model.[16]

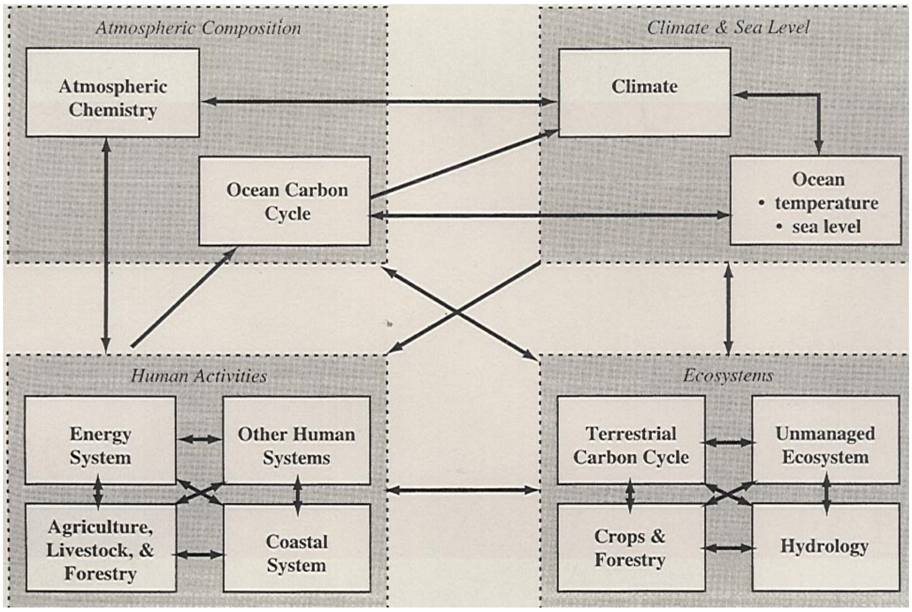

Figure 6.1: Key components of full scale IAMs. Source: (Weyant et al., 1996).

One of the main challenges (and until today the weakest part) of IAMs is to translate temperature change into market and non-market damages (both in physical units and subsequently to put a monetary value on those physical damages) in order to obtain a basis for the comparison of benefits and costs of climate change policies. The different market and non-market damages resulting from a changing climate are outlined in section 4.2. Market effects are those included in conventional national income measures and can be valued based on observed prices or demand and supply functions. Lack of observable market prices, on the other hand, is the main characteristic of non-market effects. These need to be valued based on a range of alternative revealed preference or attitudinal methods, whose scientific credibility is often questioned.[17]

The impact modules in IAMs are normally based on aggregated results from impact studies. These are based either on the modellers own research efforts or taken from the literature. Impact functions are then calibrated around these benchmark results.

(Tol and Fankhauser, 1998) provide a detailed summary of the coverage of impact types and regional detail in more than twenty IAMs. Like Weyant et al. (1996), they distinguish between two integrated assessment modelling approaches, namely *policy optimisation* models using an economics approach to analysing climate change and *policy evaluation* models, which are directed more

[16] A detailed description of the development history of IAMs and their first round of results can be found in Weyant et al. (1996).
[17] See Freeman III (1994) for a detailed overview over methods to value non-market resources.

towards the natural sciences. This report focuses on policy optimisation models because of the inclusion of monetized damages in these models. However, policy evaluation models, like IMAGE 2.1, allow for a better description of regional impact by focusing on the complex, long-term dynamics of the biosphere-climate system, albeit without the explicit calculation of costs (Alcamo et al., 1998). Extending these natural science based models with socio-economic models could be the way forward in impact modelling.

Policy optimisation models calculate for example optimal carbon emission reduction rates or carbon taxes based on certain policy goals, e.g. maximising welfare or minimising abatement costs of meeting a specific target.

Weyant et al. (1996) distinguish between three different types of policy optimisation models:

1) Cost-benefit models that balance the marginal costs of controlling greenhouse gas emissions and adapting to climate change against the costs associated with the remaining damages, thus determining optimal carbon emission reduction rates based on maximising welfare as a policy goal;
2) Target-based models that optimise mitigation responses given a specific target for emission control or climate change impact; and
3) Uncertainty-based models that attempt to incorporate uncertainty by conducting sensitivity analyses or by simulating probability distributions for major inputs and parameters. This last category appears often as a combined version with either (1) or (2).

Economic modelling of climate policy analysis can thus take on a variety of forms and their usefulness depends on the type of analysis required. This report focuses on the sharing of (economic) burdens from climate change in a North-South perspective, and the IAMs discussed below and presented in Table 6.1 have been selected with that issue in mind.

In their summary of IAMs, Tol and Fankhauser (1998) focus on the impact modeling and treatment of adaptation in the various models. Their survey reflects the state-of-the-art in 1996. The issue of impact modeling is also taken up in a recent Danish study (Linderoth, 2000), but most of the impact models discussed date back to the IPCC's Second Assessment Report. Table 6-1 below is based on the summary presented in (Tol and Fankhauser, 1998). Because the current study is primarily concerned with the regional distribution of costs and benefits, it only includes models with regional diversification. Tol and Fankhauser's summary is updated to include more recent model development, where a definitive trend towards more regional diversification can be observed. Examples here are the latest version of the RICE model (Nordhaus and Boyer, 2000) and the Global Impact Model (GIM) developed by Mendelsohn et al. (2000). The damage categories considered, the spatial details and the sources for impact benchmarks in each model are noted and the treatment of adaptation is described.[18]

Impact functions

The impact functions of the IAMs listed in Table 6.1 cover a wide variety of impact categories ranging from the traditional market impacts in the agriculture, forestry and energy sector to hard-to-measure categories like health, ecosystem, and other non-market amenity impacts. As can be seen from Table 6.1 comprehensiveness of impact analysis varies considerably among models.

Impact functions in IAMs are normally developed around the so-called benchmark estimates for a doubling of CO_2 levels, derived from the literature. These benchmark estimates specify just one point on the damage function as can be seen in Figure 6.2. How the final damage function is determined based on the benchmark estimates varies from model to model. In most of the functions damage (D) is modeled in a form similar to

$$D = \alpha * T^{\lambda},$$

where α is the benchmark estimate and T is the temperature increase since the middle of the nineteenth century. The exponent λ determines the functional form and thereby level of increase in damages with increasing temperatures (see figure 6.2). Most IAMs assume a non-linear relationship between damages and temperature increase.[19]

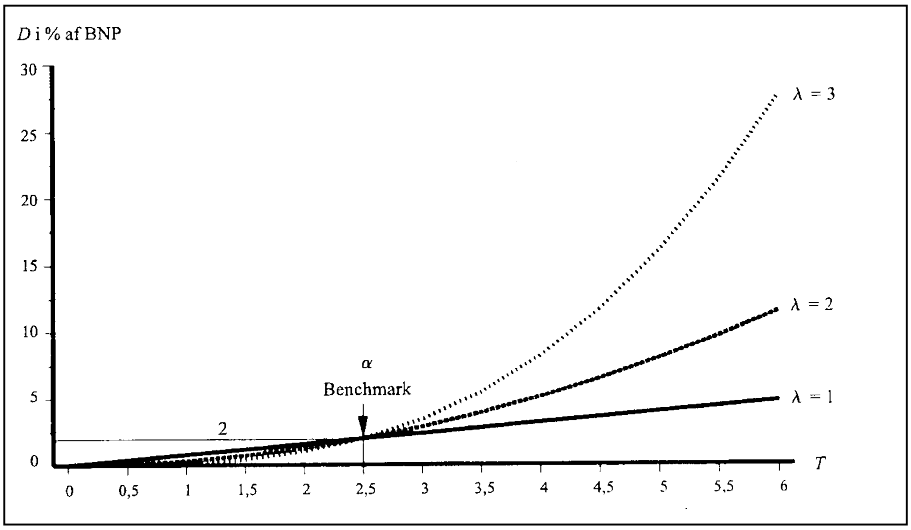

Figure 6.2: Influence of λ on the damage function. Source: (Linderoth, 2000).

Impact is driven either by global mean temperature or by regional temperature. The aggregation level of impact modeling ranges from one-equation models to models that include separate impact

[18] The reader is referred to Tol and Fankhauser (1998) for more details on the functional specifications of the different models.

[19] See Tol and Fankhauser (1998) and Linderoth (2000) for a more detailed specification of the different functional forms.

functions for each impact category. Two-equation impact models usually just separate broadly between market and non-market impacts. The recently developed Global Impact Model (GIM) from Mendelsohn et al. (2000) includes different climate response functions for the agriculture, forestry, coastal resources, energy, and water sectors, based on detailed empirical studies for each sector. While GIM only includes market impacts, thus leaving out the potentially substantial non-market effects from climate change, the latest version of the RICE model (Nordhaus and Boyer, 2000) also has separate impact functions for non-market sectors, e.g. amenity impacts, human settlements, and ecosystems.

As mentioned before, Table 6.1 only includes 'regional' IAMs, where the spatial detail varies between 4 and 13 different geo-political regions. The only two models examining impact in a more geographically explicit way are the FARM model (Darwin et al., 1995) and the GIM model (Mendelsohn et al., 2000). The FARM model employs a 0.5° x 0.5° grid-based geographic information system to empirically link climatically derived land classes with an economic model of the world. The economic computable general equilibrium (CGE) model employed, though, contains only 8 regions (Darwin et al., 1995). The GIM model calculates market impacts for a range of sectors for a total of 178 countries based on information on predictions of the change in annual surface-air temperature and precipitation from a GCM with a grid resolution of 4° latitude x 5° longitude. The results are presented in a summarized fashion for 7 regions (Mendelsohn et al., 2000).

Monetization of impacts is based on a limited number of studies. Regional estimates are primarily based on U.S. studies, reflecting the lack of studies, especially from developing countries. Even the GIM model (Mendelsohn et al., 2000) relies on response functions for market sectors that are calibrated to the United States.

Treatment of adaptation

Many of the models included in Table 6.1 date back to the mid-1990s. This is also reflected in the treatment of adaptation. Despite its importance in recent policy negotiations, adaptation is only partially included in the impact modeling part of the IAMs. But there is a definitive trend in the newer models to explicitly incorporate adaptation in their impact modeling. In most of the aggregate monetary estimates used in the earlier impact modules (one or two equation impact functions), the costs of adaptation measures (e.g. coastal protection) are lumped together with the costs resulting from any residual damages (e.g. loss of unprotected land). Only few of the damage categories included in impact studies can be categorized as primarily adaptation costs, i.e. coastal protection, space cooling and heating, and probably migration, as pointed out by Tol et al. (1998). In other categories (e.g. agriculture or health) adaptive measures are implicitly included, but their costs are not reported separately. Thus, this treatment of adaptation does not always allow for a separate measurement of adaptation costs, nor is the assumed adaptation level necessarily optimal (Tol and Fankhauser, 1998).

According to Tol and Fankhauser (1998), some models include what they call 'induced' adaptation. This refers to the inclusion of adaptation in a mechanical way (e.g. protecting all land with a population density in excess of 10 people per square km).[20] Others include behavioral rules, where adaptive capacity depends on the socio-economic situation, e.g. crop management practices in FARM and optimization in PAGE that drive adaptation. For example, in the impact model of the RICE-99 IAM the costs of protecting coastline from sea-level rise are based on a study by Yohe and Schlesinger (1998) that includes perfect foresight by the economic individuals. The assumption of perfect foresight allows for market adaptation in the form of abandonment of land if further protection is deemed uneconomically and the depreciation of structures in areas where abandonment can be expected in the future.

Another approach to adaptation modeling is the so-called Ricardian approach of Mendelsohn et al. (2000). Ricardian studies econometrically estimate the impact of climate and other variables on the value of farm real estate.[21] According to this theory, in competitive markets the land value is equal to the present value of an infinite stream of annual net revenues derived from the most economically efficient management and use of land. One of the advantages of this method is that the measurements include the immediate private adaptation measures that farmers will take in response to a changing climate.[22] However, according to Adams (1999), Ricardian models do not capture the likely changes in input and output prices resulting from changes in demand and supply by farmers adapting to a changing climate. They are also likely to neglect the costs of changes in structural characteristics that might be necessary to comply with a warmer climate, i.e. irrigation systems (Adams, 1999).

Yet another approach to impact and adaptation modeling is represented in the multi-market model developed by Darwin et al. (1995). Their Future Agricultural Resources Model (FARM) includes upward and downward linkages of farmers' adaptation activities. A geographic information system (GIS) is used to empirically link different land classes[23] to other inputs and agricultural outputs in a computable general equilibrium model. The GIS alone can be used to calculate Ricardian rents but a comparison with results from Mendelsohn et al. (1994) finds recognizable differences between the two studies (Darwin, 1999). Yet, both studies indicate a hill-shaped relationship between temperature and agricultural land rents with likely detrimental effects of climate change in Latin America and Africa, beneficial effects in the former Soviet Union, mixed effects in

[20] Definition of induced adaptation according to personal email correspondence with Richard Tol. In Tol and Fankhauser (1998) induced adaptation is defined as 'the process of readjustment to a new climate, (which) is represented through transition costs and transition time'.
[21] The approach is named Ricardian by Mendelsohn et al. (1994) after David Ricardo, who observed that in 19th century England, agricultural lands of different fertility earned different rents.
[22] See Mendelsohn et al. (1994) and Dinar et al. (1998) for a detailed description of the Ricardian method.
[23] Land classes are here defined by length of growing season, i.e. the longest continuous period in a year that soil temperature and moisture conditions support plant growth.

eastern and northern Europe and in western and southern Asia (Darwin, 1999).

As with other impact studies most of the Ricardian estimates of climate response functions have been made for the United States, thus making it necessary to transfer these findings and assumptions about adaptation possibilities to other regions of the world. While this approach has often been criticized, Dinar et al. (1998) have analyzed farm performance across climates in India using the Ricardian technique and found response functions similar to those estimated for the United States. However, they also point to the fact that moderate aggregate impact results cover over the situation that individual farmers (depending on the specific temperature change and precipitation change of the area they are living in) still may suffer large damages. Damages in marginal areas might have little to no impact on the aggregate agricultural product, indicating that poor people dependent on subsistence farming in these local areas may be highly vulnerable to higher temperatures even when damages to the national agriculture are minimal (Dinar et al., 1998).

Based on the above presentation of adaptation modelling, adaptation adjustments can be categorised in 3 different ways:

1) Direct effects of climate change on supply curves (e.g. agricultural sector), holding technology options constant;
2) Indirect effects of climate change on market prices (of inputs and outputs) due to shifts in supply curves;
3) Changes in production technology:
   a. Endogenous technological change,
   b. Exogenous technological change.

Endogenous technological change is here defined as the types of technological innovations that occur without external interventions, for example because a dryer or more moist climate raises the demand for better irrigation systems or more suitable ploughing machines and thereby provides an incentive for their development and production. Exogenous technological change, on the other hand, is here defined as those innovations that are introduced or whose invention are facilitated through outside interventions, e.g. in the form of tax reductions, governmental programs, or foreign aid projects. In this sense adjustment stages (1), (2) and (3a) can be said to constitute autonomous adaptation, while (3b) could be termed 'planned' or 'strategic' adaptation.

Following this structure the Ricardian approach of Mendelsohn et al. (2000) includes autonomous adaptation in the form of (1) and probably to some extend (3a), while Darwin's FARM model also covers (2) in addition to (1) and (3a). In the climate change community the focus is normally on strategic or planned adaptation. Given that these measures will very much depend on the specific situation and economic, social and institutional possibilities in the different countries, it is not surprising that planned adaptation is hardly modelled in IAMs. However, modelling autonomous adaptation does provide useful information about the possibilities inherent in these kinds of adaptation measures and could offer some guidance for strategic adaptation measures. For example, by pointing to the effects of providing new technological options (irrigation, other crop types, etc.) to farmers, which in turn would facilitate autonomous adaptation.

As Tol and Fankhauser (1998) point out, the impact on society and ecosystems will be determined by a combination of climate change and vulnerability. As discussed in chapter 4, vulnerability of human systems is dependent on a range of factors (i.e. financial and technical capabilities, demographics, socio-economic and institutional constraints) that are likely to change over time. Any model attempting to forecast impact in the long run should therefore include a consistent model of the evolvement of these socio-economic systems over time. 'Perhaps the most crucial area of improvement concerns the dynamic representation of impact, where more credible functional forms need to be developed to express time-dependent damage as a function of changing socio-economic circumstances, vulnerability, degree of adaptation, and the speed as well as the absolute level of climate change' (Tol and Fankhauser, 1998).

Table 6.1: Representation of impact and adaptation in selected models.

Model	Damage categories considered	Spatial detail	Impact measurement	Treatment of adaptation
RICE-99 (Nordhaus and Boyer, 2000)	agriculture, sea-level rise, other market sectors, health, nonmarket amenity impacts, human settlements and ecosystems, catastrophes	13 regions (USA, Japan, other high income, OECD Europe, Eastern Europe, Russia, Middle income, High-income OPEC, Lower middle income, China, India, Africa, Low income)	separate functions for each category; monetized based on (Nordhaus and Boyer, 2000)	Agricultural impact for most regions based on (Darwin et al., 1995), for India and Middle income subregion based on studies employing Ricardian technique (Dinar et al., 1998); sea-level rise based on study by Yohe and Schlesinger (1998) that incorporates natural and planned adaptation. Not explicitly considered in other vulnerable market sectors, non-market amenity and ecosystems and health
MERGE (Manne et al., 1995)	Farming, energy, coastal activities, other	five regions (USA, other OECD (Western Europe, Japan, Canada, Australia and New Zealand), former Soviet Union, China, rest of the world	two functions (market, non-market; monetized adjusted from Nordhaus (1991)	not explicitly considered
CETA (revised) (Peck and Teisberg, 1992)	Wetland loss, ecosystem loss, heat and cold stress, air pollution, migration, tropical cyclones, coastal defense, dryland loss, agriculture, forestry, energy, water	six regions (USA, European Union, other OECD, former Soviet Union, China, rest of the world	two functions (market, non-market); monetized adjusted from Fankhauser (1995)	not explicitly considered
FUND 1.5 (Tol, 1995; Tol, 1996)	Coastal defence, dryland loss, wetland loss, species loss, agriculture, heat stress, cold stress, migration, tropical cyclones, river floods, extratropical storms	nine regions (OECD America, OECD Europe, OECD Pacific, Eastern Europe and former Soviet Union, Middle East, Latin America, South and Southeast Asia, Centrally Planned Asia, Africa)	separate functions for each category; monetized based on Tol (1996)	only induced adaptation, i.e. adaptation included in a mechanical way

PAGE 95 (Plambeck and Hope, 1996)	Economic, non-economic	seven regions (European Union (12), other OECD, Eastern Europe and former Soviet Union, Africa and Middle East, Centrally Planned Asia, South Asia, Latin America)	separate functions for economic and non-economic damages; (CRU/ERL, 1992); (Fankhauser, 1994; Tol, 1995)	Policy variable
MARIA (Fankhauser, 1993; Mori, 1996; Mori and Takahaashi, 1996; Mori and Takahaashi, 1997)	Coastal defence, dryland loss, wetland loss, species loss, agriculture, forestry, water, amenity, life/morbidity, air pollution, migration, tropical cyclones	four regions (Japan, other OECD, China, rest of the world)	one function; (Fankhauser, 1993)	not explicitly considered
ICAM 2.5 (Dowlatabadi and Morgan, 1993)	sea level rise, other market, health, other non-market	seven regions (OECD America, other OECD, Eastern Europe and former Soviet Union, Latin America, South and Southeast Asia and Middle East, Centrally Planned Asia, Africa)	separate models or functions for each impact category; (Dowlatabadi and Morgan, 1993); WTP (including thresholds and saturation)	Only induced adaptation, i.e. adaptation included in a mechanical way

MiniCAM 2.0 (Edmonds et al., 1993; Edmonds et al., 1994)	Market, non-market	eleven regions	separate models for each impact category; mainly based on Manne et al. (1995)	Only induced adaptation, i.e. adaptation included in a mechanical way
FARM (Darwin et al., 1995; Darwin et al., 1996)	land and water resources, agriculture, forestry, other	0.5º x 0.5º for resources, 8 regions (USA, Canada, European Union (12), Japan, Other East Asia, South East Asia, Australia and New Zealand, rest of the world)	separate models for each damage category; physical indicators; monetized based on Hertel (1993)	production practices in agriculture and forestry, land, water, labour and capital allocation
GIM (Mendelsohn et al., 2000)	market impacts for agriculture, forestry, coastal resource, energy, water	178 countries based on 4° latitude x 5° longitude resolution of GCM, results are presented for 7 regions (Africa, Asia/Middle East, Latin America/Caribbean, West Europe, Former Soviet Union/Eastern Europe, North America, Oceania)	different response functions for each impact category; (Mendelsohn et al., 2000)	private adaptation included in Ricardian climate response functions

Source: Adapted from Tol and Fankhauser (1998) table 2, 3 and 4, supplemented by own descriptions

6.2 Global and Regional Impact Estimates

As explained earlier, the impact functions of the different IAMs presented in the previous section are in most cases estimated on the basis of a so-called benchmark scenario, e.g. the damages associated with doubling of the concentration level of CO_2 relative to the pre-industrialised level of CO_2 ($2xCO_2$ scenario). This $2xCO_2$ scenario represents a specific point on the damage curve, which can be expected to be of an exponential form, i.e. with damages increasing more than linearly over time and rising CO_2 concentrations in the atmosphere.

Impact estimates exist really only for the industrialized world, primarily the USA, and assumptions about how these numbers can be transferred to the situation in developing countries are crucial for the estimation of damages. Given that the economic output of most developing countries is heavily dependent on climate sensitive sectors, such as agriculture, and the fact that most of the world's biodiversity rich ecosystems can be found in the tropics, damages are likely to be much higher in terms of percentage of GNP for those regions.[24]

In the following an overview of the most recent impact studies is presented. Their various approaches to impact calculations and the inclusion of adaptation measures are described shortly and their results are presented in Table 6.2 in a summarized fashion. The outline of Table 6.2 follows the presentation in TAR, where the summary of the first round of results from impact studies by Pearce et al. (1996) has likewise been included.

IPCC SAR (Pearce et al., 1996):
The SAR summarised a first round of impact studies (Pearce et al., 1996), with benchmark estimates in the range of 1.5-2% of world GNP. The authors based their summary on best guess estimates from studies by Nordhaus (1991), Cline (1992), Titus (1992), Fankhauser (1995) and Tol (1995). These studies differed substantially with regard to the types of impact categories covered, their regional diversification, and the GCM results they were based on. Some of the estimates included both the costs of plausible adaptation as well as the remaining damages of impacts (e.g. coastal protection). Already in this early damage assessment a trend towards substantial regional variations becomes visible. Damage estimates for developed countries are between 1-2% of GNP; estimates for the developing regions vary between 2-9 % of GNP!

Estimates for developing countries are predominantly extrapolated from the US and other OECD country studies and based on present-day economic situations in the different regions. Future impacts will depend on economic, demographic and environmental developments. Following the development in industrialized countries

[24] On the other hand, some argue that, if ecological losses are valued independently of where they occur, then the willingness-to-pay (WTP) for ecological and social damages increases with income and therefore the valuation of non-economic damages should be higher in the industrialized world (Manne et al., 1995).

this would for example suggest a less than proportional growth of agricultural impacts and a more than proportional growth of non-market impacts with increases in income over time. This is based on the fact that the share of agricultural output of total GDP is likely to fall with increasing per capita income, while the willingness-to-pay for non-market impacts will increase.

GIM (Mendelsohn et al., 2000):
The Global Impact Model (GIM) developed by Mendelsohn et al. (2000) evaluates climate impacts in different regions and for different sectors combining a climate model, sectoral data, and two different climate-response functions which both are based on empirical studies. Because of the lack of empirical studies for non-market impacts the analysis is restricted to market impacts. The impact figures entered in Table 6.2 are based on the more refined version of the two different General Circulation Models (GCM) used and are only shown for a temperature increase of 2° C in 2100.

GIM incorporates country specific sectoral data (GDP, average land value, population, cropland, forestland and coastline) and projects the growth in the different economic sectors into the future. Two different approaches to response functions to climate change in the different economic sectors (based on empirical studies) are employed in the model. One set of response functions is based on detailed scientific models for the different sectors (i.e. production functions for agriculture, forestry etc.), which combined with economic models are used to construct a so-called reduced form model. This reduced form model links climate change and welfare impacts for each sector to temperature and precipitation.

The other set of response functions is based on 'Ricardian' studies for the agriculture, energy, and forestry sector. Ricardian studies are based on regression analyses that measure long run climate sensitivity of farm value or net farm income by examining a cross section of farms across a country or region big enough to exhibit different climates. One of the advantages of this method is that the measurements are likely to include private adaptation measures, e.g. behavior or choices that increase productivity or reduce costs. In contrast to the Ricardian model, the reduced-form model is based on laboratory experiments and process-based models for the different sectors, that are more likely to isolate climate effects from other influences than in the Ricardian studies, but do not capture adaptation to the same extent.[25] Unfortunately both types of response functions are calibrated to the United States and for example assume rather quick adaptation possibilities for the agricultural sector. Given the apparent lack of resources in developing countries, any unadjusted transfer of response functions to other regions seems rather questionable. Assuming the same adaptation possibilities in developing countries' economic sectors as exemplified in past adaptation to climate variability in industrialized countries is likely to overestimate global adaptation possibilities.

[25] See Dinar et al. (1998) or Mendelsohn et al. (1994) for a detailed description of the Ricardian method and reduced-form approach.

RICE-99 (Nordhaus and Boyer, 2000)
Damage estimates in Nordhaus and Boyer (2000) are based on a willingness to pay (WTP) approach which seeks to measure the 'insurance premium' society is willing to pay to prevent climate change and its associated impact. Impact calculations are made for seven categories: agriculture, sea-level rise, other market sectors, health, non-market amenity impacts, human settlements and ecosystems, and catastrophes. Table 6.2 shows impact estimates for a 2.5 °C temperature increase expressed as percentage of incomes in the year 2100.

For each category impacts are modeled as a function of temperature times an income adjustment. Benchmark estimates for a temperature change of 2.5 ºC (estimated to occur in the year 2100) are derived from a set of newer impact studies in the respective field. Where no benchmark studies have been available for an impact type or for a region, these are approximated under a number of assumptions - often extrapolated from results from US studies.[26]

In contrast to other studies Nordhaus and Boyer (2000) explicitly include estimates for catastrophic impacts, based on responses from a survey of experts on the probability of a catastrophe with different temperature increases. The percentage of income loss is assumed to vary by sub-region; for example, OECD Europe would experience twice the income loss of the United States. In order to show the influence of the catastrophic impact results on the aggregate outcomes, non-catastrophic impacts are listed separately in Table 6.2.

Tol (Tol, 1999)
Tol (1999) derives impact estimates from climate change based on a set of globally comprehensive, internally consistent studies using GCM based scenarios. Potential impacts for 7 impact categories – agriculture, forestry, unmanaged ecosystems, sea level rise, human mortality, energy consumption, and water resources – are extracted from what the author considers to be the most up-to-date impact studies.

The calculation of impacts is restricted to a global mean temperature increase of 1° C, which is expected to occur already by 2050. This short-time horizon allows the author to investigate impacts based on the present situation, while eliminating some of the uncertainties associated with longer term variations in climate. However, it also renders the calculated numbers inadequate for a possible comparison to mitigation costs: According to Tol the expected climate change of a 1° C increase in temperature is already inescapable. In contrast to other studies Tol (1999) includes estimates of the uncertainty attached to the different impacts.

As shown in Table 6.2 positive and negative impacts are distributed unevenly between the different regions. All industrialized countries

[26] For sea-level rise this involved for example the calculation of a coastal vulnerability index (equal to the coastal area to total land area ratio divided by the same ratio for the United States), while WTP for the prevention of ecosystem loss is assumed to be 1% of the capital value of the ecosystems at risk in the specific region.

are likely to benefit from a modest temperature increase while most of the developing countries can expect to suffer economically. Because of the lack of adequate impact studies, Tol (1999) omits a range of impacts, e.g. amenity, tourism, extreme weather, fisheries, and morbidity.

Total aggregate impact shows a positive effect of climate change for the world as a whole, thus indicating a potential aggregated welfare improvement. However, impacts are likely to vary substantially between regions and, as (Tol, 1999) points out, compensation paid from those that benefit to those that suffer from climate change is unlikely. Using globally averaged prices to value non-market goods and services (instead of income adjusted ones) results in a negative effect on global income of –2.7%. An equity-weighted sum of impacts, where the weights are constructed as the ratio of global to regional per capita income, still shows a positive, albeit substantially lower, effect on world income of 0.2%.

Table 6.2: Impact estimates in different regions (negative numbers are damages, positive numbers are benefits; impact measured as percent of market GDPs).

Source	***IPCC SAR***	***Mendelsohn et al.(2000) GIM***		***Nordhaus & Boyer, 2000 RICE-99***			***Tol***	
Region	***2.5 C***	***2 C Ricardian***	***2 C Reduced-form***	***2.5 C in 2100***	***Total Non-catastrophic***	***Catastrophic***	***1 C***	***stand. dev.***
North America:		0,53	0,83				3,4	(1.2)
USA				-0,45	-0,01	-0,44		
OECD Europe:							3,7	(2.2)
EU		0,05	0,10	-2,83	-0,92	-1,91		
OECD Pacific:							1	(1.1)
Japan				-0,50	-0,06	-0,45		
Eastern Europe/FSU:		1,07	2,22				2	(3.8)
Eastern Europe				-0,71	-0,23	-0,47		
Russia				0,65	1,64	-0,99		
Middle East:				-1,95	-1,49	-0,46	1,1	(2.2)
Latin America:		0,18	-0,88				-0,1	(0.6)
Brazil								
South, South East Asia:		1,34	0,57				-1,7	(1.1)
India				-4,93	-2,66	-2,27		
China:				-0,22	0,29	-0,52	2,1	(5.0)
Africa:		0,00	-1,82	-3,91	-3,51	-0,39	-4,1	(2.2)
Oceania:		0,02	-0,11					
Developed Countries:	-1,0 to –2,0							
(range of best guesses)								
Developing Countries:	-2,0 to –9,0							
(range of best guesses)								
World:								
output weighted	-1,5 to -2,0	0.16	0.09	-1,50	-0,48	-1,02	2,3	(1.0)
population weighted				-2,20	-1,15	-1,05		
at world average prices							-2,7	(0.8)
equity weighted							0,2	(1.3)

Source: Pearce et al. (1996); Tol (1999); Mendelsohn et al. (2000); Nordhaus and Boyer (2000)

Sectoral differences among regions

As can be seen in table 6.3 below, aggregate damages estimates (summed up over all impact categories) often obscure substantial differences between impacts in different sectors. Table 6.3 indicates that the coastal, health and settlement (which includes ecosystems) impact categories generally experience damages from climate change, although to a varying degree over the different regions.[27] Changes to non-market time use (mostly recreation activities) are generally of a beneficial nature, with the exception of India, Africa, and Low-income regions. Positive effects on the agricultural and non-market time use sector mainly cause beneficial aggregate results for Russia and 'Other high income' regions. For nearly all regions the inclusion of catastrophic events has large effects on total impacts (listed in the first column). Exceptions are High-income OPEC countries and Africa where other vulnerable market sectors and health impacts respectively dominate the aggregate result. It should be noted that any interdependencies, e.g. interactions of the agricultural sector with other economic sectors, usually are ignored when calculating impacts.

Table 6.3: Summary of impacts in different sectors: impact of 2.5 degree warming (positive numbers are damages; negative numbers are benefits; impacts measured as percent of market GDPs).

	Total [2.5 degree]	Agriculture	Other vulnerable market	Coastal	Health	Nonmarket time use	Settlements	Catastrophic impact [2.5 degree]	Catastrophic impact [6 degree]
United States	0.45	0.06	0.00	0.11	0.02	−0.28	0.10	0.44	2.97
China	0.22	−0.37	0.13	0.07	0.09	−0.26	0.05	0.52	3.51
Japan	0.50	−0.46	0.00	0.56	0.02	−0.31	0.25	0.45	3.04
OECD Europe	2.83	0.49	0.00	0.60	0.02	−0.43	0.25	1.91	13.00
Russia	−0.65	−0.69	−0.37	0.09	0.02	−0.75	0.05	0.99	6.74
India	4.93	1.08	0.40	0.09	0.69	0.30	0.10	2.27	15.41
Other high income	−0.39	−0.95	−0.31	0.16	0.02	−0.35	0.10	0.94	6.39
High-income OPEC	1.95	0.00	0.91	0.06	0.23	0.24	0.05	0.46	3.14
Eastern Europe	0.71	0.46	0.00	0.01	0.02	−0.36	0.10	0.47	3.23
Middle income	2.44	1.13	0.41	0.04	0.32	−0.04	0.10	0.47	3.21
Lower middle income	1.81	0.04	0.29	0.09	0.32	−0.04	0.10	1.01	6.86
Africa	3.91	0.05	0.09	0.02	3.00	0.25	0.10	0.39	2.68
Low income	2.64	0.04	0.46	0.09	0.66	0.20	0.10	1.09	7.44
Global (a)									
Output-weighted	1.50	0.13	0.05	0.32	0.10	−0.29	0.17	1.02	6.94
Population -weighted	1.88	0.17	0.23	0.12	0.56	−0.03	0.10	1.05	7.12

Note: (a) Output-weighted global average is weighted by projected output in 2100 from RICE base case. Population-weighted global average is weighted by population in 1995.

Source: Nordhaus and Boyer (2000).

Indicative results from impact measurements

At a first glance the cross-section of impact studies covered in the preceding sections seems to show more differences than common trends in impact measures. Basic reasons for this apparent lack of coherence are the different levels of benchmark warming chosen (from 1 to 2.5 ° C), different impact categories covered, the inclusion

[27] The reader should be aware that, in contrast to table 6.2, positive numbers indicate damages, while negative numbers are equal to benefits.

or exclusion of catastrophic impacts, and the type of estimation approach (Ricardian or other) chosen. The results presented in Table 6.2 nevertheless allow for a number of statements (keeping in mind the uncertainty associated with the specific numbers) about the future impact of climate change:

1. Recent studies (Tol, 1999; Mendelsohn et al., 2000; Nordhaus and Boyer, 2000) which explicitly include adaptation point to less severe impacts (at least for market sectors) and partly positive effects of climate change, at least for developed countries.
2. The inclusion of catastrophic events increases damages and costs substantially. Catastrophic events are likely to be responsible for/cause the main part of impacts, especially in developed regions.
3. While partly positive outcomes are expected at lower levels of temperature increase, impacts will increase with rising temperatures and are likely to turn negative even for developed nations at higher levels.
4. All studies point to substantial regional differences in impacts, with some of today's temperate climates experiencing potential gains in some impact categories with moderate climate change, while tropical regions are likely to suffer from losses in basically all impact categories, even for small changes in climate.

Addressing Equity Concerns by Modelling Compensation Requirements Using the Polluter Pays Principle

Although the impact studies summarised in table 6.2 show large variations in positive and negative effects for different regions, few authors have raised the issue of equity in this context. One exemption is the methodology applied by Panayotou et al. (2001) who propose '…a system of compensatory transfers from those who contribute to climate change more than they suffer from it to those countries whose damages outweigh their responsibility for the problem.'

Historical and estimated future contributions of CO_2 emissions by different regions and countries are set against the regions' shares of potential damages resulting from climate change. Data on historical emissions show that the main responsibility for the current atmospheric stock of CO_2 lies with the developed countries. However, projections of GHG emissions into the future show an increasing contribution by the developing regions. Future emissions are modelled based on econometric estimates showing dependence of emissions levels on income and population. Similar to the environmental Kuznets curve, income elasticity estimates show an inverted U-shaped relationship between income per capita and CO_2 emissions per capita, thereby suggesting that increases in CO_2 emissions per capita will eventually slow down and even begin to decline when a certain economic development level is reached.

(Panayotou et al., 2001) do not carry out any original research for estimating damages from increases in GHG concentrations. Instead they apply the projected increase in global temperature to the damage function estimated in Nordhaus (1998). By calculating the share of responsibility for global CO_2 emissions and contrasting it with the share of potential damages, they conclude that '...the temperate-zone economies are likely to impose severe net costs on the tropical regions.' In this sense, through climate change the richer countries are likely to impose a burden on the poorer countries. One exemption is China, which in this model is assumed to be one of those countries paying compensation payments, because of the country's large future contributions to CO_2 emissions and relatively few climate impacts.

While the model provides an interesting first round of results that could serve as further input to the discussion about including developing countries in climate change agreements, the results should be regarded with some caution. As the authors themselves point out, there are large uncertainties attached to the modelling of climate change effects, from the natural science base that manifest itself in various GCMs to the implications of changing climate patterns (e.g. temperature, precipitation, storms) on market and non-market sectors of the different national economies. Nordhaus' impact functions represent just one way of analysing climate change impacts. Other impact studies as shown in table 6.2 (Tol, 1999; Mendelsohn et al., 2000) might lead to different results. Similarly, determining the responsibility for CO_2 emissions based on modelled past and projected future emissions includes important quantitative uncertainties.

6.3 Discussion

Climate change is a large-scale, long-term environmental issue, which presents a major challenge to economic analysis of the environment. Most of the economic work so far has been concerned with the mitigation costs of the Kyoto Protocol. Very little economic work has been concerned with the benefits of mitigation, namely the climate damages avoided.

Climate damage studies are still in their infancy. One important weakness is that many studies base their impact estimates on a fictive equilibrium point in the future, thus taking a static approach. Second, the damage costs to developing countries are much more uncertain than the damage costs to developed countries, although it is expected that developing countries will be hit hardest by climate change. Third, given the temporal and spatial extend of the climate change problem, economic models and tools might generally be unsuitable for assessing climate change impacts.

Uncertainty in climate change impact modelling
As Pearce et al. (1996) already point out in their first summary of impact studies, the equilibrium character of the estimates could lead to an underestimate of impacts in the short term. Societies are likely to '…face a changing (rather than a changed) climate' (Pearce et al., 1996), where climate shocks could severely affect the ability of natural systems to adjust and recover. Benchmark estimates are calculated as the impact an equilibrium climate change would have on present-day society thus leaving out any impacts from changes in climate up to the equilibrium point selected and the impacts likely to occur beyond that point (which often is equal to a doubling of CO_2 concentrations).

Estimates for these before and after benchmark impacts are approximated through the impact function form chosen for the impact model in IAMs.

Impact estimates for different regions and the world as whole listed in Table 6.2 are based on best guess estimates for the different impact categories, i.e. impact scenarios that have the highest likelihood of occurring (called the 'mode' in statistical terminology). However, as illustrated in Figure 6.3, the probability associated with climate change scenarios is not necessarily normal distributed, i.e. with a symmetric range around the best guess estimate. Instead, catastrophic outcomes, for example a potential change in thermohaline circulation of the northern Atlantic, are likely to produce a large right hand tail of the probability distribution (Rothman, 2000). In a situation where the probability distribution is skewed to the right, the mode or best guess can turn out to be significantly lower than the expected damage, which is calculated as the sum of all possible impacts, weighted by their probability of occurrence.[28] As Rothman (2000) emphasises, making policy decisions based on best guess damage estimates would imply a risk-taking society because the risk premium, the difference between best guess and expected value is negative.

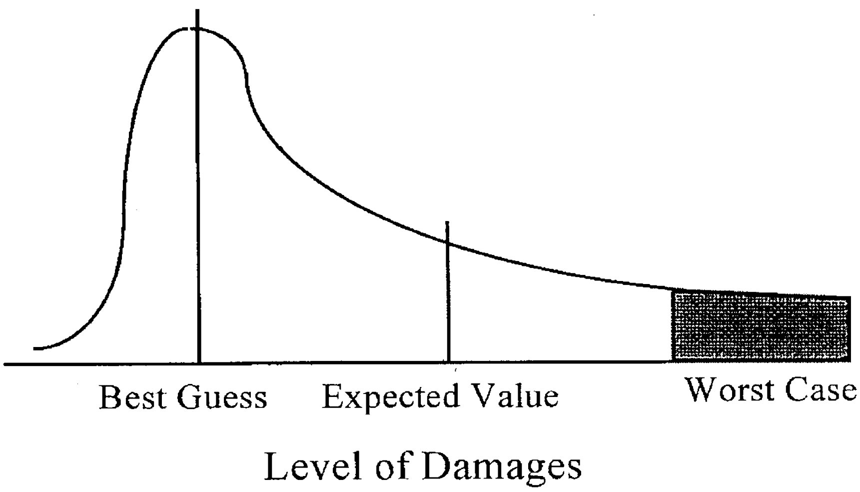

Figure 6.3: Probability distribution of damages, catastrophic events, and 'best guess' estimates. Source: Rothman (2000), from Fankhauser (1995).

It is also worth stressing that since it is impossible to predict the frequency of extreme events – including hurricanes, large-scale flooding, and severe droughts – in a changing climate, their costs are usually not reflected in climate damage cost estimates (one exemption being Nordhaus and Boyer (2000)). However, extreme events could result in massive material damages, loss of human life, and biodiversity losses. The exclusion of extreme events, although understandable from a scientific-technical viewpoint, probably leads to a serious underestimation of the costs of climate change.

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[28] In statistical terms, the mean or expected value of a discrete random variable is $E(x) = \sum x\, p(x)$, where $p(x)$ denotes the probability that the random variable takes on a specific value.

Lack of original impact studies in developing countries

Nearly all studies of the impact on agriculture and the impact resulting from sea-level rise are based on data from the United States that are extrapolated to other regions. Transferring WTP estimates from developed to developing nations does require a decision about if and how these estimates should be adjusted to reflect different income levels and thereby resulting differences in WTP for damage reduction. Especially the issue of using differential values for a statistical life in industrialized and developing countries has raised considerable debate.[29] The issue has not been discussed in detail in this report because a final solution has so far not been found and because the discussion of the different methods of valuing a statistical life lies outside the scope of this report. Some researchers have chosen to present their results using different weights reflecting differences in income levels; see for example Tol (1999).[30]

Another essential point is that the adaptive behavior that can be anticipated from well functioning markets in industrialized countries is likely to differ substantially from the kinds of adaptive responses that can be expected in developing regions. Here vulnerable sites like flood plains and river deltas are often densely populated. The affected people have limited resources and generally lack information and alternatives that would allow them to adequately protect coastal land or abandon land in time and seek a living elsewhere if protection becomes economically inefficient. The same is true for the agricultural sector where the subsistence farmer generally lacks the foresight and economic means necessary to adapt to a changing climate in an efficient manner.

In one of the few studies on a developing country Dinar et al. (1998) apply response functions to climate change for Indian agriculture including private adaptation possibilities that prove to be similar to those developed for the United States. However, Dinar et al. (1998) also point to the fact that relatively moderate aggregate impacts for India might overshadow local and regional disasters. Yet, as the authors themselves acknowledge, the Ricardian technique employed in this study is unsuited for projecting impacts for subsistence farming where farmers face different input and output prices because labor is often supplied by family members and most of the output produced is consumed in the family.

Another complicating factor is that the non-market impacts, which will be substantially larger in developing countries, cannot be estimated in standard economics models. The alternative methods available are somewhat controversial.[31] By excluding non-market effects, models systematically underestimate the total costs of climate

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[29] Azar and Sterner (1996) have for example shown that marginal costs of CO_2 emissions depend strongly on the weight given to the costs in developing countries but equally much on the discount rate chosen and the accurateness of the carbon cycle model.

[30] A more detailed analysis of weight factors in cost-benefit analysis of climate change can be found in Azar (1999) and Fankhauser et al. (1997).

[31] The main alternatives are revealed preferences (e.g. hedonic pricing methods or the travel cost method) or hypothetical markets (e.g. the contingent valuation method).

change; according to SAR, non-market costs can be between 60-80% of the total costs (Pearce et al., 1996).

Are economic tools suitable for assessing climate change impact?

Given the temporal, spatial, and socio-political scales of the issues arising from a changing climate, conventional tools of economic analysis, i.e. utility theory, benefit-cost analysis, contingent valuation and others, might be inappropriately applied in this context. As pointed out by Morgan et al. (1999) most tools of modern policy analysis were developed to address problems that covered at most the time of one generation and were confined to one nation. As soon as the system boundary of the problem to be addressed extends beyond these rather narrow margins '…more and more of the underlying assumptions upon which conventional tools are based begin to break down' (Morgan et al., 1999). That said there is no optimal climate change assessment method *per se* (Adams, 1999). All methods have their specific advantages or limitations. Given the large uncertainties in other parts of the integrated assessment process (e.g. the climate forecasts itself); variability might likely overshadow the differences in economic estimates. Adams (1999) suggests therefore that refining the climate and natural science data might help improve the quality of economic assessments more than any efforts to fine-tune the economic assessment techniques themselves.

The Integrated Assessment Modelling approaches and impact assessments presented in this chapter as well as other economic tools can provide useful policy guidance in climate change politics, given that one understands and takes into consideration the limitations associated with the different methods employed. This is sometimes not fully understood. As such, economic tools represent just one type of policy analysis tool available. The vulnerability indexes and indicators that are presented in chapter 4 constitute alternative approaches.

Basically, economic tools offer two different functions for the assessment of climate change politics:

- A (monetary) description of the situation in terms of cost estimates for either mitigation activities or climate impacts, including adaptation measures, and
- Optimisation models that integrate the two types of cost measures (mitigation and impact) in the form of a cost-benefit analysis in order to derive optimal emission paths.

The present report has focused primarily on the first function, specifically the assessment of impacts and the extent to which adaptation has been included in various modelling exercises. Given the inherent uncertainty attached to any economic impact figure the specific numerical estimates should be treated as indicative results. However, the available figures could be regarded as 'policy guideposts' concerning the vulnerability and opportunities due to climate change and could in this sense serve as input to the general discussion on adaptation and equity in the climate change context. In line with the discussions in the previous chapters, it should be noted that any description of inequity alone, expressed either in economic terms or in the form of indicators and indices, is not sufficient to assure fairness in outcomes, although it is certainly a major element in finding a fair solution. Defining what constitutes a fair outcome requires the integration of equity or fairness principles in method application and analysis.[32] Modelling compensation requirements as done in Panayotou et al. (2001) represents one application of economic tools that explicitly attempts to incorporate the issue of burden sharing and equity.

There also exist a number of attempts to integrate equity considerations in optimization models. Analyses show, for example, that the higher the aversions to inequity, the higher the optimal greenhouse gas emission reduction (Tol, 2001). Optimal emissions levels are also likely to depend strongly on the inclusion of catastrophic events, different risk aversion levels and different assumptions about the intertemporal discount rate, as an indicator for the inclusion of intergenerational equity, as shown by Gjerde et al. (1999). Azar (1999), on the other hand, shows that the inclusion of different weight factors in the estimation of climate change costs does not necessarily yield different optimal emission levels. This is because the consistent application of those weights might also require weighting abatement costs, thus offsetting the effects of increasing damage estimates from developing countries. All these analyses, if their inherent short-comings and uncertainties are taken into consideration, can serve as valid input in policy discussions.

6.4 Summary

This chapter has presented a first overview over different climate change impact studies and current state-of-the-art modelling of impacts and adaptation in integrated assessment models. While the numbers should be treated as indicative results given the vast uncertainties attached to the different monetary impact estimates, they can serve as 'policy guideposts' concerning the vulnerability and adaptation opportunities associated with a changing climate. Future research efforts in fine-tuning economic instruments for their application in the climate change field, like cost-benefit analysis or valuation studies, should focus on those issues identified as having a potentially strong influence on aggregate impact outcomes: the inclusion of catastrophic events; impact studies for (and conducted in) developing countries for market and non-market impacts; possibilities for adaptation in developing countries; and the choice of weights and discount rates.

[32] Some examples of fairness principles that could be applied to the distribution of adaptation funding are discussed in the following chapter.

7 Fairness, Damage Costs, and Adaptation Costs

This chapter examines the issue of adaptation financing in developing countries from the perspective of fairness. Obviously, the two fundamental questions with respect to adaptation financing are: First, who should finance adaptation activities and pay for the economic losses due to climate damages in developing countries? Second, who should be compensated for the damages and economic losses they incur due to climate change?

As discussed in chapter 3, most attention has so far been paid to the international distribution of mitigation costs. Only few if any studies have explicitly addressed the issue of 'fair' sharing of the costs of compensation and adaptation assistance. Some economics studies on optimization of mitigation and adaptation policies deal indirectly with some of the issues involved, such as in their analyses and comparisons of the economic value of climate damages in industrialized and developing countries (see, for example, Azar, 1999). Nonetheless, the important issues with regard to a fair sharing of the costs of adaptation and compensation - identifying the notions of fairness that are influential in this area, and examining their implications - have not been properly addressed.

7.1 Sharing and dividing adaptation and compensation costs

The question of in what way the costs of adaptation programs and projects and the costs of compensation of climate 'victims' could and should be divided among countries is fundamental. According to the Kyoto Protocol, 2 per cent of the Certified Emission Reductions generated by projects implemented under the Clean Development Mechanism (CDM) should be reserved for adaptation financing in developing countries. Additional funding opportunities may also become available under the UNFCCC in the future.[33]

The three general fairness principles relevant for sharing mitigation costs examined in chapter 3 - responsibility, capacity, and need - seem equally relevant when considering who should share the costs of adaptation assistance and compensation of climate-sensitive developing countries, and in what proportion. With regard to the first principle, because of their large historical GHG emissions, it is primarily and perhaps exclusively the industrialized countries that are responsible for the climate problem. The industrialized countries also have more capacity, measured in terms of GDP per capita, to address the problem than the developing countries. It is clear at the same time that the principle of 'need' (i.e. the 'right' to a certain

[33] The COP-6 conference president suggested in November 2000 to establish three new funds: A Special Climate Change Fund; A Least Developed Countries Fund; and a Kyoto Protocol Fund. The Kyoto Protocol Fund would be financed from the share of proceeds on the CDM, plus additional funding by Annex I countries.

minimum level of economic and social welfare) supports that the developing countries can justly claim an equal per capita share of the atmosphere. Hence, the burden of solving the problem of climate change, including coverage of the costs of adaptation and compensation payments for the residual climate damages, lies squarely with the group of industrialized countries, at least in the short to medium term. In the longer term responsibilities would have to be reassessed because of the rising GHG emissions from developing countries.

7.2 Distributing adaptation assistance and climate damage compensation

The second fundamental issue is about the distribution of the resources available for damage compensation and adaptation assistance. The issue of the division of the adaptation 'pie' has seldom been raised in the global climate negotiations and the international policy debate, but it could well become a politically salient issue.

It is possible to identify at least four different approaches to the issue of fair distribution of the resources for compensation and adaptation assistance (Table 7.1). In the first approach, an equal amount of resources per capita would be allocated to all (eligible) developing countries. This would be a symmetrical or across-the-board solution. It would be rooted in the notion of equality of all individuals and the recognition of the sovereignty of all nations. It should be realized that because significant asymmetries and differences exist among developing countries - i.e., country size, climate damage costs, and level of GDP - the amounts of resources received by countries would be similar in relative, but not in absolute, terms.

Table 7.1: Four fairness principles in adaptation assistance and damage compensation.

Underlying Principle	Implications
Equality	An equal amount per capita for all developing countries.
Vulnerability to climate change	The more vulnerable a sector/country/region is, the more assistance and compensation it would receive.
Economic efficiency and cost-effectiveness	Assistance and compensation is distributed in the way that achieves the greatest economic benefit or the least cost.
Contribution to mitigation efforts	Assistance and compensation is relative to GHG mitigation costs of countries.

The second approach is concerned with the vulnerability to climate change and the adaptive capacity of countries. Vulnerability is an intuitively appealing and perhaps even obvious approach, which might explain why it attracts much attention among decision-makers and analysts. The approach is essentially about the resources and capacities of countries to adapt - in order words, their ability or capacity to pay for adaptation. This principle would mean that countries that would suffer greater climate damages (costs) should receive greater resources than countries that would suffer less damage (costs). Obviously, countries that are not vulnerable to climate change would not be eligible for funding. Nor would countries with sufficient adaptive capacity (however determined) be eligible for funding.

In the third approach, the emphasis would be put on maximizing economic efficiency and achieving cost-effectiveness. Economic efficiency implies that one minimizes the sum of climate damages and the opportunity costs of mitigation and adaptation, or maximizes the net benefits of reducing emissions and adaptation. Cost-effectiveness implies that one has an objective that one wants to achieve (either in terms of emission reductions or some measure related to offsetting climate damages) and one wants to achieve that objective in the least-cost manner.[34] In both cases, one would search for the most economically advantageous use of the scarce resources available. Priority would be given to the protection of those resources that represent the greatest economic value, or those measures that are least-cost. The groups, regions, and sectors that represent less economic value would receive less and perhaps no compensation and assistance.

In the fourth approach, the amounts of compensation and adaptation assistance received by developing countries would be proportional (at least to some extent) to their contributions to the global mitigation effort. Countries with higher opportunity costs of mitigation would receive more adaptation assistance and funding than countries with lower opportunity costs of mitigation. Obviously, countries that would not contribute to the global effort would not be eligible for compensation and assistance. Because of the differences with respect to the size of countries, opportunities for emission reductions, and abatement costs, the total or absolute emission reductions by a country would not be a good indicator of contribution. Rather, the relative mitigated emissions - in other words, mitigated emissions relative to unmitigated emissions - and the economic cost per ton of emission reductions would seem a rough but reasonable indicator of the contributions made by countries.

7.3 Discussion

Equality would evidently be the least demanding or challenging fairness principle to agree on and to implement because funding allocations would not be linked to climate damages, need, economic benefits (i.e. damages avoided), or mitigation efforts of countries. The three alternative principles imply differentiation of assistance and compensation. Thus, some form of coherent conceptual framework for differentiation would have to be established in each case. This would in itself constitute a considerable conceptual challenge. Differentiation is a complex issue in global climate policy and it often gives rise to opportunistic behavior among nations (Ringius, 1999).

[34] The economic efficiency solution always yields greater net social benefits in theory.

It should be noted that the four principles would have quite different distributional implications. Compare, for example, the implications of the second principle (degree of vulnerability) and the fourth principle (contribution). Everything else equal, developing countries with a high level of GDP emit more GHGs (thus mitigation commitments become more likely), have more capacity to adapt but, although they are less vulnerable, would receive proportionally more funding under the fourth principle. In contrast, developing countries with a low GDP level emit less GHGs (thus mitigation commitments entailing real economic costs are less likely), have less capacity to adapt and, despite being more vulnerable, would receive proportionally less funding under the principle of contribution. This outcome differs much from the outcome under the principle of vulnerability; given the distribution of potential damages (summarized in chapters 4 and 6), countries with low levels of GDP would receive proportionally more funding under this principle, but countries with high levels of GDP would receive proportionally less funding.

It is quite plausible that both the need principle and the vulnerability principle would influence actual policy decisions about compensation. The practice of dividing countries into a small number of distinct groups is widespread in global environmental negotiations, and, if followed in the area of climate adaptation, could mean that the poorest developing countries would receive a higher equal amount per capita than other developing countries. For example, the forty-nine least developed countries might receive more assistance per capita than the Group of 77 and China. Differentiation within the group of the poorest countries may also be a possibility. In both cases, the supporting ethical argumentation would be that there exists a need for more assistance in case of the poorest countries (since the LDCs first and foremost need to invest their limited resources in raising their low living standard and improve their economic performance), or that the poorest countries are the most vulnerable to climate change (and thus suffer higher damages and costs as measured by the per cent loss in GDP). The needs of other developing countries could then be assessed on a case-by-case basis.

A conceptual framework would be necessary in order to differentiate developing countries with regard to their vulnerability and adaptability. As discussed in chapter 4, vulnerability indices for climate change might be useful in such needs identification exercises (see e.g. Downing et al., 2001) and in international comparisons of vulnerability of countries to climate change (Moss et al., 2001). But in order to determine the precise allocation of adaptation funding, it would also be necessary to establish rules and decision-making procedures for the use of vulnerability indices or other conceptual frameworks in policy decisions. These procedures and rules would have to address questions such as the following ones: Should only the most vulnerable countries or sectors be assisted? Should less vulnerable developing countries not be assisted? On what basis, and through what process, should adaptation options be prioritized and selected? The last issue could include an assessment of the implementability of options and a comparison of the costs and benefits of different adaptation alternatives.

The different impact studies that were analyzed in chapter 6 provide a first, albeit rather crude, picture of the distribution of vulnerability measured in monetary terms. It illustrated that existing studies in developing countries do not present much detailed information and data, and that it is not possible to compare the vulnerability of individual countries and sectors. Because of this, at this stage funding priorities should not be based on monetary estimates of damages.

Whereas determining the economic value of resources in market sectors (e.g., agriculture, forestry, and energy) is a relatively easy task, measuring the potential benefits from protection of non-market resources (e.g., biodiversity and human well-being) is much more complicated. Not only are the valuation methods that are available to price those resources highly disputed (see the discussion in chapter 6), but it is also necessary to decide whose values count: Do only the benefits to the local population count? Or do the benefits to the global community also count, and if so how much?[35] On a different but related issue, what should be recommended in case of highly vulnerable countries with few inexpensive options? Although appealing at first sight, it also seems evident that economic efficiency easily could turn out to be an 'unfair' criterion or principle as the lack of market prices for non-market resources could exclude these resources from an 'efficient' distribution of adaptation funding.

It is quite obvious that the four fairness principles are not mutually exclusive; they can be combined. It is quite conceivable, in fact, that any particular distribution of assistance and compensation would reflect more than one fairness principle. One example of this would be an assistance arrangement targeting a key economic sector that is highly vulnerable to climate change, e.g., the agriculture sector in sub-Saharan Africa. In general, it is quite likely that an arrangement that would combine two or more widely accepted fairness principles would seem more fair or just than any single-principle arrangement.[36]

7.4 Summary and conclusions

Clearly, several legitimate fairness principles exist in the area of adaptation and any compensation and financing scheme that would reflect only one single principle is likely to be challenged, particularly by those developing countries that would feel they were treated unfairly. At the same time, it should be expected that the developing countries largely would have to accept the distribution scheme preferred by the industrialized countries. The reasons for this are twofold; first, the developing countries have much less bargaining power than the industrialized countries in the climate negotiations; second, the issue of adaptation funding would likely raise distributional issues that could further divide the group of developing countries. It should be underlined that countries

[35] Values of the global community would for example include option and non-use values for biodiversity in industrialized countries.
[36] This is supported by the experience from the international negotiations on sharing of the mitigation costs among the industrialized countries discussed in chapter 3. (Ringius, 2001).

ultimately are concerned about the distributional implications of principles, not the principles themselves.

Including both the costs of damage compensation and adaptation assistance and the costs of mitigation does not represent a fundamental change of the approach taken to fairness. Rather, it means that the costs of climate change are viewed in a more comprehensive manner. As outlined in the Second Equity Framework, the fairness principles that pertain to the sharing of mitigation costs seem equally relevant for sharing arrangements for the total costs.

In this chapter it was claimed that widely accepted fairness principles support that the industrialized countries shoulder the bulk of the costs of adaptation assistance and climate damage compensation in the developing countries, at least in the short and medium run. With respect to the distribution of adaptation assistance and climate compensation among developing countries, four fairness principles were suggested. These principles were concerned with equality, vulnerability, economic efficiency, and contribution to mitigation efforts, respectively. It should be expected that any international adaptation fund would reflect at least one and probably two or more of these key fairness principles. The principles of vulnerability, economic efficiency, and cost-effectiveness seem particularly strong candidates. It was also noted that the distributional implications of these principles could diverge significantly.

8 Conclusions and Recommendations

This report sought to shed new light on some of the key issues with regard to climate change, international climate policy, and fairness. It was initially pointed out that while much attention has been paid to mitigation, there has been little concern for adaptation to climate change and developing countries have generally been overlooked compared to the industrialized countries. The report argued that issues of fairness and burden sharing should be examined within one consistent framework that integrates the total costs and benefits of mitigation and adaptation, as well as the costs of local climate damages, and the international distribution of all relevant costs and benefits.

Since the publication of the IPCC's Second Assessment Report a number of specific research questions and broader research agendas have developed which reflect the different sciences that are participating in international climate research. These ranges from vulnerability studies and adaptive capacity research conducted from the perspective of sociology, social geography, and political science to economic valuation, cost-benefit analysis, economic modelling, and integrated assessments. Research in adaptation processes and determinants of adaptive capacity has introduced a broader academic approach to climate change and to the interface to more general development issues. The IPCC's Third Assessment Report emphasizes the links between strengthening of adaptive capacity and the promotion of sustainable development, including strengthening and change of social and institutional systems.

Despite recent progress, climate models are still insufficiently developed at the regional level, and damage cost assessments based on integrated impact assessment models (IAMs) are surrounded by significant uncertainty. Impact results depend strongly on the type of method employed (as discussed in chapter 6). Yet, all studies point to substantial regional differences in impacts over all impact categories. While the temperate climates are expected to experience potential gains in some impact categories, the developing regions are likely to suffer losses in most impact categories, even with moderate climate change. The inclusion of catastrophic impacts implies a substantial increase in costs, resulting in negative impacts for all regions. Differences exist within regions as a result of the variability in risk of exposure and the dependence on climate-sensitive sectors as well as the capacity to adapt.

Regional and national vulnerability assessment is an issue that has attracted increasing interest since the publication of the IPCC's Second Assessment Report, and suggestions for quantitative vulnerability indices are emerging. Vulnerability assessment has a focus on sensitivity to climate change and on the capacity of societies to rebound from exposure to extreme climate events and to adapt to longer-term changes. This introduces a broader research agenda focussing on the economic, social, technological and institutional issues that influence and form the adaptive capacity of a society.

Vulnerability indices have not yet reached the operational stage and, despite general statements about lower adaptive capacity in the developing countries, the uncertainties in the regional distribution of vulnerability are considerable.

The report examined some of the key issues with regard to possible adaptive responses. It was discussed why and when adaptive measures and policies seem appropriate and which issues are important to examine when considering anticipatory adaptation, including: Which types of measures exist? How effectively could adaptive measures mitigate negative climate effects? What would these measures cost? It is clear that although progress has been made on these issues since the publication of the Second Assessment Report of the IPCC, more research and studies are needed before there will be satisfactorily answers to these questions.

The report showed some important differences between mitigation activities and adaptive actions. The key issue is that the atmosphere is a common property good and GHG 'pollution' resembles a public bad and mitigation a common good. Adaptation provides only local benefits, whereas mitigation provides global benefits. People will have incentives to adapt to climate change, to the extent adaptation reduces damages, whereas they have no such incentives with regard to mitigation.

The four principles for allocation of adaptation assistance and climate compensation illustrated that adaptation and mitigation differ from the point of view of fairness. The principles of vulnerability and economic efficiency could be seen as reflecting the different 'paradigms' that underpin development assistance. The former reflects an approach aimed at enhancing the productivity of sectors and the institutional capacity of countries broadly conceived, whereas the latter supports more targeted 'interventions' aimed primarily at economically productive segments within national economies that are vulnerable to climate change. These paradigms or schools of thought parallel to some degree the distinction made between programs and projects, or between 'macro' and 'micro' measures. The report did not make any recommendations as to which approach and projects are in some way 'better' or preferable. It should be expected that future adaptation funding programs would both reflect concern for vulnerability and for economic issues.

The report also touched upon a number of bigger questions that lie beyond this limited study. As pointed out, the change of the future GHG emissions trajectory, and hence the environmental and social benefits achieved as a result of full implementation of the Kyoto Protocol, could likely be marginal relative to the business-as-usual projection. Thus, adaptation to climate change seems inevitable; a fact that raises a number of vexing questions with regard to economic efficiency and fairness: What is the optimal balance or mix of prevention (i.e. mitigation) and cure (i.e. adaptation)? What balance of mitigation and adaptation activities would be considered fair from the point of view of developing countries, i.e. those who are most vulnerable to climate change? Do we know how to analyze this question? And do we know enough to analyze this issue?

Finally, the question of how the developing countries could be integrated better in the global climate regime is becoming increasingly salient. There is a clear need to start thinking carefully about the 'architecture' of the second commitment period (2013-17) of the Kyoto Protocol. This issue is not just about when in some way it becomes appropriate and reasonable that the developing countries take on mandatory mitigation commitments. It is equally much about how to create synergies between sustainable development and climate change in developing countries and finding useful ways of mainstreaming the climate change issue. There is also a need for more research on opportunities for integrating mitigation and adaptation in policies, programs, and projects in developing countries.

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This report explores some of the key issues related to distributional fairness and international burden sharing in the context of global climate change. A conceptual understanding of burdens going beyond costs of emission reductions and including damages of climate change and adaptation to climate change is suggested and aspects of adaptation measures, incentives to adapt, and barriers to adaptation discussed. Methods for regional differentiation of burdens and the inclusion of adaptation in vulnerability and integrated impact assessment are also explored.

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