Ter Inzage

GLOBAL CHANGE

Dutch National Research Programme on Global Air Pollution and Climate Change

Climate Change: Socio-Economic Impacts and Violent Conflict

Report no.: 410 200 006 (1996)

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Nationaal Onderzoek Programma Mondiale Luchtverontreiniging en Klimaatverandering (NOP)

Het Nationaal Onderzoek Programma Mondiale Luchtverontreiniging en Klimaatverandering (NOP) bevindt zich thans in de tweede fase (1995 - 2001). De eerste fase, waarin 150 projecten zijn uitgevoerd, liep van 1990 tot 1995. Naar verwachting zullen in de tweede fase uiteindelijk circa 80 projecten worden uitgevoerd. Gezien de aard van het klimaatprobleem is een multi-disciplinaire benadering binnen het NOP noodzakelijk. Het programma is onderverdeeld in vier thema's:
I Gedrag van het klimaatsysteem als geheel en in onderdelen
II Kwetsbaarheid van natuurlijke en maatschappelijke systemen voor klimaatverandering
III Maatschappelijke oorzaken en oplossingen
IV Integratie en assessment

Het primaire doel van het NOP, als strategisch en lange termijn onderzoekprogramma, is te voorzien in de behoefte aan beleidsrelevante informatie voor de ontwikkeling van het nationale en internationale klimaatbeleid. Naast het bereiken van dit inhoudelijke doel, wordt er ook veel belang aan gehecht dat het onderzoek op de langere termijn verankerd zal blijven in de Nederlandse onderzoeksstructuur.

Door het NOP wordt twee maandelijks de (gratis) onderzoeksnieuwsbrief "CHANGE" uitgegeven. Voor meer informatie over het NOP kunt u zich richten tot:
Programmabureau NOP, Postbus 1 (pb 59), 3729 BA, Bilthoven
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National Research Programme on Global Air Pollution and Climate Change (NRP)

The National Research Programme on Global Air Pollution and Climate Change (NRP) is currently in its second phase, 1995-2001. The first phase, in which 150 projects were carried out, ran from 1990 to 1995. About 80 projects are expected to be finally realised in the second phase.
The nature of the climate problem warrants a multi-disciplinary approach within the NRP. The programme is categorised into four themes:
I Dynamics of the climate system and its component parts
II Vulnerability of natural and societal systems to climate change
III Societal causes and solutions
IV Integration and assessment

The primary objective of the NRP as a strategic and long-term research programme is to meet the demand for policy-relevant information for the development of national and international climate policy. Besides realising this substantive objective, a great deal of importance is attached to the long-term anchoring of the research within the Dutch research structure.

The NRP Programme Office publishes a (free) research newsletter called CHANGE every two months. For more information on the NRP please contact:
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CONTENTS

PREFACE

This report contains the results of a research programming study in commission of the Dutch National Research Programme on Global Air Pollution and Climate Change, dealing with the question of what new research should be undertaken to analyse the socio economic impacts of climate change and the danger of resulting violent conflicts. The study has been carried out by the Department of General Economics of Wageningen Agricultural University, as far as the socio-economic impacts are concerned, and by the Department of Social Geography for the topic of violent conflicts as a result of climate change. The study was limited in scope and size where for each of the topics only three months of study were available. This implies that the study largely is based on a review of existing literature, including the IPCC reports, which is the basis for providing recommendations for further research. The report gives a detailed overview of existing insights and knowledge in both areas, but cannot pretend to be complete or exhaustive, given the large number of studies in these areas. During the project we received very helpful advise and comments from the members of the advisory committee, ir L. Bijlsma (Rijksinstituut Kust en Zee), drs. M. Kok (NOP programme bureau), dr. G.P. Können (KNMI), prof. dr. A. Kuyvenhoven (Wageningen Agricultural University), prof. dr. G.J. Siccama (Instituut Clingendael) and prof. dr. W. Tims (Free Univeristy). In addition we received suggestions from drs. A. Gielen (Central Planning Bureau), prof. dr. mr. C.J. Jepma (Rijksuniveristeit Groningen), drs. H. Merkus (Ministry of Housing, Physical Planning and the Environment), drs. R. Tol (Institute for Environmental Studies, Free Univeristy), dr. H. Verbruggen (Institute for Environmental Studies, Free Univeristy), dr. A Vollering (Royal Dutch Academy of Arts and Sciences) and drs. H. Timmer (Central Planning Bureau). Of course, as usual we take full responsibility for the contents of the report and its conclusions. The structure of the report is as follows. Chapters 1 contains the introduction on socio-economic aspects and violent conflicts. Chapters 2 and 3 deal with the socio economic impacts of climate change. The Chapters 4 and 5 deal with violent conflicts as a result of climate change. Finally, Chapter 6 contains the conclusions and research priorities for both areas.

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ABSTRACT

This report contains a literature study on the socio economic impacts of climate change and the possibilities of violent conflicts enhanced by the greenhouse effect. The socio-economic impacts are classified according to the economic sectors in chapter 2 of the study. The impacts on property, ecosystems and human well being are the topic of chapter 3. Chapter 4 deals with climate change and environmental security, and discusses the most important concepts of security and their relation to climate change. Chapter 5 deals with already existing and potential conflicts, that may be enhanced by the greenhouse effect as a result of resource scarcity, particularly related to availability of food and water. On the basis of the literature study and an analysis of research gaps propositions are made on new areas of research to be undertaken. The study emphasizes the need to further study the impact on agriculture in semi-arid zones, the impact on water availability in sensitive regions, a further analysis of the consequences of sea level rise particularly in sensitive areas and with regard to forced migration. Also further studies a required into the socio-economic impacts of changes in human health and mortality due to climate change, in relation to diseases. Special attention should be paid to migration because of environmental degradation and flooding. Extreme weather events have already been studied, but there still is a need for further insights into how extreme weather events will affect society, taking into account adaptive behaviour. Finally, in the area of socio-economic impacts, the implications of changes in ecosystems and biodiversity require further attention as these effects may be large but, at the same time, difficult to assess in economic terms.

EXECUTIVE SUMMARY

Economic progress has long been recognized to involve potential adverse environmental side effects at the local, regional and even the global level. In recent years it has become increasingly clear that expanding economic activity can also impose environmental damage that is irreversible over long time horizons. The central theme of the second and the third section of the report is to study the socio-economic impact of climate change. Therefore a literature review is made in order to get an overview of the present state of knowledge and to identify the most urgent and challenging research topics. The assessment of policy options for climate change requires detailed information on the cost and benefits of the various alternative policy options. The second and the third section is focussing on the *order of magnitude estimates of impact on 17 different sectors associated with a doubling of* atmospheric CO_2 concentration. Six types of the rich dynamic nature of the climate change damage costs are also distinguished. IPCC predicts that $2 \times CO_2$ will lead to an (equilibrium) increase in global mean surface temperature of 1.0 to 4.0^{0}C by 2100. The adjusted Business as Usual scenario (IS92a) will lead to $2 \times CO_2$ around 2050 and an increase in temperature of 1.0 to 3.5^{0}C around 2100. By 2100, sea level is projected to increase by 10 - 75 cm, with a best estimate of 50 cm, as a result of climate change. This increase comes on top of the present trend of 20 cm/century. The impact of the enhanced greenhouse effect on agriculture is ambiguous. All impacts strongly depend on the adaptability of the farmers, and on the reaction of markets and politics. Climate change scenarios exerted (in most cases) a slight-to-moderate negative effect on simulated world cereal production, even when the beneficial effects of CO_2, farm-level adaptations and future technological yield improvements were taken. For the OECD-E, OECD-P, CEE&fSU and S&SEA there are some *benefits to gain for agriculture. The extent to which forests and woodlands will be affected* by climate change depends on various factors like, for example, the species and age of trees, possibilities for forests to migrate and the quality of forest management. The impact of global warming on wood production is therefore also ambiguous. Climate change impacts are likely to exacerbate existing effects on fish stocks, notably overfishing, diminishing wetlands and nursery areas, pollution and UV-B radiation. Globally, saltwater fisheries production is hypothesized to be about the same and significantly higher if management deficiencies are corrected. Also, globally, freshwater fisheries and aquaculture at mid to higher latitudes should benefit from climate change. Changing climate alters established

reproductive patterns, migration routes, and ecosystem relationships. National fisheries will suffer if institutional mechanisms are not in place which enable fishers to move within and across national boundaries. The two uses of energy which are most sensitive to climate change are: a) space heating and air conditioning in residential and commercial buildings; and b) agricultural applications such as irrigation pumping and crop drying. All the relevant studies conclude that the use of fossil fuels, which are used as space heating fuels, will decline. Adjusted to the assumption of 2.5^0C warming, an average increase in US electricity demand of about 3.2 per cent for $2 \times CO_2$ is estimated. The supply of water will be affected, mainly through the change in precipitation patterns and, in coastal areas, through the intrusion of saline water into freshwater reservoirs. Higher temperatures are likely to cause an increase in water demand. In all developing countries with a high rate of population growth, future *per capita* water availability will decrease. The problem of assessing the impacts of likely climate change on construction falls into distinct parts: the assessment of the likely impacts of climate change on existing constructions and of how current design practices might require modification. The construction industry will be called on to implement adaptation options associated with sea-level rise. Existing assesssments of transport impacts have recognised the potential significance of changes in geographical patterns of economic activity on the transportation network. Climate change will have some direct effects on transportation infrastructure and the operation of transportation systems. Summer tourism would generally benefit from a longer season. The overall effect for a country as large as the United States would probably be negligible. In general, global warming might be expected to reduce the length of the skiing season in many areas and to affect the viability of some ski facilities. The costs of sea level rise divide into three types: Capital costs of protective constructions, and the costs of foregone land services, conveniently split into dryland and wetland loss. Small islands, deltaic settings and coastal ecosystems appear particularly vulnerable. The possible amount of wetlands loss depends mainly on the possibility of the systems to migrate inland, and therefore on the amount of coastal protection measures taken. Most studies on the impacts of climate change predict an increased loss of species and ecosystems. The impact of climate change on species and ecosystems has been paid relatively little attention to by economists, primarily so because the physical impact is still to large extent unknown, but also because the value of an ecosystem or a species cannot be easily estimated. The overall effect of global warming on human amenity is ambiguous, the impact being positive in colder and negative in warmer regions. Global climate change over the coming decades would have various effects, mostly adverse, upon the health of human populations. An increase in the rate of occurence of malaria is predicted. Global warming will affect the quality of air in two ways: secondary benefits and secondly, many chemical reactions depend on temperature. Warming can exacerbate the formation of smog. One study estimates of 72 million people displaced in China, eight million in Egypt and half-a-million in Poland. In Bangladesh 11.4 million people could be affected. There are two types of costs: utility sacrificed by the migrant, and cost on the target host country. There are indications that concern about increased immigration induced by global warming is especially high in Europe. Increased frequency of extreme events will potentially have more impact than mean changes in climate. On the basis of meteorological data, however, there can be no determination of an systematical increase in stormactivities. In 1987 the concept of 'environmental security' was officially introduced in the General Assembly of the UN. More recently, global climate change as one manifestation and cause of environmental degradation has been added to this debate. Environmental security is a fuzzy concept. The mutual connections between the environment and security are perceived in different ways. The adjective 'environmental' may describe the nature of a risk or threat, but 'environmental' may also refer to an agent that sets in motion a train of events that eventually increases a specific risk: violent conflict. Global climate change has two dimensions that result in different social consequences. One dimension is the gradual longterm change of climate parameters and concomitant changes in bio- and geosphere. Within limits there is a significant element of choice in societal response options. The other type is a gradual change in frequency and severity of peak events. Response time for these peak events is very short or non-existent. Some preparations are possible - they might even be encouraged by increasing frequency and severity. Societies differ in their capability to respond to these peak events and every peak event may significantly alter the history of the affected society. The causes and consequences of global climate change are unevenly and differently distributed. Those parts of the globe that contribute most to global climate change are not the ones that suffer most of the consequences. But contributions change over time and consequences may be severe for all in the long term. Because of its global nature and its perception as a collective 'bad', countering the process of climate change necessitates collective action by sovereign states. But the nature of the issue at the same time provides sovereign states with the potential for 'free riding'. The unbalanced mix of national and collective interests provides a basis for international political tension and conflict. In addition a number of specific national economic interests for some individual countries provides extra incentives to 'free riding' and thus an extra barrier to effective, common action. Collective action in this field is not completely impossible. Power, knowledge and interests decide whether an international regime, that sets norms in international interaction backed by shared convictions and social control but lacking the authority of an overarching power, can be established. Powerful states are necessary to force weaker states to comply with the terms of the regime. Learning by transnational groups of scientists and policy-makers enables the formation of the knowledge base that is necessary to craft a regime. Mutually agreeable deals that respect the interests of significant individual parties are the motivating force underlying regime formation. Climate change as a subject of regime formation differs in important respects from earlier instances because of the time frame and the size of the effects, the significance and the number of actors controlling the response mechanisms, the less even distribution of effects of global change. These factors result in less favourable circumstances for regime formation in the field of global change. Environmental security is not one, but a bundle of issues that can not be solved in the setting of one clearcut rank order of states. Because of differences in interests and strategic positions of states, every issue has to be considered on its own merits. In every instance the cooperation of one or even several groups of states is essential and they wield effective veto power in that particular instance. As a consequence every issue has to be negotiated in a differently structured arena, that often will be less than truly global. Spillovers and tradeoffs are difficult to achieve. While it is clear that there will be initial winners and losers of global climate change if it materialises, their precise enumeration is still difficult. Many of those especially at risk are probably low-income populations in low-latitude regions depending on isolated, dryland agricultural systems in semi-arid and arid areas. Global level arenas where the consequences of global climate change are treated among the members of the state system are in the short run hardly likely to deteriorate into theatres of violent conflict. The interests at issue are still insufficiently seen as matters of life and death by the most important participants to make such courses of action very likely. Of course this may well change over time. Most conflicts ultimately emanating from global climate change and possibly violent, will materialise within the macro-regions of the world. Geographical macro-regions, individual countries and parts of countries differ as to susceptibility, vulnerability and consequently the probability that their populations and political leadership will take effective measures against (the consequences of) climatic change. A decreasing resource base may cause anxiety and efforts to make up for the losses elsewhere, or it may cause an increased vulnerability to armed attack that indeed results in aggression by others. An expanding resource base (the 'winning' side in global change) may give rise to efforts of territorial expansion. Environmental decline may also result in a collapse of the social order and thereby in violent conflict. Finally, environmental degradation may condition violent conflict as a result of external effects. This may happen when environmental refugees cross international borders and cause tensions between the two countries involved. Violent conflict may thus follow in several ways from environmental change. The relevant social actors need not always be states, but states are definitely often involved, increasingly as one party in a civil war. Many of the preceding assertions considering environmental factors as conditions for violent conflict are based on general views in the literature on international relations and conflict literature and still have to be studied for the environmental sector specifically. In the literature on environmental questions the reverse relation has been emphasized: the environmentally negative consequences of war. A democratic polity and perhaps also an advanced level of socio-economic development have been suggested as restraints on the vulnerability to cope with environmental degradation and to deal with possibly ensuing violent conflicts. The chances of violent conflict as a result of social order breakdowns (e.g. due to weather extremities) are limited by the legitimacy of government, by rational response patterns from the side of the authorities, and by the availability of independent action centers in civil society. Despite the availability of more means to cope with problems in case of high development, the pronounced division of labour may result in effects either way. Reduced fresh water availability, sea level rise, diminishing food production and environmental refugees are the subjects frequently encountered in the context of possible global change impacts. Changes in these factors or their emergence are also referred to as potent causes of future violent conflicts. The chances for water conflict are highest in areas whose water supply is dependent on an internationally shared water basin, where fresh water is already scarce and where global warming is expected to have an especially deteriorating effect on the water balance. Arid and semi-arid regions in lower latitudes are generally also the regions where democratic traditions are weak and socio-economic development in many cases modest at best. In these regions there are hardly any international treaties instituting a regime for the peaceful allocation of water from shared rivers. The consequences of sea level rise would be most serious in a number of flat, densely populated coastal areas around the world. In various cases not only is the coastal area itself threatened but the national economy as a whole. At the intra-national level there is hardly a distributional conflict, and social order breakdowns might be prevented by responsive action on account of the gradual nature of the rise. The most likely security impact of sea level rise when no measures would be taken, e.g. due to low degree of socio-economic development, is thus social and political order breakdowns because of refugees in a national or an international context. Populations in sub-Saharan Africa are the most vulnerable to eventual global warming and the concomitant decrease of agricultural production. The arguments concerning democracy and socio-economic development again apply. The notion of 'environmental refugee' has recently been coined to indicate the flight of those uprooted by environmental degradation. However, the connection between environmental degradation and global climate change is hazardous in concrete cases. It is also uncertain to what extent environmental degradation contributed to the migration decision. The term 'refugee' has a well circumscribed meaning in international law and there are pros and cons in extending the definition. In spelling out the possible connections between environmental degradation and migration two different causal paths have to be considered. The first is migration immediately induced by degradation of natural resources as in migration as a consequence of a lack of rain in the growth season in semi-arid conditions. The second causal path links degradation and migration through violent conflict. Here the idea is that degradation results in distributional conflict or social order breakdown which in its turn gives rise to outmigration. This is the train of events especially relevant here. It may have a further sequence when newly arrived outmigrants have to settle amongst an established population with a full potential of a new round of distributional and social breakdown conflicts. When borders, in particular international borders are crossed, political authorities both sides of the line get involved, which may result in further extension of conflict.

SAMENVATTING

Sinds lange tijd wordt erkend dat economische ontwikkeling potentiële nadelige bijwerkingen met zich meebrengt op het gebied van milieu op lokaal, regionaal en zelfs mondiaal niveau. De laatste jaren is in toenemende mate duidelijk geworden dat een toename in economische activiteiten ook onomkeerbare milieu-schade op de lange termijn kan opleggen. Het voornaamste thema van het tweede en derde hoofdstuk van dit rapport is het onderzoek naar de sociaal-economische effecten van klimaatverandering. Daartoe is een een literatuuronderzoek gedaan teneinde een overzicht te verkrijgen van de huidige stand van zaken en om de meest urgente en interessante onderzoeksthema's vast te stellen. De beoordeling van beleidskeuzes inzake klimaatverandering vereist gedetailleerde informatie over de kosten en baten van verscheidende alternatieve beleidsmogelijkheden. Het tweede en derde hoofdstuk concentreert zich op de orde van grootte van effectenschattingen op 17 verschillende sectoren in verband met de verdubbeling van de atmosferische CO_2-concentratie. Tevens worden zes aspecten van het rijke dynamische karakter van schadekosten in verband met klimaatverandering onderscheiden. IPCC voorspelt dat een verdubbeling van de CO_2-concentratie zal leiden tot een (evenwichts-) toename van de mondiale gemiddelde oppervlakte temperatuur van 1,0 tot 4,0^{0}C in het jaar 2100. Het 'adjusted Business as Usual scenario' (IS92a) leidt tot een verdubbeling van de CO_2-concentratie in het jaar 2050 en een toename in temperatuur van 1,0 tot 3,5^{0}C rond 2100. Er bestaan ramingen dat als gevolg van klimaatverandering de zeespiegel met 10 - 75 cm, met een beste schatting van 50 cm, zal stijgen. Deze toename komt bovenop de huidige trend van 20 cm/eeuw. De gevolgen van het versterkt broeikaseffect op de landbouw zijn meerduidig. Alle effecten zijn sterk afhankelijk van het aanpassingsvermogen van de boeren, en de reacties van de markt en het beleid. De meeste scenario's op het gebied van klimaatverandering doen een gering tot matig negatief effect op de gesimuleerde mondiale graanproductie gelden, zelfs wanneer voordelige effecten van CO_2, aanpassingen op boerderij-niveau en toekomstige technologische opbrengstverhogende verbeteringen worden aangebracht. Voor de landbouw in de OECD-E, OECD-P, CEE&SU and S&SEA zijn er wat voordelen te behalen. De mate waarin bossen en bosrijke omgevingen worden beïnvloed door klimaatverandering is afhankelijk van verscheidene factoren, bijvoorbeeeld de soort en leeftijd van de bomen, mogelijkheden van bossen om te migreren en de kwaliteit van het bosbeheer. Het effect van klimaatverandering op de houtproductie is zodoende ook meerduidig. Effecten van klimaatverandering verergeren waarschijnlijk bestaande effecten

op de voorraad vis. Dit zijn met name overbevissing, vermindering van moeraslanden en kweekvijvers, vervuiling en ultraviolette straling. Algemeen wordt verondersteld dat de productie van de zoutwatervisserij ongeveer gelijk blijft en dat deze productie significant hoger ligt wanneer tekortkomingen in het beleid worden gecorrigeerd. Evenzeer wordt in zijn algemeenheid verondersteld dat de zoetwatervisserij en aquicultuur op de middelste en hogere breedtegraad voordelen van de klimaatverandering zal ondervinden. Klimaatverandering wijzigt gevestigde reproductieve patronen, migratie routes, en verhoudingen in ecosystemen. Nationale visserijen zullen schade lijden wanneer institutionele mechanismen niet geschikt zijn om vissers in staat te stellen binnen en over nationale grenzen te bewegen. De twee aanwendingen van energie die het meest gevoelig zijn voor klimaatverandering zijn: a) verwarming en airconditioning in woon- en bedrijfsgebouwen; en b) agrarische toepassingen zoals irrigatiepompen. Alle relevante rapporten concluderen dat het gebruik van fossiele brandstoffen die worden gebruikt als brandstof voor verwarming zal afnemen. Vanuit de veronderstelling van 2,5^{0}C opwarming door een verdubbeling van de CO_2-concentratie wordt een gemiddelde toename in de elektriciteitsvraag in De Verenigde Staten op ongeveer 3,2 procent geschat. Het aanbod van water zal voornamelijk worden beïnvloed door verandering in neerslagpatronen en, in kustgebieden, middels de binnendringing van zoutwater in zoetwaterreservoirs. De toename van de temperatuur zal waarschijnlijk een toename in de vraag naar water veroorzaken. In alle ontwikkelingslanden met een hoge mate van bevolkingsgroei, zal de toekomstige beschikbare hoeveelheid water *per capita* afnemen. Het probleem van het schatten van de aannemelijke effecten van klimaatverandering op de bouw valt uiteen in verschillende delen: de schatting van aannemelijke effecten van klimaatverandering op bestaande gebouwen en hoe huidige ontwerpprocedures misschien aanpassingen behoeven. De bouw industrie zal worden verzocht om aanpassingkeuzes in verband met de stijging van de zeespiegel ten uitvoer te brengen. Bestaande schattingen van effecten op de transportsector erkennen de potentiële significantie van veranderingen in geografische patronen van economische activiteiten op het transportnetwerk. Klimaatverandering zal een aantal directe effecten hebben op de infrastructuur van het transport en het functioneren van transportmethoden. Toerisme in het zomerseizoen zal in het algemeen profiteren van een langere zomer. Het totale effect van klimaatverandering op het toerisme in een land zo groot als De Verenigde Staten is waarschijnlijk te verwaarlozen. In zijn algemeenheid mag verwacht worden dat een toename van de temperatuur de lengte van het skiseizoen in veel gebieden zal reduceren en de uitvoerbaarheid van een aantal skifaciliteiten zal beïnvloeden. De kosten van een zeespiegelstijging zijn in drie soorten te verdelen: kapitaalkosten van beschermende bouwwerken, en de kosten van nutsverlies van gronden, gemakshalve gesplitst in moerasgebieden en vaste grondgebieden. Kleine eilanden, delta-gebieden en ecosystemen van kustgebieden blijken bijzonder kwetsbaar te zijn. De mogelijke grootte van het verlies is voornamelijk afhankelijk van de mogelijkheden van de systemen om landinwaarts te migreren, en zodoende op het aantal genomen maatregelen inzake kustbescherming. De meeste rapporten over de effecten van klimaatverandering voorspellen een toename in het verlies van soorten en ecosystemen. Aan de effecten van klimaatverandering op soorten en ecosystemen is door economen relatief weinig aandacht geschonken. In eerste instantie omdat de natuurkundige effecten in belangrijke mate nog onbekend zijn, maar ook omdat de waarde van een ecosysteem of een soort niet gemakkelijk te schatten is. Het totale effect van een toename van de temperatuur op de menselijke leefbaarheid is meerduidig, voordelige effecten in koudere gebieden en nadelige effecten in warmere regionen. Mondiale klimaatverandering heeft in de komende decennia verscheidene effecten, de meeste nadelig, op de gezondheid van de menselijke bevolking. Een toename van het aantal malariagevallen is voorspelt. Een toename van de temperatuur zal de kwaliteit van de lucht op twee manieren beïnvloeden: kleine voordelen en in de tweede plaats zijn veel chemische reacties afhankelijk van de temperatuur. Een temperatuurstoename kan de vorming van smog verergeren. Een rapport schat een verplaatsing van 72 miljoen mensen in China, 8 miljoen in Egypte en een half miljoen mensen in Polen. In Bangladesh zouden 11,4 miljoen mensen worden beïnvloed. Er zijn twee verschillende kosten: practische voorzieningen die worden opgeofferd door de migranten, en kosten voor het gastland. Er zijn indicaties dat met name in Europa de bezorgdheid groot is over een toename van immigratie veroorzaakt door klimaatverandering. Een toename in de frequentie van extreme gebeurtenissen heeft in potentie grotere effecten dan middelmatige veranderingen in het klimaat. Op basis van meteorologische gegevens kan echter geen systematische toename van de stormfrequentie worden vastgesteld. In 1987 is het begrip `environmental security' officieel geïntroduceerd in de Algemene Vergadering van de Verenigde Naties. Recenter is wereldwijde klimaatverandering, als een van de uitingsvormen en oorzaken van milieudegradatie, aan dit debat toegevoegd. `Environmental security' is een vaag begrip. De wederzijdse verbanden tussen milieu en veiligheid worden vanuit verschillende invalshoeken bekeken. Het bijvoeglijk naamwoord `environmental' kan verwijzen naar het karakter van een risico of bedreiging, maar ook naar een werkende oorzaak of kracht die een reeks gebeurtenissen in gang zet die uiteindelijk een specifiek risico verhoogt: gewelddadig conflict. Wereldwijde klimaatverandering heeft twee dimensies die resulteren in verschillende sociale gevolgen. Een dimensie is de geleidelijke verandering van klimaatkenmerken op lange termijn, met daaruit voortvloeiende veranderingen in de bio- en geosfeer. Binnen zekere grenzen is er een aanzienlijke ruimte aangaande de keuze van maatschappelijke antwoorden hierop. De andere dimensie is een geleidelijke verandering in de frequentie en hevigheid van extreme weersgebeurtenissen. De tijd voor een antwoord daarop is zeer kort of zelfs helemaal afwezig. Er zijn bepaalde voorzorgsmaatregelen mogelijk - deze zouden zelfs aangemoedigd kunnen worden door de toenemende frequentie of hevigheid van zulke gebeurtenissen. Samenlevingen verschillen wat betreft het vermogen om een antwoord te formuleren op deze `peak events' en elk zo'n gebeurtenis kan de geschiedenis van de betreffende samenleving ingrijpend beïnvloeden. De oorzaken en gevolgen van wereldwijde klimaatverandering zijn ongelijkmatig verdeeld. Die delen van de aarde die het meest bijdragen aan wereldwijde klimaatverandering zijn niet degene die het meest te lijden hebben van de effecten. Maar de bijdragen kunnen in de loop van de tijd verschuiven en de effecten kunnen op langere termijn ernstig zijn voor alle partijen. Als gevolg van het wereldwijde karakter van klimaatverandering en de algemene peceptie van het proces als een collectieve verslechtering, vereist het bestrijden van klimaatverandering collectief optreden door soevereine staten. De aard van het probleem geeft die soevereine staten echter tegelijkertijd de gelegenheid tot `free riding'. Dit onevenwichtige mengsel van nationale en collectieve belangen vormt een basis voor politieke spanning en conflict. Specifieke economische belangen voor bepaalde individuele landen betekenen bovendien een extra prikkel tot `free riding' en aldus een extra belemmering voor effectieve gemeenschappelijke actie. Gemeenschappelijk optreden op dit terrein is niet geheel onmogelijk. Macht, kennis en belangen bepalen of een internationaal `regime' tot stand kan worden gebracht. Een `regime' stelt de normen voor internationaal handelen, op basis van gedeelde overtuigingen en sociale controle maar zonder de autoriteit van een overkoepelende macht. Machtige staten zijn nodig om zwakkere staten te dwingen zich aan te passen aan de normen van het regime. Het `leren' door transnationale groepen van wetenschappers en beleidsmakers maakt het mogelijk de kennisbasis te creëren die nodig is om een regime van de grond te krijgen. Wederzijds geaccepteerde overeenkomsten die de belangen van relevante individuele partners respecteren zijn de drijvende kracht achter het tot stand brengen van `regimes'. Klimaatverandering als onderwerp van `regime'-formatie verschilt in belangrijke opzichten van eerdere gevallen vanwege de termijn en de omvang van de effecten, het belang van en het aantal actoren dat de tegenmaatregelen in handen heeft, en de ongelijkmatige verdeling van de effecten. Deze factoren maken de condities voor het tot stand brengen van een `regime' op het terrein van klimaatverandering minder gunstig. `Environmental security' is niet één maar een verzameling `issues', die niet kan worden opgelost in `setting' van een duidelijke rangorde van staten. Als gevolg van de verschillen in belangen en strategische posities van staten, moet elk `issue' op zijn eigen merites worden beoordeeld. In elk afzonderlijk geval is de medewerking van één of zelfs verschillende groepen van staten essentieel en deze hanteren in dat specifieke geval hun veto-macht. Over elk `issue' moet daarom worden onderhandeld in een verschillend gestructureerde arena, die vaak minder dan wereldwijd zal zijn. `Spillovers' en `tradeoffs' zijn moeilijk te realiseren. Hoewel het duidelijk is dat er, wanneer de gevolgen van wereldwijde klimaatverandering werkelijk manifest worden, aanvankelijk winnaars en verliezers zullen zijn, is het nog steeds moeilijk om deze te benoemen. De belangrijkste risico-gebieden zijn waarschijnlijk lage-inkomens bevolkingen op lage geografische breedte, die afhankelijk zijn van geïsoleerde, niet-geïrrigeerde landbouwsystemen in semi-aride en aride gebieden. Het is onwaarschijnlijk dat de arena's waar de leden van het internationale statensysteem op wereldniveau onderhandelen over de gevolgen van klimaatverandering, op korte termijn zullen afglijden tot arena's van gewapend conflict. De belangen en de `issues' worden daarvoor door de belangrijkste betrokkenen nog altijd te weinig beschouwd als zaken van leven en dood. Dit kan zich uiteraard in de loop der tijd wijzigen. De meeste, mogelijk gewelddadige, conflicten die uiteindelijk zullen voortkomen uit klimaatverandering zullen zich afspelen in de diverse macro-regio's van de wereld. Geografische macro-regio's, individuele landen en delen van landen verschillen voor wat betreft hun vatbaarheid (`susceptibility') en kwetsbaarheid (`vulnerability') voor (de gevolgen van) klimaatverandering, en dus voor wat betreft de waarschijnlijkheid dat hun bevolking en politieke leiding daartegen effectieve maatregelen zal nemen. Een afnemende bestaanbasis (`resource base') zou kunnen leiden tot bezorgheid en tot pogingen om de verliezen elders goed te maken, of tot een verhoogde kwetsbaarheid voor gewapende aanvallen, wat daadwerkelijk kan resulteren in agressie door anderen. Een expanderende bestaansbasis (bij de `winnaars' van klimaatverandering) kan leiden tot pogingen tot territoriale expansie.

Mileuverslechtering kan ook leiden tot een ineenstorting van de sociale orde en aldus tot gewelddadig conflict. Tot slot kan milieuverslechtering, door externe effecten, de condities creëren voor gewelddadig conflict. Dit zou kunnen gebeuren als milieuvluchtelingen internationale grenzen oversteken en spanningen veroorzaken tussen de twee betrokken landen. Milieuverandering kan dus via verschillende wegen leiden tot gewelddadig conflict. De relevante sociale actoren hoeven niet per definitie staten te zijn, maar staten zijn er zeker vaak bij betrokken, in toenemende mate als één partij in een burgeroorlog. Veel van de voorgaande beweringen over milieufactoren als omstandigheden voor gewelddadig conflict zijn gebaseerd op algemene inzichten in de literatuur over internationale relaties en conflicten, en moeten nog worden bestudeerd voor het specifieke terrein van milieufactoren als potentiële conflictoorzaak. In de literatuur over milieuvraagstukken ligt de nadruk op de omgekeerde relatie: negatieve milieu-effecten als gevólg van oorlog. Democratie en misschien ook een vergevorderd niveau van sociaal-economische ontwikkeling worden wel verondersteld een positief effect te hebben op de mogelijkheid om milieudegradatie te bestrijden en de mogelijk daaruit volgende gewelddadige conflicten tegen te gaan (`vulnerability'). De kans op gewelddadig conflict als gevolg van het ineenstorten van de sociale orde (bijvoorbeeld als gevolg van extreme weersomstandigheden) wordt beperkt door de legitimiteit van de regering, door een rationeel pakket van maatregelen van de kant van de overheid, en door de beschikbaarheid van onafhankelijke `action centres' in de burgermaatschappij (de `civil society'). Hoewel een hoog ontwikkelingsniveau betekent dat meer middelen beschikbaar zijn om problemen het hoofd te bieden, kan ver doorgevoerde arbeidsverdeling effecten hebben in beide richtingen. Afnemende beschikbaarheid van zoet water, stijging van de zeespiegel, afnemende voedselproduktie en milieuvluchtelingen zijn de vaak genoemde onderwerpen als het gaat om de mogelijke impact van wereldwijde klimaatverandering. Het optreden of veranderen van deze factoren wordt ook vaak genoemd als potentiële oorzaak van toekomstig gewelddadig conflict. De kans op conflict over water is het grootst in gebieden waar de watertoevoer afhankelijk is van een internationaal gedeeld stroomgebied, waar zoet water al schaars is en waar een wereldwijde temperatuurstijging wordt geacht een zeer negatief effect op de waterhuishouding te hebben. Aride en semi-aride regio's op lagere breedten zijn vaak ook de regio's waar democratische tradities zwak zijn en de sociaal-economische ontwikkeling vaak op zijn best bescheiden. In deze regio's bestaan nauwelijks internationale verdragen die een `regime' vormen voor de vreedzame verdeling van water uit gemeenschappelijke rivieren. De gevolgen van een zeespiegelstijging zouden het ernstigst zijn in een aantal platte, dichtbevolkte kustgebieden verspreid over de wereld. In verscheidene gevallen is het niet alleen het kustgebied zelf dat wordt bedreigd, maar de nationale economie als geheel. Op het intra-nationale niveau is er nauwelijks sprake van een verdelingsconflict, en ineenstorting van de sociale orde kan worden voorkomen door tegenmaatregelen, gezien het zeer geleidelijke karakter van de zeespiegelstijging. De meest waarschijnlijke veiligheidconsequentie als geen maatregelen worden genomen, bijvoorbeeld als gevolg van een laag niveau van sociaal-economische ontwikkeling, is daarom het ineenstorten van de sociale en politieke orde door het op gang komen van nationale of internationale vluchtelingenstromen. Bevolkingen in Afrika beneden de Sahara zijn het meest kwestbaar voor een eventuele wereldwijde temperatuurstijging en de afname van landbouwproduktie die daar het gevolg van kan zijn. De eerder genoemde argumenten betreffende de invloed van democratie en sociaal-economische ontwikkeling zijn ook hier van toepassing. Het begrip `milieuvluchteling' is recentelijk geïntroduceerd om diegenen aan te duiden die hun woongebied zijn ontvlucht als gevolg van milieuverslechtering. Het verband tussen milieuverslechtering en wereldwijde klimaatverandering is in concrete gevallen echter onzeker. Het is ook..onzeker in welke mate de verslechtering van het milieu bijdroeg tot de beslissing om te migreren. De term `vluchteling' heeft in het internationale recht een nauwkeurig omschreven betekenis en er zijn voor en tegens aangaande het oprekken van de definitie. Bij het uitwerken van de mogelijke verbanden tussen milieuverslechtering en migratie moeten twee verschillende causale paden in ogenschouw worden genomen. Het eerste causale pad is migratie als onmiddellijk gevolg van een verslechtering van de natuurlijke bestaansbronnen, zoals bij *migratie in geval van regengebrek in het groeiseizoen in semi-aride gebieden.* Het tweede causale pad legt een verband tussen milieuverslechtering en migratie via gewelddadig conflict. Milieuverslechtering mondt in deze gedachtengang uit in een verdelingsconflict of in ineenstorting van de sociale orde, wat op zijn beurt aanleiding geeft tot migratie naar elders. Vooral een dergelijke reeks gebeurtenissen is in dit verband relevant. De migratie kan leiden tot een verder vervolg wanneer de migranten zich moeten vestigen in een bestaande gemeenschap. Daardoor kan het potentieel ontstaan voor een nieuwe ronde van verdelings- en sociale ineenstortingsconflicten. Wanneer de migratie grenzen overscheidt, vooral internationale grenzen, raken politieke autoriteiten aan beide zijden van die grens bij het probleem betrokken, wat kan resulteren in verdere conflictuitbreiding.

1. INTRODUCTION

1.1 Socio-economic impacts and violent conflicts

This report focuses on the socio economic impacts of climate change and on the possible resulting violent conflicts that may be the results of environmental deterioration or increasing scarcity of resources due to climate change. Possible reasons for violent conflicts may be food shortages or acute water scarcity in already vulnerable and sensitive regions of the world. This introduction first deals with the socio-economic impacts of climate change in section 1.2. Section 1.3 focuses on the risk of violent conflicts.

1.2 *Socio-economic impacts*

The assessment of policy options for climate change requires detailed information on the cost and benefits of the various alternative policy options. This study is not focusing on the costs of policy options but on the damages and impacts of climate change. Therefore a literature review is made of the socio-economic impacts of climate change in order to get an overview of the present state of knowledge, and to identify the most urgent and challenging research topics to improve our understanding of the socio-economic impacts of climate change. An essential element in the question of how climate change will affect the socio-economic system is the degree of adaptation of the various categories of economic activities, like agriculture, forestry, industrial systems, the energy system and coastal protection. This study will provide an overview of research results on the impacts of climate change associated with an atmospheric CO_2 concentration of twice the preindustrial level ($2 \times CO_2$). This $2 \times CO_2$ is a completely arbitrary benchmark, chosen for analytical convenience. It is neither an optimal point nor a steady state, and warming will continue, and in fact aggravate beyond $2 \times CO_2$. IPCC (1996, Summary for policymakers, pp 6) predicts that $2 \times CO_2$ will lead to an (equilibrium) increase in global mean surface temperature of 1.0 to 4.0^{0}C. The adjusted Business as Usual scenario (IS92a) will lead to $2 \times CO_2$ around 2050 and an increase in temperature of 1.0 to 3.5^{0}C around 2100 (Können, 1997). By 2100, sea level is projected to increase by 10 - 75 cm, with a best estimate of 50 cm, as a result of climate change (IPCC, 1996, Summary for policymakers, pp 7). This increase comes on top of the present trend of 20 cm/century. Attempts at a monetary quantification of the impacts - despite being a classic application of environmental economics - have started to emerge only recently. Chapter 2 will include order of magnitude estimates of impact on the primary sector, namely agriculture (section 2.1), forestry (section 2.2) and fishery (section 2.3) and the impact on five other sectors: energy (section 2.4), water (section 2.5), construction (section 2.6), transport (section 2.7) and tourism and recreation (section 2.8). Chapter 3 will provide order of magnitude estimates of impacts of climate change on sea level rise capital loss and protection costs (section 3.1), dryland and wetland loss (section 3.2), species, ecosystems and landscape losses (section 3.3), human amenity (section 3.4), health and mortality (section 3.5), air pollution (section 3.6), migration (section 3.7) and risks of disasters (section 3.8). Figures are produced for different geopolitical regions as well as the world as a whole. The study also concerns the impact of adaptation measures on the damage due to climate change. Six types of the rich dynamic nature of the climate change damage costs are distinguished (section 3.9): valuation of damage over time, socio-economic vulnerability, higher order impacts, knowledge and uncertainty, non-equilibrium climate change, irreversibility and other accumulation. This study will draw heavily on Cline (1992), Tol (1994a, 1994b, 1994c), Fankhauser (1995), Fankhauser and Tol (1995), IPCC (1996), Tol *et al.* (1995a), Tol (1995b) and Tol (1996). Finally the study will lead to a number of knowledge gaps, and where possible relevant studies from recent literature are given. In addition a set of recommendations for further research on the socio-economic impacts of climate change will be provided.

1.3 Global change and the notion of security

The notion of security has several connotations. In one sense it has for a long time been strongly related to the risk of international military threats and violence. During the later stages of the Cold War and thereafter this traditional emphasis weakened. Definitions of security threats were widened from organized (mainly) interstate military violence to non-military threats such as lack of economic development and environmental degradation. The traditional, military, security concept was widened and new categories of security were introduced, including political security, economic security and environmental security (Buzan 1991), referring not merely to states but in addition to other social actors

(Waever a.o. 1993). Coinciding with this broadening of what 'security' is about, the notion of what and whom was to be secured shifted from 'national' states to the 'international' realm (Latham 1995), i.e. security was increasingly perceived as a collective good of states and the citizenry of the world. In the present study we concentrate the discussion on the notion of environmental security. In 1987, the concept of 'environmental security' was officially introduced at the 42nd session of the United Nations General Assembly. Since that time the notion has become a regular password in academic and political discourse. More recently, global climate change as one manifestation and cause of environmental degradation has been added to this debate. In this programming study we will focus on the possible connections between global climate change and environmental security. At present environmental security is a fuzzy concept. It is apparently often used as a cover term for discussing all kinds of phenomena and problems that are in one way or another related to the deterioration of the environment. While initially encompassing the risk of violent conflict or at least serious political destabilization, the link between environmental deterioration and potential conflict is in most of the present 'environmental security'-discussions lost or at best very partial. A thorough discussion of the concept is necessary to avoid confusion. In the present political and academic debate and literature, the mutual connections between global climate change and security are perceived in two different ways. In the first perspective, that has itself several different versions, global climate change and its physical consequences are considered as threats. Security is seen as an outcome of risk perception. Global climate change thus impinges upon a general sense of security with respect to the physical environment. The sense of security may in this context refer to an individual, a group, a state, an international organization. In case this version of environmental security refers to a state it is incorporated in the more traditional security concerns of states, i.e. the threats to their survival they perceive from internal and external enemies. This results in a broadening of the agents of (in)security and possibly in a widening of what insecurity implies (from the threat of directed, intentional bodily harm to a non-directed degradation of the living environment with possible further consequences for survival). This version of environmental security therefore carries the suggestion of utmost urgency, as does traditional state security in general. The extension of the concept of security to the realm of global climate change (or environmental degradation in general) therefore implies the same sense of urgency for risks related to global climate change. This is called the 'securitization of the environment'. The well-foundedness of this reformulation is debated (Deudney 1990, Buzan et al. 1995, Graeger 1996). The second way of framing the link between global climate change and security is different in that the intimate connection between violence (intended bodily harm) and security that is central to the traditional notion of state security, is maintained. Global climate change is here considered as the ultimate agent that changes through environmental degradation the availability and distribution of important assets (e.g. food, water) for social actors, who then engage in violent conflict. In this view global climate change via environmental degradation impinges upon security in the traditional sense, i.e. as the absence of the risk of violent conflict. It may affect state security but other social groups may as well be dragged into violent conflict. If they do, states can not be but implicated. While the adjective in environmental security refers to the nature of the threat itself in the first perspective, in this second perspective 'environmental' refers to the agent that sets in motion the train of events leading to an involvement in violent conflict. So far we have only set out some types of argument in bare outline. In section 1.2 we will further develop the concept of security. This will enable us to differentiate the notion of environmental security into a number of component parts whose relations should not be taken for granted. In our view this is useful because otherwise the concept runs the risk to replace 'sustainable development' as a temporarily effective political rallying cry but a blunt instrument for purposes of analysis. We then will highlight the difficulty of incorporating the specific notion of global climate change into the overall notion of environmental security (section 1.3). While individual links between global climate change and specific forms of environmental degradation, and between specific forms of environmental degradation and the ways this affects humans and eventually drives them into conflict, can be made, the determination of the strengths of all the chains in the argument, and of their empirical variation, is still beyond us. The lack of knowledge of the regional manifestations of global climate change is a particularly weak point in this regard. Reliable, detailed data concerning the consequences of climate change on the scale of nations and small regions are largely deficient. It hampers the development of further insights in the global change-security nexus.

Two notions of security

The notion of security has never been exclusively limited to the risk of violent conflict between states. Security generally has to do with the banning of risks. The risks may be different in nature (violence, lack of means of existence) and the actors that run the risks may differ (states, people). The two most important contexts to which 'security' is applied refer on the one hand to the states and on the other hand to the social existence of humans. State security traditionally refers to the risk of violence against the state (embodied in its central organs, its territory and its population) by internal or external forces. The discipline of national security studies, developed after the second world war, emanates from the age old problem in politology how states can be secure in a world of sovereignties. States try to lower those risks in different ways. The traditional approach to state security is very much focused on the manipulation of these risks by the disposition of armed force. This force is in the first instance used to deter violent attacks and, if unsuccessful, is available for either defence or retaliation. This classification refers primarily to external threats but may also be used fruitfully for threats from the inside. The focus on the weaponry that states had procured in order to increase their security has for a long time informed strategic studies and its predecessors in the field of international relations. Apart from force, states can engage in the cooperative exchange of values and sympathy to manipulate their environment in order to diminish the risk of violence. Towards the end of the Cold War the notion that the manipulation of armed force could no longer provide security, rather the contrary, was gaining ground and the alternative notions to provide security became again more prominent. At the same time risks tended to be perceived from a larger number of directions, e.g. from the side of environmental degradation. The connections between these different types of insecurity remain, however, difficult to grasp. The idea of social security is ancient and has historically been tied to the family, local communities and the churches. From the late 19th century in western society states have become increasingly implicated in the provision of social security. Social security refers primarily to the banning of financial risks from social life. The risks of unemployment, deterioration of health and weakness of old age, all inhibiting the capacity to earn a living have always been of central concern. Welfare provisions have later extended to housing, education, cultural participation. The notion of an unpolluted environment has been part and parcel of many welfare state discussions (e.g. in connection with health and housing since the late 19th century). Access to and levels of benefits have widely varied as have the distribution of responsibilities for financing and regulating the system. The way in which the original providers of social security have been incorporated in the current state-regulated welfare systems differs. Consequently, while the original concept of social security starts from financial risks, here again as in the case of state security, the notion has been broadened. While social security has unequivocally to be provided to individuals and families, the responsibility for its actual provision, or at least for its regulation, has increasingly been transferred to the state, though the range and level of state responsibility remains contested. Recent literature introduces an overall concept of human security (UNDP 1994, Lonergan 1996) and makes a distinction between seven types, many of them clearly overlapping. The risk of violence has become one of them, degradation of the environment is another. Human security also encompasses economic, food, health, community and political security. Running those risks are not primarily states, but individuals and groups. In sum, the two different notions of security, starting either from the state or from individuals and groups, have both been broadened to encompass all types of risks. Not only are the different types of security not clearly distinguished, their mutual relations are also undetermined. Where the previous link with state security has been consciously maintained, the notion of security still has overtones of urgency and seriousness, risks are survival risks. Charting a course through these unquiet conceptual waters is far from easy. In chapters 2 and 3 of this study we focus on the monetary costs of environmental degradation as a consequence of global climate change including the resilience of economies to absorb them. Environmental security refers in this context to the direct threats of environmental degradation as a consequence of climate change and is studied in the framework of the discipline of economics. These costs (and eventually the benefits of global change) are in their turn important conditions for the possible emergence of human conflict. In chapters 4 and 5, in which the environmental conflict potential in global and regional arenas is discussed, we will apply the notion of security in the traditional sense but take into account a wider variety of social actors than just states, i.e. we focus on serious conflicts of interest (in the ultimate case: violent conflicts) related to the consequences of climate change.

Global climate change: two types of consequences

Parameters of the world climate seem to change gradually. Human activities apparently contribute significantly to these changes (IPCC, 1996). From the perspective of impacts on social life climate change has two types of consequences. One type is a longterm, gradual change of metereological conditions (temperature) and the concomitant changes in geo- and biosphere (sea level rise, desertification, diminishing biodiversity). In terms of social impacts there is within limits some time to adapt, an element of choice in response options. The other type is a gradual change in the frequency and severity of short term disturbances and extremities in weather conditions (hurricanes, droughts) and the concomitant change in frequency of potentially severe, sudden impacts on man and biosphere (hazards). While this second type of consequence is in itself also a gradual process of changing frequency distributions, the social impacts of these peak events tend to be different. Time to ponder responses is to a much lesser extent available and the nature of the threats often constrains the feedom of choice severely. Some societies may be more successful in preparing their responses to peak events than others, each individual event may well initiate a train of consequences that significantly alters the history of the affected society. The human activities that contribute to climate change are unevenly distributed. Some are related to the distribution of specific land cover types (e.g. diminution of tropical forest), others are related to patterns of development (e.g. the distribution of industry). The consequences of climate change are also unevenly distributed. Some areas may be affected by e.g. rising sea level, desertification or a more frequent occurrence of hurricanes, others may not. The impact of climate change may in some places be benign, e.g. in arctic areas (Canada, Siberia), or perhaps where the number of weather extremities subsides. In addition to a general change that can be negatively assessed, there are winners and losers as a result of global climate change (Glantz 1995). Because the causes as well as the consequences of global climate change are unevenly distributed, the chances are that human activities in some region may cause climate induced primary impacts in completely different regions of the world. The time lags between causes and impacts make the connections even more hazardous. The gradual change of global meteorological conditions (the first type of consequences) poses regionally diverse problems (and elsewhere provides opportunities) for the conditions of human life generally and for production in particular. The availability of fresh water and the capacity of vegetation growth are perhaps most immediately affected. Fresh water is essential for human survival directly and indirectly on account of its indispensability for productive processes. For the time being shortages can not easily be compensated by transport at a massive scale from elsewhere, although some efforts in that direction are now underway. The compensation question is important because it affects the nature of the relation between local deterioration of the environment and human existence conditions. Agricultural production is the economic sector most sensitive to these gradual changes. Food production is dependent on some quantities of water, particularly in combination with other physical attributes that produce the evaporation conditions and the chemical and physical qualities of the soil. All these features can be affected by climate change. Food shortages can be compensated by transport over large distances for considerable periods of time. In case the concrete, physical base of existence disappears through climate change induced processes like sea level rise, the question of compensation from elsewhere of course becomes irrelevant. Where world climate change leads to changes in the frequency and severity of extreme weather conditions (consequence type two), the human impacts are of a different nature. While the change of frequency is in itself a gradual process, events like floods, hurricanes and peak droughts are unexpected and catastrophic. They pose immediate challenges to ways of life, even survival, and also to the regulating mechanisms of the social order. Crops may be destroyed in one stroke and so are possibly productive assets of all sorts, housing and even the land on which people live. With the fear and panic that may strike the populations that suffer these hazards, the social order is shaken and authorities are under stress. They may give up, continue their routines while these are no longer apt, or may rise to the occasion. Consequences may be accidental deaths, famines, large numbers of environmentally induced refugees or all of these. The dynamics induced at the outset produce immediate further changes. In sum, although climate change is a gradual process, it is useful to make a distinction between the gradual incremental consequences of this change and the changes in the pattern of extremities that are the concomitants of this process. Both dimensions of climate change result in different social impacts. To elucidate the relations between global climate change and security, it is useful to subdivide the world in production sites and territory-based political actors, the states. The fate of the populations that each one of them encompasses is dependent on either. The fate of production sites and states is obviously intertwined. Environmental degradation as a result of global change has the most immediate consequences for production sites. It disturbs the way of life of those populations that are dependent upon them and consequently affects their security to the extent that this is directly based on welfare level. States are deeply affected by changes in the conditions of production on their own territory and elsewhere. Despite trends undermining their predominant position, states remain at present the most important regulators of social orders. States may deem their position jeopardized by the impacts of environmental change on the productive apparatus relevant to their interests and consequently feel victim of environmental insecurity. They may also get involved in violent conflict through the disequilibrating impacts of environmental degradation. In that sense their security and that of those who are living in the social orders they are supposed to regulate, also get diminished.

1.4 Conclusion

We have distinguished two ways in which global climate change may affect social life. By incremental change in the long run, conditions of social life may alter through environmental degradation (and in some cases by upgrading). By an increasing frequency of extreme weather conditions, a lot of extra material damage and human misery may result, plus more breakdowns of social orders that may invoke further suffering (a decrease of such extremities obviously results in less catastrophes). These two aspects of global climate change have to be linked to our earlier distinctions with respect to the concept of environmental security. This gives rise to the further classification of the results of our overview of the literature in the following four chapters of this study. Both types of global climate change result in economic changes that can be assessed. They may differ as the adaptive mechanisms that are available to deal with the two types differ. These threats (or boosts) to the economies emanating from the environment affecting levels of environmental security of the first type (the threat of environmental damage), are analyzed in chapters 2 and 3. Chapter 2 describes sectoral impacts, chapter 3 concentrates on property, ecosystems and human well-being. The consequences of these two types of - global climate change induced - environmental degradation or upgrading for the probabilities of violent conflict may also vary. The time scale and the spatial scale of the two types of changes are different. Therefore the adaptive capacity of regulatory mechanisms is differently exercised and different actors may be involved. We deal with these aspects of environmental security (environmental change leading to violent conflict) in chapters 4 and 5. Chapter 4 deals with the negotiating arena at the global level. This follows the logic of a global issue that has to be encountered at the global scale. At the same time many impacts of global climate change are regionally specific and raise concerns at lower spatial scales. In chapter 5 we describe the most relevant regional arenas focusing on water and food problems. The final chapter 6 contains our recommendations for further studies in the field of socio-economic impacts of climate change and environmental security based on our findings in chapters 2-5.

2 ECONOMIC CONSEQUENCES: SECTORAL IMPACTS

This chapter provides order of magnitude estimates of impact on the primary sector, namely agriculture (section 2.1), forestry (section 2.2) and fishery (section 2.3) and the impact on five other sectors, energy (section 2.4), water (section 2.5), construction (section 2.6), transport (section 2.7) and tourism and recreation (section 2.8) associated with a doubling of atmospheric CO_2 concentration. Figures are produced for different geopolitical regions as well as the world as a whole. This chapter also concerns the impact of adaptation measures on the damages due to climate change. This leads to a number of knowledge gaps and recommendations for further research.

2.1 Agriculture

The impact of the enhanced greenhouse effect on agriculture is ambiguous, despite the large research efforts in the past decade. All impacts strongly depend on the adaptability of the farmers, and on the reaction of markets and politics (Tol *et al.*, 1995). Together with the costs of sea level rise the effects on agriculture are probably the most studied aspect of the enhanced greenhouse effect. Much of this research concentrates on productivity or output aspects and does not include the impact of changing prices. Price effects are crucial, however, for the economic valuation of agricultural damage (Fankhauser, 1995). Elevated CO_2 may lead to more carbon stored in the vegetation. Through an increased root growth it may lead to an elevated carbon pool in the soil, too. The consequences for the total carbon balance may be considerable. The question remains whether carbon or nitrogen is the controlling factor in this process (Schapendonk *et al.*, 1995). The estimates of the costs to agriculture in Table 2.1 are based on a study by Kane *et al.* (1992) which includes price effects, but neglects managerial responses as well as the effect of CO_2-fertilization. Working with two scenarios, Kane *et al.* analysed the impact of climate change on crop yields, data which are then fed into a 'world food model' to analyse the effects on world agricultural markets. Welfare changes (measured as changes in producer and consumer surplus) can occur in two ways: firstly by a change in a region's agricultural output due to different climate conditions, and secondly by a change in world prices. The welfare effects (as percentage of GDP) for the two scenarios considered in the study are reproduced in Table 2.1. Absolute values for the year 1988 are also shown. They are based on average figures from the two scenarios. The results are

Table 2.1 Costs to Agriculture ($2 \times CO_2$ - 10^9 US \$ 1988)

	Range of welfare change (% GDP[a])	Average welfare change (10^9\$[b])
EU	-0.400.. -0.019	-0.9666
USA	-0.310.. +0.005	-0.7392
Ex-USSR	-0.520.. +C.032	-0.6185
CHINA	-5.480.. +1,280	-0.7812
OECD	-0.316.. -0.018[c]	-2.3130
WORLD	**-0.470.. +0.010**	**-3.9141**

[a] Range from the two scenarios of Kane *et al* (1992).
[b] For ex-USSR the result is based on GNP rather than GDP.
[c] Average over several subregions.

Source: Fankhauser, 1995

significantly negative for all regions, but the discrepancies between the two scenarios are considerable. This is particularly the case for China, where impacts range from a loss of more than 5 per cent to benefits of over 1 per cent of GDP, and to a lesser extent for the former USSR. It should be emphasized, however, that particularly the 'upper bound' case is quite optimistic, compared to e.g. Rosenzweig and Parry (1994). It assumes non-negative yield effects in most regions. The first scenario assumes negative yield effects even for northern regions such as Canada and the former USSR, and is more within the Rosenzweig and Parry range. Rosenzweig and Parry (see Table 2.2) base their results on three of the older equilibrium General Circulation Model (GCM) experiments. Impact on yields for wheat, rice, maize and soybeans is calculated for some sixty sites in 18 countries, for three modes of adaptation, i.e. no adaptation (1), minor shifts (2) and major shifts (3) in behavior. For the rest of the world, yield changes are interpolated in an unreported fashion. Table 2.2 contains the nine world regions Tol (1995) is working with in the Climate Framework for Uncertainty, Negotiation and Distribution called FUND. Based on this, yield changes are then assessed per country, and these are also fed into a 'world food model' called the Basic Linked System, leading to impact on production levels, prices, and the number of people at risk from hunger. The Basic Linked System does not provide feedback to the yield models. In real life, the crop choice depends on market considerations. Change in crop is a powerful form of adaptation, but, as any other form of adaptation, little is known of the driving processes. How fast farmers will adapt,

Table 2.2 Agricultural Yield Changes ($2 \times CO_2$ - % of Gross Agricultural Product)[a,g,h]

model[b] region/scenario[c]	UKMO 1	UKMO 2	UKMO 3	GISS 1	GISS 2	GISS 3	GFDL 1	GFDL 2	GFDL 3	avg. 2+3[d]	avg. 1[e]	diff. avg.[f]
OECD-A	-20.0	-5.0	-5.0	-5.0	+10.0	+10.0	-5.0	+10.0	+10.0	+5.00	-10.0	-15.0
OECD-E	+5.0	+5.0	+5.0	+10.0	+10.0	+10.0	-5.0	-5.0	-5.0	+3.33	+3.33	0.00
OECD-P	+7.5	+7.5	+7.5	+7.5	+7.5	+7.5	+7.5	+7.5	+7.5	+7.50	+7.50	0.00
CEE&SU	-7.5	-7.5	-7.5	+22.5	+22.5	+22.5	+7.5	+7.5	+7.5	+7.50	+7.50	0.00
M-E	-22.5	-22.5	-7.5	-7.5	-7.5	+7.5	-7.5	-7.5	+7.5	-5.00	-12.50	-7.50
L-A	-22.5	-22.5	-8.5	-15.0	-15.0	-1.0	-10.0	-10.0	+4.0	-8.83	-15.83	-7.00
S&SEA	-20.0	-20.0	-10.0	-10.0	-10.0	0.0	-10.0	-10.0	0.0	-8.83	-13.33	-4.50
CPA	-7.5	+7.5	+7.5	+7.5	+22.5	+22.5	+7.5	+22.5	+22.5	+17.5	+2.50	-15.00
AFR	-20.0	-20.0	-20.0	-7.5	-7.5	+7.5	-15.0	-15.0	0.0	-6.67	-14.17	-7.50

a After Rosenzweig *et al.* (1993); cf. also Fischer *et al.* (1993), Rosenzweig and Parry (1994) and Reilly (1994).

b The climate change scenarios used are the equilibrium $2.CO_2$ experiments according to the General Circulation Models of the United Kingdom Meteorological Office (UKMO), the Goddard Institute for Space Studies (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL).

c The scenarios concern no adaptation (1), minor shifts (2) and major shifts (3) in behavior.

d The average of adaptation scenarios 1 and 2 over the three models.

e The average of no adaptation scenario over the three models.

f The difference between the averages described under notes d and e.

g The costs due to a changed climate correspond to the yield losses associated with the average over the three models and the two adaptation strategies. The costs due to a changing climate correspond to the difference between this average and the average over the three model without adaptation.

h The source can be criticised for two reasons: (i) the climate sensitivity of all three models is above the IPCC consensus best guess, and (ii) the carbon fertilisation effect is based on too high assumptions for the atmospheric concentration of carbon dioxide (Cline, personal communication). As the effects of this are unclear to Tol, but of opposite sign, they are supposed to cancel out.

Source: Tol, 1995

and under which circumstances adaptation will be successful is a crucial but largely unknown determinant of the damage costs. Cropping practices including crop rotation, tillage practices and nutrient management are quite effective in combatting or reversing deleterious effects (IPCC, 1996, Chapter 13, pp 1). Scientific studies will tend to overestimate the damage if no adaptation is assumed (see Table 2.3). This bias is sometimes called the 'dumb-farmer scenario' to suggest that it omits a variety of the adaptations that farmers customarily make in response to changing economic and environmental conditions. Omitted variables are the effect of extremes and ranges in climatic variables as well as the effect of changes in irrigation. Another bias arises in the production-function approach, because it fails to allow for economic substitution as conditions change (Mendelsohn *et al.*, 1995). Newer studies increasingly emphasise also other (non-climate change) stress factors, and the need for integrated assessment of

Table 2.3 Economic effects of 3 GCM equilibrium scenarios (10^6 US $ 1989)

Region\GCM[a]	With CO_2 & Adaptation GISS	GFDL	UKMO	With CO_2, No Adaptation GISS	GFDL	UKMO	No CO_2, No Adaptation GISS	GFDl	UKMO
Developing									
<$500/cap.	-210	-2573	-14588	-2070	-5322	-19827	-56692	-66110	-121083
$500-$2000/cap.	-429	-2927	-10669	-1797	-5135	-15010	-26171	-27839	-48095
>$2000/cap	-603	-534	-1021	-818	-878	-328	-6661	-4351	-3870
Eastern Europe	2423	-125	-4875	1885	-2048	-10959	-12494	-28854	-57471
OECD	5822	25	-6470	2674	-3644	-15101	-13453	-21485	-17606
TOTAL	**7003**	**-6135**	**-37623**	**-126**	**-17028**	**-61225**	**-115471**	**-148640**	**-248124**

[a] GISS = Goddard Institute for Space Studies; GFDL = Geophysical Fluid Dynamics Laboratory; UKMO = General Circulation Models of the United Kingdom Meteorological Office

Source: IPCC, 1996, Chapter 13, pp 27

damages. The rate of change may be equally important, as are the speed of adaptation and restoration. Moreover, changes in socio-economic vulnerability are as important as the actual shape of the damage function. In addition to adaptation, vulnerability will change exogenously to climate change (Fankhauser and Tol, 1995). In Rosenzweig and Parry (1994) physical production potential is the driving force for agricultural production. Land use change is excluded from adaptation. Climate change scenarios near the high end of the IPCC range of doubled-CO_2 warming exerted (in most cases) a slight-to-moderate negative effect on simulated world cereal production, even when the beneficial direct effects of CO_2, farm-level adaptations and future technological yield improvements were taken into account. The only scenario that increased global cereal production was one involving major, and possible costly, changes in agricultural systems, for example, installation of irrigation. Climate change was found to increase the disparities in cereal production between developed and developing countries (see Table 2.3). Whereas production in the developed world benefited from climate change, production in developing nations declined. Adaptation at the farm-level did little to reduce the disparities with the developing world suffering the losses. Cereal prices and thus the population at risk from hunger, increased despite adaptation. The number of people at risk of hunger is estimated at 640 million or 6% of the total population in 2060 (compared to 530 million in 1990, 10% of total current population). The largest negative changes in cereal production occur in developing regions, though the extent of decreased production varies greatly by country depending on the projected climate. Price increases resulting from climate-induced decreases in yield are estimated to range between 24-145%. These increaeses in price affect the number of people at risk of hunger. Their estimated number increases 1% for each 2-2.5% increase in prices (depending on climate change scenario). People at risk of hunger increase by 10% to almost 60% in the scenarios tested, resulting in an estimated increase of between 60 million and 350 million people in this condition (above the reference scenario projection of 640 million) by 2060. Even a high level of farm-level adaptation in the agricultural sector did not entirely prevent such negative effects (Rosenzweig and Parry, 1994). Several studies (Nordhaus, 1991; Titus, 1992; Nordhaus, 1994; and Fankhauser, 1995;) have estimated the damage costs of agriculture in the US due to climate change. These scientists have respectively damage costs of 1.0, 1.0 and 0.6 billion dollars. The latest estimates of Tol (Tol, 1996) are 10.6 billion dollars in OECD-A and with the 15.2 billion dollars of Cline (Cline, 1992) this scientist has the highest damage costs for agriculture in OECD-A. Table 2.4 summarises the latest regional impact assessment of Tol (Tol, 1996). For the OECD-E, OECD-P, CEE&fSU and S&SEA there

Table 2.4 Costs to Agriculture ($2\times CO_2$ - 10^9 US \$ 1988)[a]

Regions[b]	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Agriculture	10.6	-6.0	-6.1	-23.2	7.6	13.1	23.9	-3.2	11.4	-1.5	29.7	-24.7	52.9	28.2

[a] The impact of a 2.5°C warming at a pace of 0.04°C, accompanied with a sea level rise of 50 cm, an increase of 25% in hurricane activity, a 10% increase in winter precipitation, and a 6% increase in storm intensity in the extratropics.

[b] 1 = OECD-A; 2 = OECD-E; 3 = OECD-P; 4 = CEE&fSU ; 5 = ME; 6 = LA; 7 = S&SEA; 8 = CPA; 9= AFR; 10 = OECD; 11 = nOECD; 12 = North; 13 = South; 14 = World;

Source: Tol, 1996

are some benefits to gain for agriculture. A recent study by Mendelsohn *et al.* (1995) shows a significantly lower estimated impact of global warming on U.S. agriculture than the traditional production-function approach and, in one case, suggests that, even without CO_2 fertilization, global warming may have economic benefits for agriculture. Some general implications for the US agricultural sector can be drawn. First, because of possible changes in domestic and foreign production under a GFDL (see Table 2.3) climate, the role of the United States in agricultural export markets may change. Second, patterns of agriculture in the United States are likely to shift as a result of changes in regional crop yields and in crop irrigation requirements. Third, concern for future agricultural impacts on important natural resources, especially land and water, seems to be justified (Adams *et al.*, 1990). In the European Union various climate change scenarios appear to yield considerable different changes in yield both for each location and for the EU as a whole (Wolf and Van Diepen, 1994).[1] Some other recent studies from literature are: Bumb (1995), Darwin *et al.* (1995), Oram and Hojjati (1995), Rötter *et al.* (1995), Brinkman and Sombroek (1996), Mendelsohn (1996), Mendelsohn *et al.* (1996), and Reilly (1996).

Important recent developments and research topics

* Development and broad application of integrated agricultural modeling efforts and modeling approaches particularly applicable at the regional scale including increased attention to validation, testing, and comparison of alternative approaches. Climate effects on soils and plant pests, consideration of other environmental change, and adaptation options and economic response should be an integrated part of the models rather than treated on an ad hoc basis or as a separate modeling exercise. Inclusion of these multiple, joint effects may significantly change our 'mean' estimate of impact and more careful attention to scale and validation should help to reduce the range of estimates for specific regions and countries across different methodologies (IPCC, 1996, Chapter 13, pp 2).
* Developing the capability to readily simulate agricultural impacts of transient climate scenarios. Study of the sensitivities of agriculture to climate change and the impacts of $2 \times CO_2$ equilibrium scenarios has not led to the development of methods that can readily be applied to transient climate scenarios. Thus, conclusions regarding specific transient scenarios are largely speculative. In particular, to credibly deal with the cost of adjustment of which there is significant disagreement, the process of

[1]Tol *et al.*, (1995) make the following observation: *In abstracto* the damage costs of climate change are based on limited, parly outdated information, inconsistent combination of models, uncontrolled up- and downscaling, gross inter- and extrapolation, and non-expert interpretation.

socio-economic adjustment must be modeled to treat key dynamic issues such as how the expectations of farmers change, whether they can detect climate change, and how current investments in equipment, education, and training may lead to a system that only slowly adjusts or adjusts only with the high cost and significant discruption. Current approaches are clearly inadequate to deal with transient climate scenarios as they become available (IPCC, 1996, Chapter 13, pp 2).

* Further research on the effects of variability rather than changes in the 'mean' climate, and the implication of changes in variability on crop yields and markets is needed. Extreme events have the most severe effects on crops, livestock, soil processes, and pests. The more serious human consequences of climate change are likely to involve extreme events such as drought, flooding, or storms where agricultural production is severely affected. The state-of-the-art of research in the area has begun addressing these topics and a number of promising approaches have begun to appear in the literature or are expected soon. Most are, as yet, 'demonstration' research projects, choosing limited geographic areas where data are more available and considering convenient examples for climate scenarios. Caution in drawing broader policy implications from such studies is warranted as there is little or no basis to make inferences to broader populations, to other locations, or to specific climate scenarios (IPCC, 1996, Chapter 13, pp 2).

2.2 Forestry

Many of the world's forests are amongst the last ecosystems on Earth that remain relatively undisturbed by human influences. Especially in the tropics, they harbour the majority of the world's biodiversity. As such, they are indispensable, selfmaintaining repositories of genetic resources. Forests are of great socio-economic importance as a source of timber, fibre for pulp for paper making, fuel and for many non-wood forest products. Forests are also of special economic and spiritual importance to many indigenous people. As components of climatic system forests play a major role in the present and projected future global carbon budget. They also influence ground temperatures, evapotranspiration, surface roughness, cloud formation, and precipitation (IPCC, 1996, Chapter 1, pp 2). Roughly one-third of the world's land surface is covered by forests or woodlands (IPCC, 1990). The extent to which this area will be affected by climate change depends on various factors like, for example, the species and age of trees, possibilities for forests to migrate and the quality of forest management. The impact of global warming on wood production is therefore ambiguous. The IPCC (1996) assumes that although net primary productivity may increase, the standing biomass may not increase. Regional impacts will be strongly influenced by the extent to which forest zones can shift northwards. Sedjo and Solomon (1989) used the Holdridge Life Zone classification to estimate that as a consequence of $2\times CO_2$ the world-wide forest area could reduce by about 6 per cent. Temperate and boreal forests would decline more, by about 16 per cent, whereas tropical forest areas would expand by some 9 per cent. These figures form the basis of the estimates in Table 2.5. Adjusted to 2.5^{0}C warming they correspond

Table 2.5 Damage to the forestry sector (100 km^2 and 10^6 US $, 1988)

	Loss in forest area (100 km^2)	Forestry loss (10^6 US $)
EU	52	104
USA	282	564
Ex-USSR	908	363
CHINA	121	24
OECD	901	1,801
WORLD	**1,235**	**2,005**
temperate	2,169	2,284
tropical	-934	-279

Source: Fankhauser, 1995

to changes of -3.5 per cent, -9.6 per cent and 5.2 per cent, respectively. Further underlying assumptions are as follows. Forest and woodland area statistics can be found in FAO (1991). Based on Sedjo and Solomon and World Resources Institute (1992) it was assumed that 40 per cent (42% according to IPCC, 1996, Chapter 13, pp 14) of all forest areas are tropical, and that no tropical forests can be found in the OECD, the ex-USSR, and China. That is, in the five regions EU, US, China, ex-USSR and OECD forest areas uniformly decrease by 9.6 per cent. Studies by Fankhauser, Cline and Titus estimate damage cost on forests in the United States due to climate change on respectively 1.0, 2.9 and 38.0 billion dollars (Tol *et al*, 1995). For the world as a whole the picture is mixed. Forty per cent of all forest areas are growing - those in the tropics - the remaining 60 per cent are decreasing. Internationally, the shift toward tropical, and away from boreal and temporate, forests suggests that most developing countries would experience relatively less forest loss than would the mid- to high-latitude countries (Cline, 1992). Table 2.5 shows the reduction in forest areas implied by these assumptions. More recent estimates can be found in IPCC (1996, Chapter 15, pp 7). The forest area of ecosystems projected by BIOME (IPCC, 1996, Chapter 15, pp 7) for present and for the year at which climate reflects a doubling of greenhouse gases is shown in Table 2.6. Note that estimated present

Table 2.6 Global, tropical, temperate and boreal forested areas in 10^6 km^2 under different future climate scenarios, projected by BIOME 1.0 Model

	Present Area Est.*	Present Area Modeled♦	GFDL Area	GISS Area	OSU Area	UKMO Area	GFDL % diff	GISS % diff	OSU % diff	UKMO % diff
Tropical Forests	17.6	36.8	40.6	42.9	41.3	41.4	11	16	13	13
Temperate Forests	10.4	10.6	15.7	15.7	13.3	16.1	48	49	25	52
Boreal forests	13.7	16.7	8.4	11.5	13.5	9.1	-50	-31	-20	-46
All Global Forests	**41.7**	**64.1**	**64.7**	**70.1**	**68.1**	**66.6**	**1**	**9**	**6**	**4**

* From Dixon *et al.*, 1994

♦ From Solomon *et al.*,1993

Source: IPCC, 1996, Chapter 15, pp 7

forested areas and modeled present forested areas are similar except for a serious discrepancy in the tropics. There, the differences are in both definition and in model capability. The major pattern to emerge from comparison of all four climate scenarios with modeled present area is a moderate increase in area occupied by tropical forests, a strong increase in area occupied by mid-latitude temperate forests, and a similarly severe decline in area occupied by boreal forests. Table 2.7 presents forested areas in tropical, temperate and boreal zones, projected by IMAGE (IPCC, 1996, Chapter 15, pp 7) at 1990, 2000, 2020 and 2050. The areas of tropical, temperate and boreal forests estimated for the present by the two models differ substantially. The differences appear to arise from a much larger agricultural area calculated in IMAGE than in BIOME. BIOME indicates a total global increase in forested area from 1 to 9%, IMAGE calculates a decline of 25%. The value of forests in the US was estimated by Titus (1992) as \$11,000-\$37,000/km^2, based on observed differences in land values before and after logging. This figure is roughly in line with the ratio of income from the forest sector relative to forest area in countries with comparatively small forest areas like Germany or France. It is, however, more than an order of magnitude too large for a country with wide forest areas, such as Canada. A very small number of countries report forestry income in their national

Table 2.7 Tropical, temperate, boreal and total global forested areas in 10^6 km^2 under a single, future climate and land use scenario generated by IPCC and projected by IMAGE 2.0 Model

	Area of Forest				% Difference in Area		
	1990	2000	2020	2050	2000	2020	2050
Tropical Forests	27.6	25.0	21.0	14.4	-9	-24	-48
Temperate Forests	5.4	4.1	4.9	5.3	-24	-9	-2
Boreal Forests	13.8	14.3	15.2	15.3	4	10	11
All Global forests	**46.8**	**43.4**	**41.1**	**35.0**	**-7**	**-12**	**-25**

Source: IPCC, 1996, Chapter 15, pp 7

income statistics. Yet, a very small number of countries do so, anf from there Fankhauser (1995) deduced an average forest value of about $2,000/$km^2$. The value in the middle income countries is assumed to be $400/$km^2$ and in low income countries $200/$km^2$. The resulting forestry loss is also reported in Table 2.5. In the short term, timber supplies from all zones can be readily assured in intensively managed forests. Unfortunately, past intensive management, especially fire suppression and tree selection at species and intra-specific levels, has created forests that may now be more vulnerable to fire, pests and pathogens (Schowalter and Filip, 1993). Other scientists dispute this conclusion. Given the current degree of uncertainty over future climates and the subsequent response of forests ecosystems, adaptation strategies (those enacted to minimize forest damage from changing environment) entail greater degrees of risk than do mitigation measures (those enacted to reduce the rate or magnitude of the environmental changes) (IPCC, 1996, Chapter 15, pp 19). The figures are inexact in several ways. First, they are based on an equilibrium assessment of $2\times CO_2$ damage, i.e. after enough time has passed for forests to migrate or adjust. It has been pointed out by Cline (1992) that the slow adjustment speed of forest systems may cause a temporary decline in forested area over 200-300 years, before a new equilibrium is reached. The estimates would in this respect be too optimistic. On the other hand they neglect the managerial response from the forestry industry, which may help to ease both transitional and equilibrium losses. On a conceptual level it should be noted that the approach used here is only an approximation of the exact welfare changes to producers and consumers. A more accurate analysis would have to be based on a general equilibrium assessment which allows for price changes as well as trade effects. Finally it should be noted that the valuation is restricted to timber benefits, i.e. it neglects non-timber aspects like, for example, the aesthetic or recreational value of forests. To some extent these will be included in the figures on ecosystems loss (Fankhauser, 1995). Some other interesting and recent literature on the forestry sector: Mendelsohn (1996).

Research and monitoring needs

* Long-term monitoring and measurements of site characteristics and climate, biomass total and partitioning, stand characteristics, stem diameters, growth rates, mortality and wood removal;
* The direct effects of elevated ambient CO_2-concentrations and the associated plant responses such as acclimation, water use efficiency, stomatal conductance or density, or the possible effects on fine root production, and on biological nitrogen fixation etc;
* Large scale experiments and studying of landscape processes;
* Global scale monitoring, e.g. by remote sensing techniques;
* Modeling capabilities on the stand level up to that of the globe (IPCC, 1996, Chapter 1, pp 23).

Knowledge gaps

* To assess transient responses we need global, dynamic vegetation models. The currently already available, comprehensive equilibrium models which differentiate sufficient forest classes are at an infant stage and need to be improved. To succeed, these efforts require validation data on a global scale, from ground observations as well as from remote sensing, and to be collected in a way that ensures comparability, accessability of data bases, and on-going sampling on a long-term basis (IPCC, 1996, Chapter 1, pp 23).
* Too little is known about the potential effects of changing temperature and water availability on existing forests and their adaptive capabilities. What are the thresholds that will kill populations? What are the community dynamics when

conditions have become unfavourable for species due to climatic changes? What is the potential for acclimation within established trees or genetic adaptation within species? What are the key factors that determine successful seedling establishment? What are the physiological and ecological processes that affect carbon sequestration into soils and living biomass, including an understanding of the effects of competition between species, host/pest interactions and the factors that control the fluxes in and out of soil organic matter? At what rates will species be able to migrate? Were past migration rates maximal after the end of the last ice age, or could they be faster due to faster anticipated rates of climatic change, or might they be slower due to anthropogenic impediments that have isolated populations (IPCC, 1996, Chapter 1, pp 23)?

2.3 Fishery

As one of a few sectors, the fishing industry will be affected by both the rise in sea level and the changing climate itself. Of the coastal infrastructure threatened by sea level rise a large proportion can be associated to fisheries (Fankhauser, 1995). Climate change impacts are likely to exacerbate existing effects on fish stocks, notably overfishing, diminishing wetlands and nursery areas, pollution and UV-B radiation (IPCC, 1996, Chapter 16, pp 1). Globally, saltwater fisheries production is hypothesized by the IPCC (1996, Chapter 16, pp 2) to be about the same and significantly higher if management deficiencies are corrected. Also, globally, freshwater fisheries and aquaculture at mid to higher latitudes should benefit from climate change. Even without major change in atmospheric and oceanic circulation, local shifts in centers of production and mixes of species in marine and fresh waters are expected as ecosystems displace geographically and change internally. While the biological relationships are not well understood, positive effects should be offset by negative factors such as a changing climate which alters established reproductive patterns, migration routes, and ecosystem relationships. Where ecosystems are changing, economic values can be expected to fall until long-term stability (i.e., at about present amounts of variability) is reached. National fisheries will suffer if institutional mechanisms are not in place which enable fishers to move within and across national boundaries. Subsistence and other small scale fishermen, lacking mobility and alternatives, are often most dependent on specific fisheries and will suffer disproportionately from changes (IPCC, 1996, Chapter 16, pp 2). Of particular importance for the fishing industry could be the loss of coastal wetlands. Wetlands serve as habitat or breeding ground for various species and, through the food chain, changes in this area could easily spread. Bigford (1991) estimates that a 50 per cent reduction in marsh productivity (for whatever reason) would lead to a 15 per cent to 20 per cent loss in estuarine-dependent fish harvests. Given an expected loss of about 33 per cent of all coastal wetlands, a loss of 10 per cent to 13 per cent in estuarine-dependent fish harvests can be expected. Bigford also estimates that about 68 per cent (by weight) of all commercially harvested species in the USA are in some way estuarine dependent. This would then imply a reduction in total catches of 7 per cent to 9 per cent in the USA. Assuming that this average holds world-wide it can be derived to the reductions in annual catches shown in Table 2.8. Remember, however, that the estimates for wetland loss will include the damage to commercial fisheries (Fankhauser, 1995). A tentative impact

Table 2.8 Reduction in fish harvests (1000 tons, 1988)

	Nominal catches (1988, 1000 t)	Reduction (8%, 1000 t)
EU	6,977	558
USA	5,656	452
Ex-USS	10,171	814
CHINA	5,806	464
OECD	31,288	2,503
WORLD	**85,358**	**6,829**

Source: Fankhauser, 1995

ranking can be constructed, with the first item being impacted the most: (a) fresh water fisheries in small rivers and lakes, in regions with larger temperature and precipitation change; (b) fisheries within Exclusive Economic Zones (EEZs) particularly where access regulation mechanisms artificially reduce mobility of fisher groups and fleets and thus their capacity to adjust to fluctuations in stock distribution and abundance; (c) fisheries in large rivers and lakes; (d) fisheries in estuaries, particularly where there are species without migration or spawn dispersal paths, or estuaries impacted by sea level rise or by decreased river flow; and (e) high sea fisheries. Adaptations options providing large benefits irrespective of climate change are: (a) design and implement management institutions which recognize the finite, varying nature of the resources and the different social and economic organization of fisheries, and which promote economically efficient harvesting; (b) support innovation by research on management systems and aquatic ecosystems; (c) expand aquaculture to increase and stabilize seafood supplies, to help stabilize employment, and to carafully augment wild stocks; (d) in coastal areas, integrate the management of fisheries with other uses of coastal zones; and (e) monitor health problems (e.g., red tides, ciguatera, cholera) which could increase under climate change and harm fish stocks and consumers (IPCC, 1996, Chapter 16, pp 2).

Research and monitoring needs

* Useful inferences can be made about global change impacts on fisheries but existing knowledge is insufficient to predict specifically, localize, separate and quantify the various effects. GCMs are inadequate to forecast changes at regional scale and even more so at the smaller scales of the spawning and nursery areas that are critical in the relationships between environment and fish populations. Marine fishery scientists neglected the question of natural stock variability during the expansion of large scale fisheries, so historical statistical series are few and limited in terms of factor and process coverage. Knowledge of the reproductive strategies of many species and links between recruitment and environment is poor, but interest has been growing rapidly (IPCC, 1996, Chapter 16, pp 20).
* Information is most valuable if there are institutions and management mechanisms to use it. Research on improved mechanisms is needed so that fisheries can operate more efficiently with global warming as well as in the naturally varying climate of today. There is relatively little research underway on such mechanisms, although several international, broad-scale research programs are in place, some of which are aimed at providing a scientific basis and linkage to ecosystem sustainability programs (IOC, 1993; Sherman *et al.*, 1992; Wu and Qiu, 1993; Mee, 1992).
* The growing partnership among funding agencies, marine ecologists and socio-economic interests marks an important step toward realization of the UNCED declaration aimed at reversing the declining condition of coastal ecosystems, and enhancing the long-term sustainability of marine resources (IPCC, 1996, Chapter 16, pp 20).

2.4 Energy

The two uses of energy which are most sensitive to climate change are: a) space heating and air conditioning in residential and commercial buildings; and b) agricultural applications such as irrigation pumping and crop drying. Changes in energy demand attributable to climate change will affect the quantity of energy which must be supplied to meet demand for energy services. Supply companies will adapt by changing: a) the amount of new investment required to meet peak demand on electricity and gas networks; and b) the composition of investment which would most cost-effectively meet changed temporal patterns of demand (IPCC, 1996, Chapter 11, pp 10). Although the results of the various studies are very location-dependent, a number of rubust themes emerge. All the relevant studies conclude that the use of fossil fuels, which are used as space heating fuels, will decline. Whether electricity demand is likely to rise or fall as a result of climate change depends on the relative importance of space heating or air conditioning (Linder *et al.*, 1989). In areas where there is high summer load associated with cooling, climate change will result in increased electricity demand (IPCC, 1996). Adjusted to the assumption of 2.5^{0}C warming, the EPA estimates imply an average increase in US electricity demand of about 3.2 per cent for $2\times CO_2$. The regional differences are, however, considerable. Nevertheless, on a rough and ready basis, it can be argued that the US climate mix may be roughly representative for at least the OECD, the EU and to a lesser extent also for Chine and the world as a whole. For the ex-USSR a value of -1 per cent is assumed. The approximate increase in energy costs derived from this method is shown in Table 2.9. The approach simplifies in at least two ways. First, the EPA study is

Table 2.9 Costs of increased electricity demand (10^6 US \$, 1988)

	Electricity demand (1988, TWh)	Electricity price (1988, 10^6\$/TWh)	Increased energy costs (10^6 \$)
EU	1,693.7	129	6,992
USA	2,874.8	75	6,900
Ex-USSR	1,705.0	40	-682
CHINA	545.2	40	698
OECD	6,601.1	97	20,490
WORLD	**11,061.4**	**n.a.**	**23,065**

Source: Fankhauser, 1995

restricted to electricity demand and neglects other forms of energy such as fossil fuels. For the US it is assumed that the demand for non-electricity energy could fall, since a large share of fossil fuels is typically used for space heating (Nordhaus, 1991a, b; Cline, 1992). The limitation to electricity may thus lead to an overestimation of the total expenditures increase. Second, constant price are assumed (Fankhauser, 1995). Estimates of damages to the US energy sector by Cline (1992) and Titus (1992) are respectively 9.0 and 7.1 billion US dollars. According to a study referring to representative residential buildings conducted by the Japan Architecture Society (1992), temperature rise will lead to a reduction in energy consumption in Sapporo (43^0N) whereas in Tokyo (36^0N) the reduction of energy for heating in winter is balanced by an increase due to cooling in summer. At Naha (26^0N), the overall energy load will be increased. It has been concluded that, in the UK, peak demand for heating fuels will decline less than total annual demand leading to a reduced demand load factor. This would be due partly to a shorter heating season. The seasonal occurence of the peak demand for electricity is an important factor. If peak demand occurs in winter, maximum demand is likely to fall whereas, if there is a summer peak, maximum demand will rise. The precise effects are highly dependent on the climate zone (Linder and Inglis, 1989). Climate change may cause some areas to switch from a winter peaking to a summer peaking regime (IPCC, 1996, Chapter 11, pp 12). It is important to note the strong connection of the costs of increased energy demand with the amenity value of climate. Heating or cooling expenditures are adaptation or defence measures, similar in character to sea level rise protection activities. They are made in order to avoid climate disamenities, by adjusting the (inside) temperature to a more favourable level. Much as in the case of sea level rise, the total amenity costs then consist of two aspects: the costs of defence plus the costs of the remaining temperature disamenity (Fankhauser, 1995). Some other interesting and recent literature on the energy sector: Mendelsohn, R. (1996).

Need for future assessments

The sensitivety of the energy sector to climate change has received less research attention than has the potential impact on natural ecosystems or agriculture. The coverage of work which has been carried out is strongly biased towards specific world regions and branches. The degree of methodological uniformity used in existing studies of climate impacts in the energy system has been limited. Attention to guidelines on assessment approaches (Carter et al., 1992) and the adoption of more coherent approaches to scenario assumptions would increase the value of the studies. This is particularly important in the context of more integrated assessments which consider sectoral interdependencies and the indirect economic impacts of climate change. The impacts literature referring to energy focuses largely on sensitivities and impacts while remaining weak on questions of adaptation. Adaptation may well occur autonomously in many sectors because life cycles of planning and investment are shorter than those associated with climate change in most analyses. However, rapid climate change, which appears to have occured in the past (Schneider, 1992; Horgan, 1993), would significantly increase the problems associated with adaptation. Although there have been many studies of the impact of climate on energy demand, there is still considerable uncertainty about the possible links between the adoption of new air-conditioning systems and climate change, particurlarly in temperate climates where the use of air conditioning is currently marginal. All forms of renewable energy are sensitive to a greater or a lesser degree to climate variables. The most important impact of climate change would be on the size of the resource available. Possible impacts on wind energy and, even more importantly, hydro-electric power could be of the greatest significance. As in other areas, there is a need for authoritative guidance for those developing renewable energy projects which must reflect knowledge about possible climate change at the regional level (IPCC, 1996, Chapter 11, pp 30).

2.5 Water

Water availability is an essential component of national welfare and productivity. Much of the World's agriculture, hydroelectric power production, municipal and industrial water needs, water pollution control and inland navigation is dependent on the natural endowment of surface and groundwater resources (IPCC, 1996, Chapter 14, pp 1). Hydrological impacts are one of the most important and basic aspects of the coming climate change. Changes in the magnitude, frequency and duration of hydrological factors influence the availability of water resources (Matsuoka *et al.*, 1995). The supply of water will be affected, mainly through the change in precipitation patterns and, in coastal areas, through the intrusion of saline water into freshwater reservoirs. Climate change will also affect the demand for fresh water. Higher temperatures are likely to cause an increase in water demand. A Dutch study quoted by Rijsberman (1991) estimates salinity damage for Holland at $6 million a year, but wider studies are not available (Fankhauser, 1995). The purpose of water resources management is to ameliorate the effects of extremes in climate variability and to provide a reliable source of water for multiple societal purposes (IPCC, 1996, Chapter 14, pp 1). Abstracting from groundwater and other reservoirs, the amount of water available in a certain period of time is roughly, the difference between precipitation and evapotranspiration in that period. Global estimates predict an increase in precipitation of 7 per cent to 15 per cent and one in evapotranspiration of 5 per cent to 10 per cent (Schneider *et al.*, 1990). The confidence in these estimates is, however, low (Fankhauser, 1995). Further, seasonal and regional differences will be considerable. According to Schneider *et al.* (1990) the American Midwest, mid-Europe, South Canada and probably also parts of Siberia and South China will face a much lesser difference between precipitation and evapotranspiration. Table 2.10 summarizes the combined impact of population growth and climate change on water availability in selected countries, based the IPCC 1992 socio-economic scenarios, and on the results of three transient GCM runs.

Table 2.10 Water availability [m^3/year/cap] in 2050 for three transient climate scenarios

Country	Present Use (1990)	Present Climate (2050)	GFDL-tr (2050)	UKMO-tr (2050)	MPI-tr (2050)
Cyprus	1,280	770	470	180	1,100
El Salvador	3,670	1,570	210	1,710	1,250
Haiti	1,700	650	840	280	820
Japan	4,430	4,260	4,720	4,800	4,480
Kenya	640	170	210	250	210
Madagascar	3,330	710	610	480	730
Mexico	4,270	2,100	1,740	1,980	2,010
Peru	1,860	880	830	690	1,020
Poland	1,470	1,200	1,160	1,150	1,140
Saudi Arabia	310	80	60	30	140
South Africa	1,320	540	500	150	330
Spain	2,850	2,680	970	1,370	1,660
Sri Lanka	2,500	1,520	1,440	1,600	4,900
Togo	3,400	900	880	550	700
United Kingdom	2,090	1,920	1,810	1,510	1,750
Vietnam	5,640	2,630	2,680	2,310	2,760

Source: IPCC, 1996, Chapter 14, pp 8

The results show that in all developing countries with high rate of population growth, future *per capita* water availability will decrease independently of the assumed climate scenario. Large discrepancies may be noted among results obtained for some countries (Cyprus, El Salvador etc.) by means of various atmospheric models (IPCC, 1996, Chapter

14, pp 8). Fankhauser (1995) assumes a 7 per cent reduction in water availability for the United States as a whole, which is a lower value than the 10 per cent used by Cline (1992). Figures on annual water withdrawals can be found in the data tables of the World Resources Institute. They are reproduced in Table 2.11. The different water prices in each

Table 2.11 Damage to the water sector (km^3 and 10^6 US $, 1988)

	Annual water withdrawal (km^3)	Welfare loss in water sector (10^6 $)
EU	218	14,039
USA	467	13,730
Ex-USSR	353	2,965
CHINA	460	1,610
OECD	889	34,849
WORLD	**3,296**	**46,749**

Source: Fankhauser, 1995

region are derived from The Economist (1991). The US average price is 42 cents/m^3. This value is rather high, compared to Cline (1992) and Titus (1992) who use values of 8-20 cents/m^3 for the US. The discrepancy could be due to differences between water prices in urban areas and for agricultural use. The estimates of Fankhauser (1995) are based on the figures from The Economist (1991). In addition he assumes for the former USSR and other middle income countries a price of 12 cents/m^3, and for low income countries like China 5 *cents/m^3.The loss to the water sector under these assumptions is shown in Table* 2.11. It should be emphasized again that these are averages. For areas in which run-off will increase and for those with an abundant supply of water the figures may be too high. For many arid and semi-arid zones, however, a further decrease in the supply of an already scarce commodity could be disastrous. The fact that areas of both types can be found in each of the regions considered gives some credibility to the average values in Table 2.11 (Fankhauser, 1995). Cline (1992) and Titus (1992) estimate the damage costs to the water sector in the United States on respectively 6.1 and 9.9 billion US dollars. Titus (1992) has estimated the costs of increased water pollution. A reduced stream flow would mean pollutants would be carried away more slowly, requiring additional clean-up efforts to maintain standards. For the US, Titus (1992) estimates the damage costs of water pollution to be in order of $28.4 billion for a 4^0C temperature rise. Instream uses, e.g. from recreation or fishery, may also be significant, albeit difficult to assess. To give an impression of the order of magnitude, Hervik *et al.* (1987) estimated the willingness to pay of Norwegian households to prevent rivers from being subject to hydroelectric development as $120-240. The purpose of water resources management is to ameliorate the effects of extremes in climate variability and to provide a reliable source of water for multiple societal purposes. Water management is generally concerned with four issues: (1) new investments for capacity expansion; (2) operation of existing systems for optimal use (instream and offstream); (3) maintenance and rehabilitation of systems; and (4) modifications in processes and demands (e.g. conservation, pricing and institutions). The emphasis of water resources management in the next decades will be in response to increased demands - largely for municipal water supply in rapidly urbanizing areas and agricultural water supply. Water management strategies will focus on demand management, regulatory controls, legal and institutional changes and economic instruments (IPCC, 1996, Chapter 14, pp 2). Some other interesting literature on the water sector is a running project on the impact of climatic change on the River Rhine and the implications for water management in the Netherlands (Kwadijk, J.C.J., 1996).

Conclusions and research needs

The principal conclusions are as follows:

* The current generation of transient GCMs, while much improved, do not offer the requisite degree of watershed-specific information nor of anticipated variability in future climate states;
* Temporal streamflow characteristics appear to be more variable under future climate scenarios, along with amplification of extremes;
* Arid and semi-arid watersheds and rivers basins are inherently more sensitive to decreases in precipitation;
* The vulnerability of water systems decrease as the degree of streamflow regulation and water management increases;
* Freshwater-dependent ecosystems, especially wetlands, are likely to be most vulnerable in unmanaged (natural) watersheds;

* Changes in the mean and variability will require a systematic reexamination of engineering design criteria, operating rules, continency plans and water allocation policies;
* Contemporary water resources management is inherently adaptive in nature, and can be used more effectively in developing nations to deal with both increased demands and climate change;
* Water demand management and institutional adaptation are primary components for increasing the flexibility of water resources systems under increasing uncertainties due to global warming;
* Technological innovations (desalting) and cost-effective technologies have already played a major role in water management-future likely changes can serve to ameliorate many of the adverse consequences of global warming (IPCC, 1996, hapter 14, pp 2).

Studies of the impacts of climate change on the hydrological cycle require climate scenarios with adequate spatial and temporal resolution, only then, it will be possible to formulate realistic hydrologic scenarios at local levels to simulate the hydrology and distribution of the resulting freshwater resources in the various regions of the earth's land surface. The World Climate Research Programme sponsored by the World Meteorological Organisation and the International Council of Scientific Unions launched a Global Energy and Water Cycle Experiment (GEWEX) to assist with this need.

Other *research needs include the following:*

* The influence of climatic scenarios on storage design as predicted by the model substantiates the need for consideration of effects of climate variations on the design and operation of water resource projects;
* The effect of climate change on large international river basins, as a collaborative effort of the riparian countries;
* The effects of climate change on water quality parameters of aquatic systems (IPCC, 1996, Chapter 10, pp 17).

In attempting to quantitatively analyze the direct effects of global warming on water resources demands, we are confronted by an increasing array of uncertainties and analytical difficulties. Those uncertainties require considerable investment in research in order to improve prediction and adaptive responses:

* Uncertainties in the GCMs and lack of regional specificity of where impacts will occur;
* The absence of information on future climate variability - a basic element of water management;
* Transference of precipitation data to runoff and basin water budgets;
* Uncertainties in the future demands by each water sector;
* Uncertainties in the socio-economic and environmental impacts of response measures (IPCC, 1996, Chapter 14, pp 1).

2.6 Construction

The construction industry, which is very weather sensitive, embraces architecture, building and civil engineering. The construction industry carries out work both above and below ground in a wide range of terrains, some sheltered, others very exposed. A variety of special constructions, including port facilities and built interchanges between water-borne and land-borne transportation systems, are needed at the land-sea interface. The construction industry also plays an important role in the development of river and other hydrological works. These include dams, water supply systems and works for safeguarding against risks such as flood and urban drainage failure. Other works are required to secure water quality. The industry is also responsible for the civil engineering component, above and below ground, for land-based transportation systems, such as roads, railways, oil/gas pipelines and electric power lines, as well as interchanges between air-borne and land-borne transportation systems. All of these works are climate sensitive (IPCC, 1996, Chapter 11, pp 13).

The problem of assessing the impacts of likely climate change on construction falls into distinct parts:

* The assessment of the likely impacts of climate change on existing constructions; and
* The assessment of how current design practices might require modification.

It is often assumed that climate change would benefit the construction sector because 'lengthening of the construction season' would be 'likely to increase productivity' (Nordhaus, 1991b). However, the increased incidence of heat waves would seem likely to eliminate some summer construction days. More important, although construction is adversely affected by frost, it is also inhibited by rainfall (Cline, 1992). The key climatic risks in relation to constructions are: high wind; snow load; driven rain; thermal expansion; excessive rates of weathering; thawing of permafrost; and sea-level rise (Table 2.12). In general, risks are created by extremes values and events (e.g., very high winds) rather than average conditions. Therefore, the use of climate models to predict changes in

Table 2.12 Examples of Climate Sensitivities in the Construction Sector

	Temperature (T) Precipitation (P)	Frequency of Extreme Events	Sea-Level Rise
Construction	* building design (T) * changed producyivity of construction activity (snow, rain) (P)	* impacts on construction activity, building design	* markets created by coastal zone manage ment

Source: IPCC, 1996, Chapter 11, pp 8

the magnitude and frequency of extreme events is a prerequisite for assessment work in this area. There are great uncertainties attached to the future frequency of extreme events at the regional level (see also section 3.8). Other risks are associated with the increased vulnerability of timber and timber-derived products to insect and fungus attack, the interaction of short wave radiation with cloudiness and the impact of ambient temperatures on indoor climate (IPCC, 1996, Chapter 11, pp 13). The construction industry will be called on to implement adaptation options associated with sea-level rise. Titus *et al.* (1991) estimate that about 2600 km^2 of low-lying land in the United States may need to be protected from sea-level rise. The cost would be $5-13 billion for a 50 cm rise, approximately the current best estimate for the year 2100, and $11-33 billion for a 100 cm rise. Dikes would not be used on barrier islands because of their narrowness and aesthetic considerations. As a result, 420 km^2 of land on Atlantic Coast islands would need to be gradually raised. The cost of elevating buildings would be $15 billion under the 50 cm sea-level rise scenario and $30 billion under the 100 cm scenario. Gradually elevating roads and other infrastructure may be cheaper than building dikes (IPCC, 1996, Chapter 11, pp 14). Quantitative analyses were performed for three different types of Japanese fishing port assuming sea-level rise scenarios of 65 cm and 110 cm. It would be necessary to increase the height of the design wave and, consequently, the weight of breakwater structures. It has been estimated that protecting Japanese ports, harbours and adjacent coastal areas against sea-level rise cost $92 billion (IPCC, 1996, Chapter 11, pp 14). An even greater amount of construction activity might be required in Africa, where industry tends to be concentrated in capital cities, many of which are seaports (IPCC, 1996, Chapter 11, pp 14). The greatest negative impacts on constructions are likely to arise from the interaction between sea-level rise and inland water hydrology. The impacts will be localised in vulnerable areas. The stability of foundations built on shrinkable soils would be affected by increased winter rainfall combined with drier summer soil conditions. Southeastern England, for example, has many properties at risk. Design codes, currently based on historical climate records, may need to be changed in order to anticipate risks assessed in climate impact studies (IPCC, 1996, Chapter 11, pp 14).

Research needs

No regional or global studies of the interaction between climate and construction activity have been conducted. Regional and meso-scale model assessments of wind, rain, snow, typhoon and other extreme events are necessary in order to assess the impact of climate change on existing and future constructions. The development of climate guidelines is necessary for the construction and location of coastal structures such as seawalls, harbours, piers and causeways which have long useful lives. Such guidelines would also assist with the design of new buildings, particularly in respect of energy use characteristics. Improved monitoring of coastal zones, covering sea level, tidal and wave patterns, weather, marine ecosystems, coral reefs, coastal geomorphology and sedimentology is required (IPCC, 1996, Chapter 11, pp 31).

2.7 Transport

Climate-induced changes in the distribution of population and economic activity and the consequent effects on the performance of transportation infrastructure and infrastructure needs are of great potential importance. Transportations requirements are closely linked to patterns of human settlement (IPCC, 1996, Chapter 11, pp 15). Changes in the nature and location of agricultural production, in the rates of population growth in different regions, in the volumes and types of fossil fuels used and in tourism and recreational travel (see section 2.8) can have profound effects on the performance of existing transportation facilities and on requirements to construct new ones. Although it is widely acknowledged that climate change could produce significant redistributions of population and economic activities, particularly agriculture, detailed geographic predictions of these phenomena are lacking (IPCC, 1996, Chapter 11, pp 15). Existing assesssments of transport impacts have recognised the potential significance of changes in geographical patterns of economic activity on the transportation network. While increasing temperatures may open up regions to increased development in northern climates, sea- level rise may also force massive migrations in settlements on river deltas and other low-lying areas (IPCC, 1996, Chapter 11, pp 15). Climate change will have some direct effects on transportation infrastructure and the operation of transportation systems. These may be divided into three categories: a) the effects of sea-level rise on coastal facilities; b) the effects of climate on infrastructure; and c) the effects of climate on operations. The cost of raising vulnerable streets in Miami was put at $575/m for 410 km of road, or $237 million (IPCC, 1996, Chapter 11, pp 17). Environmental external costs amount to $0.02 to $0.1 per km driven by cars (IPCC, 1996, Chapter 21, pp 28). Assumed damage costs associated with global climate change are shown in Table 2.13. In comparison to other estimates the figures are very high. The

Table 2.13 Damage costs of transport in OECD Countries

Cost Item	Costs as percentage of GDP Quinet (1994) *All Transport*
Total Pollution	**1-10**

Source: IPCC, 1996, Chapter 21, pp 28

transport sector is affected by cold weather, snow and ice, and might thus profit from a warmer climate, particularly through reduced disruptions and lower winter maintenance costs. On the other hand, heatwaves can be similarly disruptive, for example, through heat stress on railway tracks. Probably more importantly, the transport sector is also negatively affected by rainfall, and precipitation is likely to increase under $2\times CO_2$ (Fankhauser, 1995). The effects of different transportation scenarios on energy consumption and quantities of pollutant released to the environment can be easily analysed using a model developed by Barbieri *et al.* (1995). They have developed such a model for Italy (Barbieri *et al.*, 1995). A comparative analysis of options for sustainable transport and traffic systems in the 21st century has been done by Nijkamp *et al.* (1995).

Research needs

* More assessment of climate change impacts on transportation infrastructure and operations are needed. It is especially important to extend the studies to developing countries and countries with economies in transition. Issues other than submergence as a result of sea-level rise should be considered. Temperature, precipitation, and catastrophic weather, and their impacts on both infrastructure and operations should also be included. Where sea-level rise indicates a major relocation of population, social, and economic functions, an assessment should be made of the additional costs for new infrastucture (IPCC, 1996, Chapter 11, pp 31).
* In the virtually neglected area of climate change impacts on regional transportation systems via the redistribution of population and economic activities, there is a need to develop and refine an assessment methodology by adapting existing transportation models to the task. A key aspect of the methodology must be the ability to evaluate the time stream of investments required so that climate change scenarios can be compared to the base case of construction, rehabilitation, and maintenance. Eventually, such models would be employed to evaluate scenarios of regional growth derived from climate change impact studies of migration, agriculture, industry, and other sectors to determine changes in transportation demand and impact on transportation networks (IPCC, 1996, Chapter 11, pp 31).

2.8 Tourism and recreation

Tourism and outdoor recreation is one of the most important and rapidly growing service industries throughout the world (IPCC, 1996, Chapter 11, pp 20). There is both a market and non-market component to outdoor recreation. The market component is concerned with expenditures for equipment and services with outdoor recreation. Climate, to the extent that it encourages or discourages outdoor recreation, affects both elements of tourism. Given that Americans spend approximately $240 per capita annually on wildlife related recreation or a total of $54.4 billion, the market component of tourism is not trivial (Mendelsohn, 1996). Summer tourism would generally benefit from a longer season (Fankhauser, 1995). Although only to the extent that activities are not hindered by excessive heat or increased rainfall. A monetary estimate for the United States has been predicted as a loss from leisure activities in the order of $1.7 billion per year (Cline, 1992). The overall effect for a country as large as the United States would probably be negligible, though specific regions could experience adverse or favourable effects (IPCC, 1996, Chapter 11, pp 20). Two of the most obvious tourism and recreation facilities exhibiting climate sensitivity are skiing and beach resorts. In general, global warming might be expected to reduce the length of the skiing season in many areas and to affect the viability of some ski facilities. On the other hand, the summer recreation season in many areas may be extended. However, in some coastal areas the benefits resulting from a longer season may be offset by the loss of economically important beaches and coastal recreational resources, particularly on low-lying and vulnerable tropical islands (IPCC, 1996, Chapter 11, pp 20). Tourism could also be affected in areas where coral reefs are attractions (Cline, 1992). In a study of the implications of an effective CO_2 doubling on tourism and recreation projected that the downhill ski season in the South georgian Bay Region could be eliminated with an annual revenue loss of $36.55 (Canadian dollars). This outcome reflected an assumed temperature rise of 3.5-5.7°C and a 9% increase in annual precipitation levels. A 50-70% decrease is projected in the number of skiable days in Southern Quebec (IPCC, 1996, Chapter 11, pp 20). As many recreational activities and related facilities are associated with coasts and beaches, sea level rise may be of special concern to the recreation and tourist industries. The cost of sand required to protect major US recreational beaches from a 50 cm sea-level rise would be $14-21 billion. In addition, elevating infrastructure would cost another $15 billion on the Atlantic coast alone (IPCC, 1996, Chapter 11, pp 20). In the UK, higher temperatures are likely to stimulate an overall increase in tourism, with the greatest being on holiday activity and some forms of outdoor recreation. An increase in sea temperature would increase the pressures of tourism on UK beaches, while coastal erosion may reduce beach area. Warm springs, falls and winters, the absence of a rainy season and very hot dry summers were found to have a favourable impact on tourism in Japan. On the other hand, typhoons, cool and rainy summers, extended periods of rain in the early summer, heavy snow and cool springs were found to create unfavourable conditions (IPCC, 1996, Chapter 11, pp 21).

3. IMPACTS ON PROPERTY, ECOSYSTEMS AND HUMAN WELL-BEING

This chapter provides order of magnitude estimates of impact on property, namely sea level rise capital losses and protection costs (section 3.1) and dryland and wetland losses (section 3.2) associated with a doubling of atmospheric CO_2 concentration. This chapter also provides order of magnitude estimates of impact on species and ecosystems losses (section 3.3), human amenity (section 3.4), health and mortality (section 3.5), air pollution (section 3.6) and migration (section 3.7). Risks of disasters, like storms, floods, droughts and hurricanes is also a category (section 3.8). Figures are produced for different geopolitical regions as well as the world as a whole. The chapter also concerns the impact of adaptation measures on the damages due to climate change. Six types of the rich dynamic nature of the climate change damage costs are distinguished (section 3.9): valuation of damage over time, socio-economic vulnerability, higher order impacts, knowledge and uncertainty, non-equilibrium climate change, irreversibility and other accumulation. This leads to a number of knowledge gaps and recommendations for further research.

3.1 Sea level rise capital losses and protection costs

The costs of sea level rise divide into three types: Capital costs of protective constructions, and the costs of foregone land services, conveniently split into dryland and wetland loss (section 3.2). The three damage categories strongly interact with one another. The total impact of sea level rise, and its distribution over its categories, strongly depends on the adaptive policy chosen. Consequently, the estimated damage depends strongly on the projected policy (Tol *et al.*, 1995). National vulnerability profiles have been developed for a 1 metre rise in sea level using the vulnerability classification of five impact categories. Some results are summarized in Table 3.1. Small islands, deltaic settings and coastal ecosystems appear particularly vulnerable. Several caveats are in order so that the following impact estimates can be put into a proper perspective. First of all, the impacts have been assessed assuming a 1 metre rise in sea level by 2100, which is the high estimate of the IPCC'90 Business-as-Usual sea-level rise scenario. Furthermore, the baseline scenarios on which all the studies depend assume that existing settlement and related economic assets patterns and development trends continue largely unchanged into the future. Finally, besides the scientific uncertainties surrounding sea-level rise, the

Table 3.1 Synthesized results of case studies. Results are for existing development and a one metre rise in sea level. People affected, capital value at loss, land at loss and wetland at loss assumes no measures (10^6 US $)

Country	People Affected		Capital Value at Loss		Land at Loss		Wetland at Loss	Adaptation/ Protection Costs	
	# people (1000s)	% Total	10^6 US$	% GNP	km^2	% Total	km^2	10^6 US$	% GNP
Antigua	38	50	-	-	5	1.0	3	76	0.32
Argentina	-	-	5600[c]	6	3400	0.1	1100	>1800	>0.02
Bangladesh	71000	60	-	-	25000	17.5	5800	>1000[e]	>0.06
Belize	70	35	-	-	1900	8.4	-	-	-
Benin	1350	25	126	12	230	0.2	85	>430	>0.41
China	72000	7	-	-	35000	-	-	-	-
Egypt	4700	9	59272	204	5800	1.0	-	13133[f]	0.45
Guyana	600	80	4000	1115	2400	1.1	500	200	0.26
India	7100[b]	1	-	-	5800	0.4	-	-	-
Japn	15400	15	807000	72	2300	0.6	-	>159,000	>0.12
Kiribati[a]	9	100	2	8	4	12.5	-	3	0.10
Malaysia	-	-	-	-	7000	2.1	6000	-	-
Marshall Islands[a]	20	100	175	324	9	80.0	-	>380	>7.04
Mauritius	6	1	-	-	10	0.5	-	-	-
The Netherlands	10000	67	186000	69	2165	5.9	642	12286	0.05
Nigeria	3200[b]	4	18000[c]	52	18600	2.0	16000	>1400	>0.04
Poland	235	1	24000	24	1700	0.5	36	1500	0.02
Senegal	110[b]	>1	700	14	6100	3.1	6000	>1000	>0.21
St. Kitts-Nevis[a]	-	-	-	-	1	1.4	1	53	2.65
Tonga[a]	30	47	-	-	7	2.9	-	-	-
Uruguay	13[b]	<1	1800[c]	26	96	0.1	23	>1000	>0.12
United States	-	-	-	-	31600[d]	0.3	17000	>143000	>0.03
Venezuela	56[b]	<1	350[c]	1	5700	0.6	5600	>1700	>0.03

a Minimum estimates - incomplete nattional coverage.
b Minimum estimates - number reflects estimated people displaced.
c Minimum estimates - capital value at loss does not include ports.
d Best estimate is that 20,000 km^2 of dry land is lost, but about 5,400 km^2 are converted to coastal wetlands.
e Adaptation for Bangladesh only provides protection against a 1 in 20 year event.
f Adaptation costs for Egypt include development scenarios.

Source: IPCC, 1996, Chapter 9, pp 20

impact studies do not adequately capture the risks posed by combined sea-level rise and possible changing frequencies, intensities and distributions of extreme weather events. It is also assumed that the rise in sea level will be a slow gradual process, which may not be the case for all regions. Scientific uncertainties are compounded by the socio-economic adaptation uncertainties and by the fact that the economic cost estimate results are very sensitive if discount rates are applied (IPCC, 1996, Chapter 9, pp 19). Some other interesting studies about the costs of sea level rise are IPCC (1994) and Turner *et al.* (1996).

Research and monitoring needs

- * greater data accessability and compatibility, both among different scientific disciplines and among the relevant agencies charged with data collection and interpretation;
- * *improved data acquisition and analysis and its application to optimize decisions in* response to climatic change and resolution of coastal resource use conflicts;
- * improved application of tools and techniques, including remote sensing, geographic information systems and global positioning systems, to develop, efficiently manage, and analyze large and consistent coastal datasets (IPCC, 1996, Chapter 9, pp 30).
- * continued investigations of geomorphological responses of coastal types and critical ecosystems to climate change and sea-level rise, including improved methodologies *for incorporating existing, high quality historical and geological data into models;*
- * improved coastal processes data (especially in developing countries), based on instrumentation (e.g., tide gauges, current meters, wave recorders etc.);
- * improved data bases on coastal socio-economic trends such as population changes and resource utilization, taking into consideration differences in socio-cultural characteristics of countries and ethnic groups;
- * continued education and training relevant to vulnerability assessment and integrated coastal zone management (ICZM), employing, as far as practicable, standardized methodologies and framework (IPCC, 1996, Chapter 9, pp 31).
- * integrated coastal-response models, which seek to combine the interactions of biogeophysical, socio-economic and other factors, incorporating the knowledge and technologies of traditional societies and local peoples;
- * a framework for the analysis, planning and management of coastal zones, as was recognized by the participants of the World Coast Conference 1993 (WCC'93, 1994) (IPCC, 1996, Chapter 9, pp 31).

3.2 Dryland and wetland

The estimated damage on dryland loss depends strongly on the projected policy. For instance, IPCC uses the *ad hoc* rule that all dryland with a population density above 10 people per square meter will be protected while Fankhauser (1995) and also Yohe *et al.* (1996) employs a model which choose the economically optimal value of protection. The difference can be rather drastic. The loss of dryland due to climate change will be restricted to undeveloped and sparsely populated areas in the studie of Fankhauser (1995). The values are partly based on Rijsberman (1991) and partly on Fankhauser's (1995) own calculations. In both cases the estimation method used is that of Delft Hydraulics (IPCC, 1990b). The high figure for the former USSR reflects its vast undeveloped coastal areas along the north coast of Siberia, while, at the other extreme, the figure for China is zero because its coastline is either densely populated (and then the assumption is made that these areas will be protected against the rising sea) or not "low-lying" in the sense of the Delft Hydraulics definition. The dryland loss prediction of Titus *et al.* (1991) under the "partial protection" scenario implies a loss of about 0.46 km^2 per kilometre of undeveloped coastline. Valuing coastal lands is rather difficult and figures differ by several orders of magnitude, depending on the use and location of the piece of land in question. Rijsberman (1991) reports values ranging from 1$ to 200$ m/km^2. Bearing in mind that the land under threat is only sparsely populated and in general undeveloped, a rather low value seems apprpriate and Fankhauser (1995) therefore adopts, at least for OECD countries, the average value of $2 m/$km^2$ used in Titus *et al.* (1991), a value which has also been advocated by Rijsberman (1991). Such a value would, however, be too high in the case of the former USSR, where the main area under threat is the almost uninhabited north coast. For the former USSR Fankhauser (1995) therefore assumes an arbitrarily chosen price of $0.5 m/$km^2$. For the world as a whole Fankhauser uses $1 m/$km^2$, assuming that this is an acceptable average between the high price in the industrialized world and the lower prices in less developed countries. Some research and monitoring needs are summarized in section 3.1. Along with dryland and urban structures the predicted rise in sea levels will also threaten coastal wetlands, important ecosystems which are already heavily endangered by current coastal development and water drainage schemes. The possible amount of wetlands loss depends mainly on the possibility of the systems to migrate inland, and therefore on the amount of coastal protection measures taken. The more comprehensive the defence measures, the more difficult backward migration becomes and the more coastal wetlands will be lost. Titus *et al.* (1991) estimate that for the United States a complete protection of all coastal zones would lead to a loss of one-half of all remaining wetlands. The number is lowered to one-third with only a partial protection and 30 per cent under a complete retreat scenario (Fankhauser, 1995). It is assumed that this estimate is comparable to world-wide values and that therefore, given the assumption of partial protection, 33 per cent of all coastal wetlands will be lost. An inventory of wetland areas has been provided by the IPCC (1995, Table 3.1 in section 3.1) and in OECD countries by Rijsberman (1991). Fankhauser (1995) derived the figures for the former USSR and China by using the world average of wetland areas per km of low-lying, densely populated coast. Titus *et al.* (1991) estimate the value of coastal wetlands as \$1.5-7.5 m/km^2, including all quantifiable benefits. Rijsberman (1991) quotes a figure of \$3 m-\$13/km^2 and thus works with a median \$8 m/km^2, while Cline (1992) prefers a more cautious \$2.5 m/km^2. As an overall average between these estimates Fankhauser (1995) works with a value of \$5 m/km^2 for the OECD countries. It seems reasonable to assume a different value for non-industrialized nations. In these regions the emphasis will be mainly on the returns from commercial fisheries and to a lesser extent maybe on indirect benefit, while recreational benefits are less important. For the countries of the former USSR Fankhauser (1995) assumes benefits of \$1.25 m/km^2 and for China \$0.5 m/km^2. The figure \$1.25 m/km^2 also seems to be an appropriate average for the world as whole, given that over 85 per cent of all wetlands are in middle or low income countries (Rijsberman, 1991). Assuming a return on land of 10 per cent per year yields the annual costs. The estimates of Fankhauser (1995) also include the damage to coastal fisheries, a category which was listed separately in Table 2.8 in section 2.3. It has to be noted that there are some differences in outcomes between the estimates of the IPCC (see Table 3.1 in section 3.1) and the average damage estimates of wetland losses due to climate change of Tol (1996). Some research and monitoring needs are summarized in 3.1.

3.3 Species, ecosystems and landscapes

Most studies on the impacts of climate change predict an increased loss of species and ecosystems (Fankhauser, 1995). Specially threatened are, according to IPCC (1990), geographically localized and slowly reproducing species as well as poor dispersers and communities 'where climate change adds to existing stress'. The impact of climate change on species and ecosystems has been paid relatively little attention to by economists, primarily so because the physical impact is still to large extent unknown, but also because the value of an ecosystem or a species cannot be easily estimated. Climate economists therefore face a double problem, i.e., how to derive a total value of something which is unknown in quantity and price. Nevertheless, some numbers have been tried, based on scattered *ad hoc* information on ecosystems change, medicinal value of plants, current wildlife protection expenditures, and surveys (Tol, 1996). In measuring the total value of a species or an ecosystem, economists distinguish between use, option and existence value. There are various methods to measure these, but the only method to capture all three aspects is the contingent method (Fankhauser, 1995). Pearce (1993) reports from several studies which yield an average willingness to pay of $9-$13 (1990) per person and year for the preservation of animals ranging from the emerald shiner to the grizzly bear. The perhaps more relevant figure for the preservation of entire habitats is somewhat higher, ($9-$107 per person, or some $50 on average. A willingness to pay estimate of about $30 (1988) per person and year in high income countries does not seem unreasonable, therefore, bearing in mind the wider, although as yet unspecified, threats from climate change. For the middle income countries (e.g., those of the former Soviet Union), where hardly any valuation studies are available, Fankhauser (1995) assumes an arbitrary value of $8 per person and year, and for low income countries like China $2/person and year. The total cost of ecosystems loss was achieved by simply multiplying the above per capita values by the number of people living in each region. The results are shown in Table 3.2. The figures in Table 3.2 consist of option and use as well as

Table 3.2 Value of lost ecosystems (10^6 US $, 1988)

	Total economic value (10^6 US $)
EU	9,750
USA	7,380
Ex-USSR	2,288
CHINA	2,176
OECD	25,470
WORLD	**40,530**

Source: Fankhauser, 1995

existence values. Note that Fankhauser's (1995) method then implies that people have use and existence values for the same number of sights. Evidently, this need not be the case. Existence values, on the one hand, are more or less independent of geographical locations, and people may value a variety of sites scattered around the globe. People all over the world are, for example, willing to pay for the preservation of the blue whale. Use and option values on the hand are geographically limited, and only occur to the subset of people who actually use or profit from a certain habitat. By threating the three value categories equally, Fankhauser (1995) thus introduces a bias, the size of which is however unknown. Tol (1996) estimates and values species and ecosystems loss as follows. The Fankhauser (1995) assumption of one loss per year is borrowed. The value of that is set an average of $60 per person and year in the OECD. The other regions have relative values (i.e., in percentage of GDP) proportional to ((GDP/Capita)/20,000) / (1 + ((GDP/Capita)/20,000)) which is scaled to unity for the OECD. Table 3.3 displays the resulting figures. The loss for OECD-America (20,810 million US dollars) is considerably

Table 3.3 Species and ecosystems loss (10^6 US $)

region	value (% GDP)	weight	value ($/cap)	population (10^6)	loss (10^6 US $)
OECD-A	0.41	1.08	75.22	280	20,810
OECD-E	0.33	0.66	40.42	440	17,710
OECD-P	0.44	1.18	96.38	140	13,880
CEE&fSU	0.22	0.59	15.59	400	6,310
ME	0.10	0.26	2.57	140	370
LA	0.07	0.19	1.30	440	570
S&SEA	0.02	0.06	0.12	1,540	180
CPA	0.01	0.04	0.05	1,260	60
AFR	0.03	0.07	0.18	620	110
OECD	0.38	1.00	60.00	860	51,530
non-OECD	0.05	0.14	0.67	4,390	2,940
World	**0.13**	**0.35**	**4.88**	**5,250**	**25,620**

Source: Tol, 1996

higher than Fankhauser's (1995) $7,380 million US dollars and Cline's (1992) $4,000 million US dollars, which they themselves consider rather conservative. The global value ($25,620 million US dollars) is considerably lower than Fankhauser's (1995) ($40,530 million), which is explained by the difference in valuation assumptions for poorer regions. Damage estimates for the aggrgate regions follows from the average value in that region (Tol, 1996). A missing point in the discussion is landscape change, and animal and plant life loss. Humans attach value to lanscape, and climate change will undoubtly change landscapes. The implied change in landscape value has not been assessed, with a main reason that these value changes are local and hence cannot be predicted. People also attach a value to an animal or plant life, and in some groups and cultures this value can be as high as the value of a human life. This has not been taken into account yet, again because of lack of physical impact estimates (Tol, 1996). Estimating non-market ecological impacts is one of the most challenging aspects of climate change assessment. The challenge goes beyond the issue of estimating values not obserbed in the market. The dynamic evolution of these values through time is also in question. Morgan and Dowlatabadi (1994) have proposed that when the individual is not a sophisticated observer of the environment (i.e., the majority of the public) healthy stands of trees will be indistinguishable (Dowlatabadi *et al.*, 1994). Thus, succession is a healing process and loss of species may not be experienced, or if experienced will be 'forgotten' through time. Morgan and Dowlatabadi (1994) have coined the term 'value erosion' to describe this process. Value erosion is subject to manipulation. Nature programs on television, environmental activists at the door, all serve to heighten awareness about the environment. These can lead to value amplification and further complicate the question of how values may change through time (Morgan and Dowlatabadi, 1994). With respect to non-market damages, the adjustment takes place within the human cognitive system. Both memory effects and cohort effects lead to successive generations rarely valuing losses cumulatively and in perpetuity. This adjustment process can make the actual losses much smaller than hitherto estimated (Dowlatabadi *et al.*, 1994). Some running projects are: 'Assessment of long-term effects of climate change on biodiversity and vulnerability of terrestrial ecosystems' of F. Berendse (1996), 'Climate change and the vulnerability of small natural riverine ecosystems' of P.E.V. van Walsum (1996) and 'Modelling the impact of climate change on the Wadden Sea ecosystem' of W.J. Wolff (1996).

3.4 Human amenity

It is hardly disputed that climate is an important factor of the quality of life. Global warming will therefore also affect human amenity. It has been claimed that this effect could be beneficial, given that warmer weather is in general preferred to cooler (Fankhauser, 1995). However, warmer weather is not better throughout. There seems to be an optimal temperature level, beyond which further increases are detrimental. The overall effect of global warming on human amenity is ambiguous, the impact being positive in colder and negative in warmer regions. Mearns *et al.* (1984) use statistical distributions of current temperatures to explore the impact of global warming on extreme temperature events for the United States. There is a reason to believe that people would be willing to pay something to avoid a threefold increase in heat waves (Cline, 1992). One way to approach estimation would be the survey technique (contingent evaluation), with questions formulated to elicit a meaningful evaluation of what the respondent would be prepared to pay to avoid the change. It is possible to split the willingness to accept the welfare loss into two parts (Fankhauser, 1995). First people need to be compensated for the additional cooling expenditures they undertake in order to mitigate the most adverse effects. Second, they need to be compensated for the remaining, unmitigated temperature. Unfortunately, estimating this second part proved impossible with the currently available information. The monetary value of a benign climate is still largely unknown, although attempts towards a valuation can be found in Hoch and Drake (1974) and Gyourko and Tracy (1991). A careful distinction between winning and losing regions would further require fairly accurate information about regional and seasonal temperature patterns. Estimates of the change in human amenity due to climate change focused on the disamenity caused by the expected increase in frequency and intensity of heat waves (Tol, 1995a). For purposes of establishing an order of magnitude, if people were willing to pay just 0.25 per cent of personal income to avoid the sharp increase in heat waves and other effects of a benchmark $2\times CO_2$ warming in outdoor comfort, the damage of such disamenity would stand at some $10 billion annually for the United States (Cline, 1992). The extra amenity of generally warmer weather has, as yet, not been taken up (Tol, 1995a). Disamenity damages in other countries would depend on location and income level. For high-latitude countries, the effect would probably be favorable (i.e., negative disamenity damage). For mid- and low-latitude countries, disamenity effects might dominate, and almost certainly would do so under very-long-term warming. Valuation would tend to be higher for higher income countries, even relative to GDP, under the assumption that amenity is an income-elastic service (Cline, 1992).

3.5 Health and mortality

Global climate change over the coming decades would have various effects, mostly adverse, upon the health of human populations. The disturbance, by climate change, of physical systems (e.g., weather patterns, sea-level, water supplies) and of ecosystems (e.g., agro-ecosystems, disease-vector habitats) would pose risks to human health (IPCC, 1996, Chapter 18, pp 1). The health effects would be both direct (e.g., deaths from heatwaves and from extreme events such as floods) and indirect (e.g., changes in the range and transmissibility of vector-borne infectious diseases). It was found that both air and water temperature are the most important factors determining mosquito phenology and density (Takken *et al.*, 1994). There is an U-shaped relationship between mortality and outdoor air temperature, the lowest death rates being found at temperature levels of about 16-25^{0}C (Kunst *et al.*, 1993a, b). Some impacts would be deferred in time, occuring on a larger scale than most other environmental health impacts with which we are familiar. If long-term climate change ensues, indirect impacts would probably predominate (IPCC, 1996, Chapter 18, pp 1). Different populations, with varying levels of natural, technical and social resources, would differ in their vulnerability to climate-induced health impacts. Such vulnerability, due to crowding, food insecurity, local environmental degradation, and pertubed ecosystems, already exists in many communities. Hence, for reasons of both the geography of climate change and these variations in population vulnerability, climate change would impinge differently on different populations (IPCC, 1996, Chapter 18, pp 1). An increased frequency or severity of heatwaves would cause a significant increase in (predominantly cardio-pulmonary) mortality and illness, even in populations that acclimatise to higher background temperatures. Studies in large urban populations in North America, North Africa and China indicate that the annual number of heat-related (summer) deaths would increase by a mean of 2-3% in response to the 2050 IPCC climate change scenarios (Table 3.4). For example in very large cities this would represent several thousands extra deaths annually. This heat-related increase in deaths may be partially offset by fewer cold-related deaths, although the balance would vary by location (and would also depend on adaptive responses) (IPCC, 1996, Chapter 18, pp 1). The importance of acclimatisation should be emphasized. Cities that already accustomed to a warmer climate are far less affected by a further warming than cities with a moderate climate. Whether, and if so to what extent and how quickly, a society will acclimatize is, however, a fiercely debated issue. It is mainly for this matter that the climate impacts on mortality remain a controversial question (Fankhauser, 1995). Most economic valuation studies are based upon Kalkstein (1989, 1993) leading to an increased mortality of 27-40 persons per million for the benchmark climate change. This estimate is based on the

Table 3.4 Present-Day and Future Estimates of Total Summer Deaths* in Selected Cities

Location	Present Mortality	GFDL 89 Year 2020 Uacc.	GFDL 89 Year 2020 Acc.	GFDL 89 Year 2050 Uacc.	GFDL 89 Year 2050 Acc.	UKTR Year 2020 Uacc.	UKTR Year 2020 Acc.	UKTR Year 2050 Uacc.	UKTR Year 2050 Acc.
UNITED STATES									
Atlanta	78	191	96	293	147	247	124	436	218
Dallas	19	35	28	782	618	1364	1077	1360	1074
Detroit	118	264	131	419	209	923	460	1099	547
Los Angeles	84	205	102	350	174	571	284	728	363
New York	320	356	190	879	494	1098	683	1754	971
San Francisco	27	49	40	104	85	57	47	76	62
CANADA									
Montreal	69	121	61	245	124	460	233	725	368
Toronto	19	36	0	86	1	289	3	563	7
PEOPLE'S REPUBLIC OF CHINA									
Shanghai	418	1104	N/A	2950	N/A	1308	N/A	1486	N/A
EGYPT									
Cairo	281	476	N/A	830	N/A	839	N/A	1024	N/A

Uacc. = unacclimatised, acc = acclimatised populations

* Numbers represent average summer-season heat-related deaths for each city under each climate change scenario. For example, during a typical summer today, 78 extra deaths occur in Atlanta from heat-related causes and, assuming no acclimisation, this number rises to 191 deaths.

* Numbers assume no change in population's size and age distribution.

Source: IPCC, 1996, Chapter 18, pp 9

impact of heat waves in US cities. The economic studies assume instantaneous acclimatisation. Without acclimatisation, death rates would have been about six times as high (Tol *et al.*, 1995). The increase in mortality for each region is shown in Table 3.5. To arrive at a monetary valuation the number of casualties has to be weighted by the

Table 3.5 Damage from increased mortality (10^6 US $ 1988)

	Increased mortality (deaths)	Loss from increased mortality (10^6 US $)
EU	8,775	13,163
USA	6,642	9,963
Ex-USSR	7,722	2,317
CHINA	29,376	2,938
OECD	22,923	34,385
WORLD	**137,727**	**49,182**

Source: Fankhauser, 1995

value of each life. A first crusial point is that Fankhauser doesn't attempt to measure the value of an (individual) life as such. What is measured is the amount of money needed to compensate people for an additional risk of death, that is the value of safety. Multiplied by the change in the risk of death, this yields a figure which is often called the value of a *statistical* life (Fankhauser, 1995). The willingness to pay in each region to prevent an increase in mortality is given in Table 3.5. Several studies (Cline, 1992 and Titus, 1992) estimate the damage costs from mortality in the US due to climate change somewhat lower. These scientists have respectively damage costs of >5,000 and 8,200 million dollars. The latest estimates of Tol (Tol, 1996) are 8,600 million dollars in OECD-A. Table 3.6 summarises the latest regional impact assessment of Tol (Tol, 1996). Net increases in the geographic distribution (altitude and latitude) of the 'vector' organisms of infectious diseases (e.g., malarial mosquitoes, schistosome-spreading snails), and changes (typically an acceleration) in the life-cycle dynamics of both vector and infectious parasite, would increase the potential for transmission of many vector-borne infectious diseases.

Table 3.6 Mortality from Climate Change ($2\times CO_2$ - 10^9 US \$)

region	heat[a]	cold[b]	malaria	death	value[c]	
		deaths per million		10^3	10^9\$	%GDP
OECD-A	18	-9	0	2.5	8.6	0.17
OECD-E	18	-9	0	3.9	9.5	0.17
OECD-P	19	-9	0	1.4	5.6	0.18
CEE&SU	15	-9	0	2.6	3.8	0.13
M-E	51	0	0	7.4	5.2	1.37
L-A	284	0	80	159.0	90.6	11.37
S&SEA	111	0	80	293.4	101.0	12.23
CPA	105	0	80	223.3	72.0	16.73
AFR	30	0	80	67.7	24.7	6.09

a Assumed heat stress is 24 per million city dwellers in the OECD and Central and Eastern Europe and the former Soviet Union, 93 per million city dwellers in Africa and the Middle East, and 398 per million city dwellers in Latin America and the Asian regions. figures are without acclimatisation; figures with acclimatisation are one-sixth of those presented for the OECD and Central and Eastern Europe and the former Soviet Union, and one- third for the remaining regions. Source: Kalstein (1995).

b Source: Kalkstein (1989); cold stress is -4 per million with acclimatisation.

c The value of a statistical life is set at \$250,000 plus 175 times the per capita income.

Source: Tol, 1996

For example, mathematical models - based on knowledge of the dynamics of malaria transmission, and with their recognised simplifying assumptions - predict an approximately 25% increase in the rate of occurrence of this disease in Indonesia by 2070 (IPCC, 1996, Chapter 18, pp 2). Pim Martens of the National Institute of Public Health and Environmental Protection in Bilthoven, the Netherlands, has deceived a computer model of malaria infections based on an extended range of malaria-carrying mosquitoes. The results indicate that an average global temperature increase of 3 degrees in the next century could increase the range of malaria-carrying mosquitoes and result in 50 million to 80 million new malaria cases per year (Stone, 1995). Any such global increase would primarily affect tropical, subtropical, and some less well protected temperate-zone populations, currently at the margins of endemically infected areas (IPCC, 1996, Chapter 18, pp 2). The estimation of the socio-economic impact of malaria and the expression of this impact in terms of money is highly precarious (Martens *et al.*, 1994). The biological activity and geographic distribution of the malarial parasite and its vector are sensitive to climate influences, especially temperature and precipatation. Assessment of the potential impact of global climate change on malaria risk suggests a widespread increases of risk due to an expansion of areas suitable for malaria transmission. The health impact will be most pronounced in populations living in the less economically-developed temperate areas in which endemicity is low or absent (Martens, 1994). WHO (1990) fears that the so far disease-free highlands of Ethiopia, Indonesia and Kenya may be invaded by vectors (Fankhauser, 1995). Some increases in non-vector-borne infectious diseases, such as cholera, salmonellosis, and other food- and water-related infections could also occur, particularly in tropical and sub-tropical regions, because of climatic impacts on water distribution and temperature, and on micro-organism proliferation (e.g., cholera vibrio-amplifying algae) (IPCC, 1996, Chapter 18, pp 2). Other climate-induced health impacts could include increases in deaths, injuries and psychological disturbances from any increases in extreme weather events (droughts, floods, storms, cyclones, etc.). In response to the 2050 IPCC climate change scenarios, an increase could occur in the frequency and severity of those weather conditions that enhance the formation and persistence of air pollutants in urban environments; increases in allergic disorders and in cardio-respiratory disorders and deaths caused by various air pollutants (e.g., ozone and particulates) could thereby occur. The effects of climate change upon agriculture, animal and fisheries productivity, while still uncertain, could increase the prevalence of malnutrition and hunger and their long-term health impairments, especially in children. This would most probably occur regionally, with some regions likely to experience gains, and others losses, in food production. There could also be many health impacts of the physical, social and demographic disruptions caused by rising sea-levels, and by climate-related shortages in natural resources (especially fresh water) (IPCC, 1996, Chapter 18, pp 2). One potentially important category of indirect public health impact would result from the deterioration in social and economic circumstances which might arise from adverse impacts of climate change on socio-economic infrastructures, and therefore on patterns of employment, wealth distribution, and population mobility and settlement (IPCC, 1996, Chapter 18, pp 2). Adaptive options to minimise health impacts include: improved and extended medical care services; environmental management; disaster preparedness; protective technology (housing, water purification, etc.); public education directed at personal behaviours, and appropriate professional and research training. It will also be important to assess in advance any risks to health from proposed technological adaptations (e.g., chemical and physical exposures that could result from using certain alternative energy sources and replacement chemicals for chlorofluorocarbons.) (IPCC, 1996, Chapter 18, pp 2). A running project on this subject is: 'Climate Change and Malaria Risk: An Integrated Modelling Approach' of W. Martens *et al.* (1996).

Conclusion and research needs

In conclusion, the impacts of global climate change, particularly if sustained in the longer term, could include a multitude of serious, but thus far under-recognised, impacts on human health. Human population health is an outcome that integrates many other inputs, and it depends substantially on the stability and productivity of many of Earth's natural systems. Therefore, human health is likely to be adversely affected by various other impacts of climate change upon those systems (IPCC, 1996, Chapter 18, pp 2). There is immediate need for improved and internationalised monitoring of health-risk indicators in relation to climate change (and other associated global and regional environmental stresses). Existing global monitoring activities should encompass health-related environmental and bio-indicator measurements, and, where appropriate, direct measures of human population health status. Monitoring activities should interact with ongoing health risk research and assessment activities (IPCC, 1996, Chapter 18, pp 2).

3.6 Air pollution

Global warming will affect the quality of air in two ways. The first has to do with what is called secondary benefits. All CO_2 abatement will also lead to a reduction in the emission of major pollutants such as as NO_x, SO_2 and CO. Many chemical reactions also depend on temperature. The formation of acidic materials could increase (Fankhauser, 1995). Air pollution increases the occurence of respiratory diseases, such as emphysema and asthma (Tol, 1996). An increase in tropospheric ozone level is expected, brought about through the increase in NO_x and HC emissions as well as through a higher reaction rate (Fankhauser, 1995). Tropospheric pollutants, such as O_3, NO_x, SO_2 and their indirect effects via soil acidification, can have detrimental effects on plant growth and survival. Effects of these pollutants are best documented in Europe and parts of the USA, but NO_x, SO_2 and tropospheric O_3 concentrations may be at damaging concentrations in all industrialised areas. These pollution effects constitute a cumulative stress factor on plants, which could be further compounded by changed rainfall patterns or increased temperature, but may be partly alleviated by increasing CO_2 concentration (IPCC, 1996, Introduction to cological/climate/physiographic systems, pp 6). Climate change does not directly lead to air, water, or soil column pollution. However, if changes in climate significantly alter local and regional weather patterns, underlying trends in pollution damage may change non-linearly. Global monitoring of urban air quality in cities indicates that nearly 900 million people are exposed to unhealthy levels of SO_2 and more than 1000 million are exposed to excessive levels of particulates (IPCC, 1996, Chapter 12, pp 9). Warming can exacerbate the formation of smog. Global warming and stratospheric ozone depletion appear likely to aggravate tropospheric ozone and other air quality problems in polluted urban areas. If climate change were to add to the number of air stagnation periods, the effects on human health and economic productivity (from pollution itself or from emergency countermeasure) would be more severe (IPCC, 1996, Chapter 12, pp 9). To achieve a monetary estimate the assumption seems appropriate, however, as the damage from an increased O_3 concentration is fully attributed to NO_x in all available estimates. For SO_2 Fankhauser assumes a rise in emissions of 2 per cent. The emissions increase in absolute terms is shown in Table 3.7. The estimates for NO_x range from about $0.10 to

Table 3.7 Damage through increased air pollution ($2\times CO_2$ - 1000 tons 10^9 US \$ 1988)

	Increase in NO_x emissions (1000 tons)	Increase in SO_2 emissions (1000 tons)	Damage from increased air pollution (10^9 \$)
EU	566	285	3.543
USA	1,073	422	6.420
Ex-USSR	1,584	1,100	2.134
CHINA	227	258	0.178
OECD	1,943	873	11.898
WORLD	**4,545**	**2,737**	**15.402**

Source: Fankhauser, 1995

\$15 of damage per kg emitted. The figure is exclusive of the damage from acid rain. The divergence in the figures mainly stems from differences in the assessment of health impacts. In the following Fankhauser uses an average of \$5/kg for developed countries, \$1/kg for middle income countries and \$0.5/kg in LDCs (Fankhauser, 1995). Again excluding acid deposition, SO_2 causes a damage of \$0.6/kg to 3.5/kg, mainly through health effects and corrosion. Fankhauser uses an average value of \$2.5/kg in OECD countries. For middle and low income countries he assumes \$0.5/kg and \$0.25/kg, respectively. The estimates resulting under these assumptions are shown in Table 3.7 above (Fankhauser, 1995). Several studies (Cline, 1992 and Titus, 1992) estimate the damage costs of air pollution in the US due to climate change somewhat different. These scientists have respectively damage costs of >3.0 and 23.7 billion dollars.

3.7 Migration

This section provides order of magnitude estimates of impact on migration associated with a doubling of atmospheric CO_2 concentration. Additional immigrants, emigrants and the costs involved are produced for different geopolitical regions as well as the world as a whole. Beside this section, more information on this subject can be found in the part of Nierop and Van der Wusten in this report. Global warming could trigger a large migration stream away from the worst-affected regions (Fankhauser, 1995). It is assumed that under a worst-case scenario as many as 100 million people could be displaced world-wide (Ayres and Walter, 1991). Cline (1992) quotes estimates of 72 million people displaced in China, eight million in Egypt and half-a-million in Poland. In Bangladesh 11 per cent of total population (*ca* 11.4 million people) could be affected (Fankhauser, 1995). Conflict between groups in society can exacerbate the effects of climate, creating refugee problems of major dimensions. As land and water resources bear increased population and development burdens, disputes over resource use become increasingly acute and may themselves become a source of conflict. In some cases, climate-related environemental disaster has created significant refugee populations, while in other cases the management of resources to prevent disaster has created the problem. These refugee populations are often either socially marginalized or become a source of conflict. For example, repeated flooding in Bangladesh has resulted in migration of thousands of Bangladeshis to India, where etnic conflict has resulted (IPCC, 1996, Chapter 12, pp 6). Forced migration may well be one of the most pronounced impacts of sea-level rise (Myers and Kent, 1995), considering the fact that people tend to cluster in deltas and near shores (Tol, 1996). Table 3.8 provides an assessment of the numbers. The costs of emigration are set to an arbitrary three times the per capita income. The costs of immigration are set to 40% of

Table 3.8 Movement of people due to sea level rise (thousands)[a]

from to	ME	LA	S&SEA	AFR	**total**
OECD-A	0	33	46	0	**79**
OECD-E	11	0	23	46	**80**
OECD-P	0	0	46	0	**46**
CEE&fSU	0	0	0	0	**0**
ME	98	0	0	0	**98**
LA	0	294	0	0	**294**
S&SEA	0	0	1,036	0	**1,036**
CPA	0	0	0	0	**0**
AFR	0	0	0	416	**416**
total	**109**	**327**	**1,152**	**462**	**2,464**

[a] *In the poorest regions where dryland is assumed to get lost, 0.75 per thousand of the people is assumed* to leave; 90 per cent is assumed to remain in the region of origin.

Source: Tol, 1996

the per capita income in the host country (Tol, 1996). The costs are shown in Table 3.9. Fankhauser uses 17 per cent additional immigrants per year for US due to global warming. For lack of better data Fankhauser assumes that this percentage is representative

Table 3.9 Annual emigration/immigration costs of a 50 cm sea level rise (10^6 $)

	Emigration[a]	Immigration[b]
OECD-A	0	580
OECD-E	0	400
OECD-P	0	4,010
CEE&fSU	0	0
ME	850	100
LA	1,790	220
S&SEA	1,860	220
CPA	0	0
AFR	910	110
World	**22,680**	**7,270**

[a] The costs of emigration are set at three times the per capita income (in the region of origin) per emigrant. The number of emigrants can be found in Table 3.8.

[b] The costs of immigration are set at forty per cent of the per capita income (in the host region) per immigrant. The number of immigrants can be found in Table 3.8.

Source: Tol, 1996

for the world as a whole. The estimated immigration increases are shown in Table 3.10. Another study (Cline, 1992) estimate the damage costs of migration in the US due to climate change somewhat different. This study has damage costs of 0.4 billion dollars (Tol, 1995a). To the costs would have be added the costs of hardship and stress suffered by migrants. People have often fought wars to avoid being forced to leave their homelands against their will (Cline, 1992). It is therefore quite likely that the costs exceed the pure

Table 3.10 Migration costs ($2\times CO_2$ -10^6 US $ 1988)

	Additional immigrants (in 1000)	Total costs (10^6 $)
EU	229	1,031
USA	100	450
Ex-USSR	153	153
CHINA	583	583
OECD	455	2,048
WORLD	**2,734**	**4,327**

[a] 455,000 immigrants to OECD countries at $4,500, remaining immigration at $1,000.

Source: Fankhauser, 1995

economic losses. Unfortunately, it seems almost impossible to assess them properly (Fankhauser, 1995). There are two types of costs: utility sacrificed by the migrant, and cost on the target host country. For migration from developing to industrial countries, neoclassical economic analysis from a global standpoint might attribute a gain rather than a cost for each additional immigrant. However, in terms of political economy, revealed behaviour indicates that the perception of imposed costs from increased immigration dominates (Cline, 1992). Outside the United States, there are indications that concern about increased immigration induced by global warming is especially high in Europe, where immigration problems already have intensified in the past decade as the consequence of political change in Eastern Europe and North Africa. As semi-arid African states are among those expected to be seriously affected by global warming, such concern would appear well founded (Cline, 1992). Once again, more can be read on this subject in the part of Nierop and Van der Wusten in this report.

3.8 Risk of disasters

Increased frequency and magnitude of extreme events is often mentioned as a potential characteristic of future global climate. Both *individual* events, such as major rainfall event which recharges deep moisture stores, and *periods* of above or below-average rainfall, for example, are significant. Extreme events are particularly important in rangelands; since they already drive the system, small changes in their frequency may have a disproportionate effect on what management must cope with. Increased frequency of extreme events will potentially have more impact than mean changes in climate (IPCC, 1996, Chapter 2, pp 12). On the basis of meteorological data, however, there can be no determination of an systematical increase in stormactivities (KNMI, 1996). The catastrophic aspects of storms and storm surges are well known, particularly in exacerbating flood situations in coastal areas and, in erosion and restructuring of coastal formations. The causal relationship between sea surface temperature and the formation of tropical cyclones suggests that the intensity and frequency of tropical cyclones will increase in future. The evidence from models is however conflicting (IPCC, 1996, Chapter 8, pp 13). Wind storms in Europe can be costly. A small increase in wind speed could have a dramatic effect (Dorland *et al.*, 1995). In Table 3.11 the damage costs of selected extreme events, underwhich wind storms, are shown. Extreme events sometimes occur successively or simultaneously. When this happens, as in the case of a series of typhoon hits, the damage is more serious because the area has been made vulnerable by

Table 3.11 Damage costs of selected extreme weather events (10^6 $)

region	wind storm[a] (10^6 $)	river flood[b] (10^6 $)	tropical cyclones[c] (deaths[d])	(10^6 $)	total (10^6 $)	(%GDP)
OECD-A	179	102	83	13,278	13,848	0.271
OECD-E	191	109	0	0	299	0.006
OECD-P	110	63	144	31,371	32,128	1.024
CEE&fSU	100	57	81	11	289	0.010
ME	0	8	0	0	8	0.002
LA	0	16	44	16	57	0.007
S&SEA	0	17	7,677	825	3,483	0.422
CPA	0	9	1,005	69	389	0.090
AFR	0	8	0	0	8	0.002
World	**579**	**388**	**9,034**	**45,570**	**54,628**	**0.282**

[a] Additional wind storm damage for a 6% increase in modal wind speed. Assumed vulnerability is 0.0035% of GDP for the OECD and Central and Eastern Europe and the former Soviet Union, and 0 for the other regions.

[b] Additional river flood damage for a 10% increase in winter precipitation. Assumed vulnerability is 0.002% of GDP for all regions.

[c] Additional tropical cyclone damage for a 25% increase in intensity. Assumed vulnerability for deaths and property damage follows Fankhauser (1995), and the MAP.

[d] The value of a statistical life is set at $250,000 plus 175 times the per capita income.

Source: Tol, 1996

previous damage (IPCC, 1996). Windstorms can cause several types of harm to socioeconomic systems - property damage, lost production, macroeconomic disruption and personal death, injury or stress. Table 3.12 contains information on the impact of major windstorms worldwide since 1960 (IPCC, 1996, Chapter 17, pp 9). Research results of

Table 3.12 Major windstorms* worldwide: annual impact 1960-1992 (valued at 1990 prices)

	1960s	1970s	1980s	1990s
Number	0.8	1.3	2.9	5.0
Insured cost($B)	0.5	0.8	1.7	11.3
Total damage ($B)	**2.0**	**2.9**	**3.4**	**20.2**

* A major windstorm is defined as one costing more than $500 million in total damage

Source: IPCC, 1996, Chapter 17, pp 10

damage costs from tropical storms are shown in Table 3.11 and Table 3.13. In Table 3.11 (Tol, 1996) the pattern of vulnerability is the same as in Table 3.13 (Fankhauser, 1995). Fankhauser's dollar figures are based on PPP-exchange rates and Tol's figures are based on market exchange rates. A 25% increase in hurricane intensity is used. The damage function is quadratic in Table 3.11 (Tol, 1996). It seems reasonable to assume that storm damages rise more than linearly with intensity. The costs of increased tropical storms are shown in Table 3.13. Over the last 40 years, US hurricanes have caused an annual

Table 3.13 Costs from increased tropical storms ($2\times CO_2$ -10^6 US \$ 1988)

	Additional deaths	Value of lost lives (10^6 \$)	Destruction damage (10^6 \$)	Total costs (10^6 \$)
EU	0	0	0	0
USA	72	108	115	223
Ex-USSR	44	13	1	14
CHINA	779	78	13	91
OECD	313	470	506	976
WORLD	**8,000**	**2,073**	**630**	**2,703**

Source: Fankhauser, 1995

average of \$1.5 billion in damages at 1989 prices. For other countries, especially islands states, hurricane damage from global warming could be more severe (Cline, 1992). Damages under very-long warming could be far greater proportionately than the corresponding ratio of temperature increase to that under benchmark $2\times CO_2$ warming (Cline, 1992). If a warmer climate will result in a more intense hydrological cycle, leading to more heavy rain events, and specificially to increases in the intensity of precipitation events and more heavy rainfall days, then the particular concern for the hydrologic cycle is in changes in the related occurrences of floods and droughts. Changing flood and drought conditions will require actions in the area of reservoir planning, design and operation. Droughts may also prevent the achievement of food self-sufficiency in many regions, which is determined in part by the timing and the amount of precipitation. The problem of droughts and floods under instationary hydroclimatic conditions is an area that needs additional research efforts in future (IPCC, 1996, Chapter 10, pp 8). Riverine floods belong to the class of hazards climatologists can provide reasonable information about, at least for larger rivers. It is concluded that a 10% increase in winter precipitation could lead to a rough doubling of annual average damage from Dfl. 21.8 million in the Limburg Meuse Valley (Tol, 1996). The damage cannot be all ascribed to climate change, as improper management in the past, land use changes in the river catchment and nature development in the river bed are the main considerations for action (Tol, 1996). Hence, it may be better to ascribe the additional damage in case the river bed remains as it is (i.e., Dfl. 12 million, or 0.002% of GDP) to the enhanced greenhouse effect. The damage costs of river floods are shown in Table 3.11. Extreme events are often related to disease outbreaks. Both droughts and floods are related to outbreaks of vector-borne diseases (see also section 3.5) and agricultural pests (IPCC, 1996, Chapter 12, pp 14). Drought is measured in soil moisture availability, which is composite of precipitation, moisture transport, temperature and soil characteristics (Tol, 1996). The impact of extreme events on human settlements can be affected by the grade of the extreme event, the level of economic and technological development, and the extent of countermeasures taken (IPCC, 1996, Chapter 12, pp 15). Empirical data do not confirm the view that weather disasters hamper macro-economic development (Dorland *et al.*, 1995). Climate change may affect the intensity or the probability of extreme events (IPCC, 1996, Chapter 12, pp 15). On the basis of meteorological data, however, there can be no determination of an systematical increase in stormactivities (KNMI, 1996).

3.9 The dynamic aspects of climate change

This section will treat, mainly on the basis of Tol (1994a, 1994b and 1994c), the dynamic nature of the climate change damage costs. Six types of dynamics are distinguished, respectively: valuation of damage over time, socio-economic vulnerability, higher order impacts, knowledge and uncertainty, non-equilibrium climate change, irreversibility and other accumulation. First of all the damage costs of climate change are split into a tangible and an intangible part. The former represents the damage to (more or less) marketed goods, such as agriculture (section 2.1), energy (section 2.4), and protection from the sea (section 3.1, 3.2 and 3.3), the latter to non-marketed goods, which are nevertheless of human value, such as ecosystem and human health (respectively section 3.3 and 3.5). Intangible damages are compared to tangibles by assigning some monetary value to them. The most common and general way of doing so is the contingency valuation method (Tol, 1994c). The validity of economic valuation techniques is in particular the main subject which has been fiercely critised by many authors. Grubb (1993) for example critised $2 \times CO_2$ damage estimates as being based on a 'largely subjective valuation of non-market impacts'. Tol (1994a) criticises Nordhaus (1994) DICE model for the way in which the intangibles losses are treated. After a monetary value has been attached to the intangible damages, DICE treats them as market goods, which they are not. Moving the intangible losses from the production function to the utility function implies enhancing the prospects for economic growth, thereby increasing the possibility for emission abatement (Tol, 1994c). The problem of climate change damage estimates is currently perhaps not so much the accuracy of valuation methods as such, but the fact that they have not yet been applied to the problem to a sufficient degree. This is not to say that a full and complete valuation of all climate change impacts will ever be possible (Fankhauser, 1995). Peck and Teisberg (1993) presented a first effort at placing a value on resolution of climate change uncertainties. What is particularly needed is a broadening of the scope from the emphasis on agriculture and sea level rise to the inclusion of other damage aspects such as ecosystems loss, climate amenity, health and morbidity (Fankhauser, 1995). Secondly the damage costs are not only a function of climate change but also of the state of the system climate acts upon. The system's vulnerability changes for numerous reasons, and also purportively to diminish the damages. The latter is commonly referred to as adaptation. Damage should be kept at a minimum through appropriate adaptation measures. This may, for example, include the erection of sea defences, the development of heat resistant crops, a change in agricultural and forest management, the construction of water storage and irrigation systems, the adaptation of houses, and the like (Fankhauser, 1995). Schelling (1992) has even argued that for developing countries the best adaptation strategy may simply be economic development. Only some broad generalities are observed on the dynamics of the underlying system upon which climate change acts. The agricultural shares in the Gross Domestic Products (GDP) have been decreasing with economic growth. Relative agricultural demand has fallen with economic growth. If this trend continues, countries tend to be less vulnerable for climate change than at present (Tol, 1994c), as far as agricultural is assumed. But will this trend continue? Individuals do spend relatively less on food as they grow richer (given fixed food prices) because of saturation. But together with the economy the population is projected to grow, leading to an increasing *absolute* demand for agricultural products. The supply is stimulated by technological progress and liberation of the world market, but hampered by environmental degradation including climate change, and confronted with increasing competition for land (the absolute amount of which decreases with the sea level rise) for urbanisation, manufacturing, and perhaps biomass plantations and solar energy parks. So the answer depends on the prospects for more efficient production and distribution of agricultural products. If they can keep up with the growing demand, vulnerability will fall. If they cannot, the market will be under stress, and climate change is likely to further enhance this (Tol, 1994c). The continuous development of coastal regions increases the costs of sea level rise as either more land requires to be protected. Increasing demand for land pushes up land prices and so the costs of dryland loss (section 3.2). Enhanced protection induces additional wetland losses (also section 3.2). On the other hand, the presently poor regions have better opportunities in weighing land loss and protection, not only because of growing means but also because of shrinking protection costs with technological progress and experience (Tol, 1994c). The third dynamic aspect refers to the fact that climate change damages also set in motion a chain of other effects. For instance, coastal defence commonly is considered a government's task. Increased government spending on this part inevitably leads to either reduced spending elsewhere, or tax or loan increases. Reductions in agricultural yield imply price increases. The macroeconomic impacts of small changes to not too significant sectors are likely to be small. More important sectors, larger direct changes, and compound effects may, however, add substantially to the total damage costs (Tol, 1994c). In general, if the environmental circumstances decline, more defensive expenditures need to be made. Defensive investment is defined as the expenditure on durable goods which only serve to help common (productive) capital properly (Tol, 1994c). The distinction between defensive and productive capital goods and investment is highly artificial, but the intuitive appeal is clear: dikes, say, are not productive; without them, the plants behind them would not be either. Defensive consumption is defined in a similar fashion. Consumption and production capacity are lower than without the increase in defensive expenditures. Another, but related indirect impact of climate change is risk. Risk has to do with probability distributions (Jansen, 1992). Climate change increases uncertainty (particularly so if insurance gets dearer and less available). As most investors are risk averse, this implies that higher rate of return on investment is required, and so that overall investment may decline (Tol, 1994c). The fourth dynamic aspect refers to uncertainty which is simply 'not knowing' (Jansen, 1992) and a dominant characteristic of environmental externalities, including the accumulation of greenhouse gases leading to climate change (Kolstad, 1993). The uncertainties exhibit considerable dynamics, just like their underlying phenomena do. Experiences and research continuously add to the available knowledge. Reviewing the development of climatology over the last few decades shows little progress in narrowing down the range of unknowns (Tol, 1994c). The impact studies rapidly progressed at first, as any field does in its infancy, but this has slowed down as well. Based on the present knowledge, there is simply no way to predict what future knowledge will look like. So, any decision making model should, besides adequately reflecting the present state of uncertainty, at least treat the rate and direction of learning as a scenario, discuss several scenarios, and present the results as such (Tol, 1994c). Kolstad (1993a) presented an empirical model of learning with uncertainty in the context of the control of greenhouse gases. He has demonstrated that when irreversibilities exist in both climate change and emission control, emission control dominates. Accelerated learning tends to reduce current period optimal emissions. Kolstad (1993a) is one of the propagators of the so-called 'learn-then-act' strategy, postponing action until more certainty is gained. Another aspect of the dynamics of uncertainty is that the further remote in the future we get, the larger the uncertainty becomes, from our present point of view. This sounds like a trivial remark, but in fact none of the models have incorporated this aspect (Tol, 1994c). Equally trivial, important and ignored is the point that it is not only the parameter values which are uncertain, but also the form of the equations and essentially the structure of the system. The best advice is perhaps to do also a robustness analyses into the structure of the model (Tol, 1994c). The fifth type of dynamics of the climate change damage costs is non-equilibrium climate change. Tol (1994b) proposed a set of damage cost functions. This was rather to start the discussion on this than to present a final answer. Damage cost functions express damage costs as a function of suitable climate parameters. Tol (1994b) argued that the damages are, in general, convex functions of climate change, i.e., damages increases more than proportional with climate change. Little progress has been made on the damage costs expressed as a function of changes in suitable climate parameters. Basically, one has to assume some functional form which does not seem too implausible. A way out is to go back to the detailed impact studies and rerun the analyses with enough climate perturbations so as to derive functions instead of benchmark estimates; this very elaborate way out is often blocked by the inadequacies or the back of the envelope nature of the underlying studies (Tol, 1994c). Tol (1994c) proposed a particular solution which is to approximate the 'true' damage function by its power expansion cut off after the second term, and then use common sense to state which part of the damage is proportional (linear) and which more-than-proportional (quadratic) in climate change. This excludes *a priori* the possibility of concave damage. The sixth type of dynamics of the climate change damage costs is about the characteristics of the damage function, irreversibility and other accumulative aspects. The damage should be a function of the most appropriate climatic parameter, and the distinction between damages due to the rate of change and damages due to the total changes of temperature is an important one (Tol, 1994b). Yet another dimension of the nature of damage costs is whether they are symmetrical in climate change, i.e., are the costs the same (i.e., of the same sign and order of magnitude) for changes in the opposite direction? (Tol, 1994c). Irreversibilities (e.g., Kolstad, 1993b) work on both costs and benefits of emission reduction, but need not necessarily influence the optimal decision (Ulph and Ulph, 1994).

4. ENVIRONMENTAL SECURITY IN THE GLOBAL ARENA

4.1 Introduction

The concept of environmental security was officially introduced at the 42nd session of the United Nations General Assembly in 1987 but the introduction of the theme of environmental degradation and resource depletion as a relevant political issue at the global level is of far earlier date. The first report of the Club of Rome was published in 1972. In the same year, the issue was discussed in an institutional global setting during the first United Nations Conference on the Human Environment in Stockholm. The conference resulted in the establishment of UNEP. In the 1980s the Palme, Brandt and Brundtland Commission reports focussed the attention of a worldwide circle of policymakers at the links between violent conflict, economic development and environmental degradation. They gave rise to the encompassing notion and rallying cry of 'sustainable development' for a 'common future'. Since 1988 the Intergovernmental Panel on Climate Change instituted by the UN has endeavoured to seek agreement on the best possible scientific predictions on and insights into climate change. The United Nations Conference on the Environment and Development in Rio de Janeiro 1992, the sequel to the Stockholm gathering, centered around global climate issues and came up with an encompassing programme of urgent change necessitated by overall environmental deterioration plus wideranging disputes concerning the contributions of more and less developed regions of the world. During the same period an international agreement concerning the worldwide problem of ozone depletion was made and flexibly and successfully implemented and elaborated in a series of follow up conferences. From the late 1970s onwards, environmental problems were increasingly linked to the notion of 'security'. Several authors argued for a redefinition of national security to encompass non-military threats like environmental degradation (e.g. Brown 1977, Tuchman Matthews 1989, Myers 1989). Some developed this line of thought one step further than merely defining the environmental as an urgent, threatening (and therefore: 'security'-)problem and mentioned environmental factors - more in line with the traditional security-concept - as (potential) causes of conflict (e.g. Westing, 1986, Homer-Dixon 1991). Gradually, the theme of environmental security was also incorporated in national political debates. US Senator Al Gore, now vice-president, in 1990 extensively pleaded the case of the environment as a 'national security issue' (Deudney 1990, p.462). In the late 1980s and 1990s the acceptance of the issue in academic and policy-making circles gained momentum. The issue of environmental security was also put on national political agendas. The Dutch Ministry of Foreign Affairs, to cite one example, notes that if population growth and environmental degradation are not stopped, the environment and the distribution of scarce resources will be the subject of increasing international and intra-national competition, and may in the 21st century become a 'security issue of the first order' (Herijkingsnota 1995, p.23). During recent years, global climate change was added as a separate topic to this discussion. Climate change, like environmental degradation in general, is sometimes not merely regarded as a problem in itself but as a potential threat to international peace and security. The United States National Academy of Science in 1991 recognized that climate change may in the future be an important contributor to political instability, especially in areas that are already facing security poblems because of social and economic changes (Lonergan 1996, p.4). In a similar context, the Dutch government supports an 'active environmental diplomacy' to restrict the emission of greenhouse gasses (Herijkingsnota 1995, p. 23). Particularly in connection with global climate change the environmental degradation that might give rise to violent conflict is primarily perceived as an issue to raise in worldwide forums.

4.2 Collective goods and free riders: barriers to effective political action and potential bases for conflict

In a study of environmental crises and international security Schellnhuber and Sprinz (1995) distinguish, in general, three basic categories of environmental threats: 'home-made' threats, threats caused by neighbours, and threats caused by 'faraway' actors. Climate change, if perceived as a threat, clearly belongs to the last category. It is a global phenomenon, caused by actors all over the globe. Because of its global nature and its perception as a collective bad, countering the process of climate change necessitates collective action by sovereign states. But the nature of the issue at the same time provides sovereign states with the potential for 'free riding'. States may profit from the, perhaps costly, measures to be taken by other states. This unbalanced mix of national and collective interests provides a potential basis for international political tension and conflict. The core of the problem in this problem formulation is that the global environment, i.c. the global climate, is perceived as a collective good (Olson Jr., 1965), i.e. a good that, when made available to some (people, states), is automatically available to all. If air pollution is reduced or the green house effect limited, everyone will enjoy the benefits, regardless if they have contributed to this reduction or not. Because of the opportunity for 'free riding', actors are faced with a prisoner's dilemma. Individual interests do not run parallel with the common interest and therefore there is no guarantee that collective decisions are made and effective action is indeed taken. As to this point, Mancur Olson Jr (1965, p.2) states: "It does not follow, because all of the individuals in a group would gain if they achieved their group objective, that they would act to achieve that objective, even if they were all rational and self-interested. Indeed, unless the number of individuals is quite small, or unless there is coercion or some other special device to make individuals act in their common interest, rational self-interested individuals wil not act to achieve their common or group interests. In the case of global climate change a number of specific national economic interests for some individual countries pose extra incentives to 'free riding' and thus an extra barrier to effective, common action. Notable examples are the American dependence on automobiles and the economic interests of oil-producing countries. Serious measures to limit the emission of greenhouse gasses will harm these interests and this circumstance will play a role in national decision-making. National political trade-offs between the economic costs and benefits of particular measures may thus inhibit the realization of a collective goal. The incentives for free riding may provide a basis for international political tension and conflict between any conceivable pair of states. On top of this, as mentioned in chapter 1, it is far from certain that all countries will equally suffer or will suffer at all from an overall rate of climate change nor will all equally benefit or benefit at all from diminishing overall climate change. In that sense climate change is not really a collective good/bad. We will elaborate on this in the next section. Collective action is not by definition impossible. An example of how international diplomacy can succesfully establish international collective action for the protection of a collective good, is the Protocol of Montréal (1987). This protocol, which was later sharpened in London (1990) and Copenhagen (1992), regulates a global reduction of the production and consumption of CFCs, a major cause of the depletion of the ozone layer. The ozone-treaty is regarded as an outstanding example of how environmental diplomacy can contribute to establish an effective global regime (Benedick 1991, Gijswijt 1995). A regime sets norms in international interaction that are widely upheld by shared convictions and social control that lacks the authority of an overarching sovereign power. Various factors decide whether an environmental regime can be established or not. According to Young (1994, p. 45-46) three clusters of factors have claimed the attention of those concerned with regime formation: power, knowledge and interests. The supposed role of power refers to the idea that powerful states (in a material sense) can sometimes promote, assist or force weaker states to comply with the formation and terms of an international regime. Viewed from this perspective, regimes are the reflections of the international distribution of power (Strange 1983). As regards the factor of knowledge, authors refer to the role of consensual knowledge and social learning among transnational groups of scientists and policy-makers concerning the subject at stake. As regards the role of interests, analysts focus on interactive decision-making and the search by individual parties for mutually agreeable deals as the motivating force underlying regime formation (Young 1994, p.46, Payne 1996). Climate change, as a subject for regime formation, substantially differs from the ozone layer issue, especially as concerns 'knowledge' and 'interests'. First, there is still much uncertainty on the concrete time frame, extent and effects of climate change, especially at a sub-global (national, regional) level. IPCC 1996 (Working Group II, Summary for policymakers, p.4): "Although our knowledge has increased significantly during the last decade, and qualitative estimates can be developed, quantitative projections of the impacts of climate change on any particular system at any particular location are difficult because regional-scale climate predictions are uncertain." Because of this lack of certainty there is no consensus on the causal effects of CO2-emission and global warming in terms of tangible costs or damage in particular regions or countries. This inhibits a solid economic cost-benefit analysis by the individual parties, which affects the conditions for agreement and action. Second, whereas the production of CFCs concerned only a small part of even the most involved economies, and chemical producers were able to develop alternative products in a relatively short period, the main causes of global warming (the emission of greenhouse gasses, i.e. the use of fossil fuels) touch the heart of the economy. The interests (costs) at stake with potential measures against climate change are therefore much larger, while no alternatives are readily available. Apart from the interests affected by potential measures, national interests with respect to the results pose an extra complication. Contrary to saving the ozone layer, stopping climate change is not a process with only winners: while some countries will benefit from stopping global warming, others will be hurt. Contrary to its popular image as a unambiguous 'global threat', with a consequently 'globally' shared interest in countering this threat, climate change is not disadvantageous for all parties. Whereas the destruction of the ozone layer has only losers - at least on a macro-scale: producers of particular products may benefit - global warming produces losers as well as winners (section 4.3). This poses an extra barrier to a collective solution.

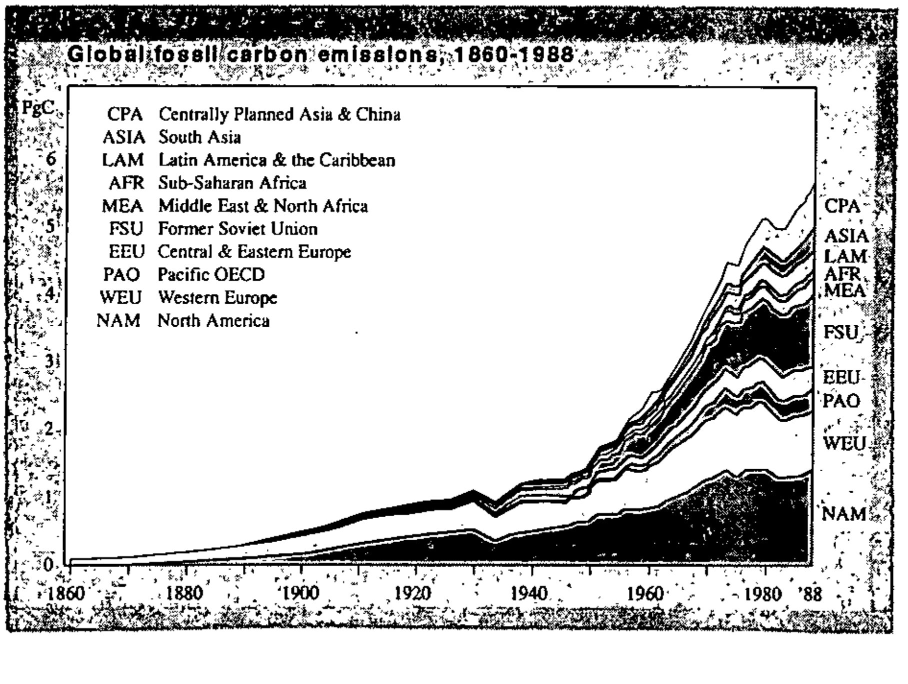
4.3 Winners and losers

Although climate change is commonly perceived as a collective global threat ('no winners') it is at least in the short run (more on this further down in this section) also a distributional problem with winners and losers. Apparently, this last view has for a long time more or less been a 'political taboo'. Glantz (1995) points to the striking difference between the scientific and political responses in the 1970s to a potential global cooling and today's responses to a supposed warming. During the brief, yet to be explained, period of global cooling from about 1940 to the late 1960s, one issue widely considered was how it might (positively or negatively) affect the relative economic and political positions of different countries. The US Central Intelligence Agency for example undertook a set of studies to show how the cooling might affect the agricultural production and energy demand in the USSR. Some analysts went so far as to identify specific countries (e.g. Equatorial Brazil, Zaire, Indonesia) that, in the event of cooling, would become climate-related world powers (Glantz 1995, p.42). Glantz notes that with respect to the current issue of global warming, the discussion of winners and losers or even of differential impact has, at least up to the recent past, been politically 'not done'. There is only one exception to this observation: sea level rise. This might be explained by the fact that, at the national level, sea level rise is the only impact of a global warming for which there are no obvious winners (Glantz 1995, p.43). Despite being politically taboo, the existence of winners and losers from climate change is obvious. Global warming can be disadvantageous or advantageous, depending on the already existing climatic conditions. Some winners are evident. A rise of temperature will for example enlarge the agricultural possibilities in arctic Russia, Canada and Scandinavia. Florida, to cite another obvious case, would no longer fear the loss of its citrus production to occasional frost. Buzan, Waever and De Wilde (1995, p.14), in a similar vein as Glantz, argue that with respect to environmental security in general, two agendas exist: a scientific agenda and a political agenda. They state (ibid., p. 21) that "the rhetoric of the political agenda makes us believe that we are dealing with an essentially globalized sector" and conclude that "this sounds good, but is not true". According to these authors, the global dimension in environmental security is certainly there, but not so overwhelmingly as often suggested. This applies as well to the specific issue of climate change. In the view of Buzan, Waever and De Wilde (1995, p.15), environmental security issues are not ruled by hegemonic power structures or balance of power structures, but by strategic positions that are issue-specific. Because of differences in interests and strategic positions there are in every global environmental issue at least one or perhaps even more groups of states whose cooperation is so essential that they have an effective veto power over a successful agreement for coping with that environmental problem (Porter and Brown 1991, p.17). As a consequence every issue has to be negotiated in a differently structured arena and spillovers and tradeoffs are difficult to achieve. While the existence of winners and losers from global warming is obvious, detailed knowledge of which countries will win and lose is lacking. The IPCC reports make some references to regions that will encounter the strongest impacts of particular aspects of global warming, but these are mostly put in general terms. Regional warming so far has been greatest over the mid-latitude continents in winter and spring, with a few areas of cooling, such as the North Atlantic Ocean. Precipitation has increased over land in high latitudes of the northern hemisphere, especially during the cold season (IPCC 1996, Working Group I, Summary for policymakers, p.3). With respect to food production, studies tend to show more negative impacts for areas in the tropics, where problems of poverty and food supply are already greatest (IPCC 1996, Working Group II, Summary for policymakers, p.14). Low-latitude, low-income populations depending on isolated, dryland agricultural systems in semi-arid and arid regions are particularly vulnerable. Many of these at-risk populations are found in Sub-Saharan Africa, South, East and Southeast Asia, and among the Pacific Island nations. However, these studies have considered only a limited number of adaptation measures, are based on yield analyses on a limited number of sites and did not include for example changes in water supply caused by alterations in river flows and irrigation, and changes in soils and soil management practices. Moreover, large yield losses in one location and for one type of crop may be balanced by yield gains elsewhere, both within and among countries. Although the present state of scientific knowledge does not enable to identify the winners and losers with some detail, the issue cannot be avoided. The theme is pivotal to the chances for collective, global action and must be part of any profound discussion about the conflict potential rising from climatic change. In the context of winners and losers, it is curious that much scientific and political attention for the climate change problem comes precisely from areas of the world where the process will most likely be advantageous (i.e. Canada, Scandinavia). While we do not fully understand it, this paradoxical phenomenon can probably not be separated from the difference between short- and long-term effects and perspectives. Although the effects of climate change may for some countries be advantageous in the short run, nobody knows in what direction and with what pace the process will develop when it has passed an as yet unknown point of no return. This basic uncertainty, accompanied by a high saliency of environmental problems generally, may induce even countries that expect advantages in the relatively short term, to take action against a process that may in the long run have serious adverse effects. In general, however, short run expectations will cause differences of (perceived) interests and will thus further complicate the search for collective solutions. The lack of knowledge on the current situation has a paradoxical side to it as well: more detailed scientific knowledge will probably not enhance the political chances for effective global action. Rather on the contrary: the more sophisticated and the more regionally detailed the knowledge concerning climate change and its effects will be, the greater the political barriers to establish a collective policy. In the words of Glantz (p.44): "If winners and losers are identified with some degree of reliability, the potential for unified action against the global warming may be reduced." And, we might add, the potential for conflict may be enlarged.

4.4 Distribution of causes and effects

Neither the emission of CO2 nor the beneficial/negative effects of climate change are on a global scale evenly distributed. The point of departure in any global negotiation about measures to counter climate change thus differs from country tot country. Although their share has been declining, the OECD-countries are still the major energy users and fossil fuel carbon emitters. Almost half of the global CO2 emissions is produced by North America, Western Europe and the Pacific OECD-nations. Roughly a quarter of all emissions comes from Central and Eastern Europe and the former Soviet Union. Less than a third of all emissions is contributed by developing nations in Asia, the Middle East, Latin America and the Caribbean and Africa. The share of the developing nations as a group is growing rapidly, with the exception of Sub-Saharan Africa. CO2 emission per capita is also highest in the industrialized countries. Especially the United States and the

Figure 4.1 Global Energy-Related CO2-Emissions by Major World Region (cumulative totals) in PgC/Year



Source: Marland, G.et al.1993: "National, Regional and Global CO2-Emissions Estimates 1950-1991". NDP-03/RS. Carbon Dioxide Information Center, Oak Ridge National Laboratory, Oak Ridge, TN, USA: Grubler, A. and Nakieenovic, N., 1992: "International Burden Sharing in Greenhouse Gas Reduction, "Environment Working Paper No.55, World Bank Environment Department, Washington, DC, USA: Fujii, 1990: "An Assessment of the Responsibility for the increase in the CO2-Concentration and Inter-Generational Carbon Accounts,'WP-90-55. IIASA, Laxenburg, Austria.

former Soviet Union are large emitters. Emission by the countries of the European Union averages less than half of the United States' level. The developing countries rank lowest, with an average per capita emission level of around a third of the global average. As seen

Table 4.1 Annual CO_2-emission per capita 1990 ('in ton C')

USA	5,4
Former USSR	5,0
European Union	2,4
Japan	2,4
Germany	3,0
England	2,7
Netherlands	2,6
Italy	1,8
France	1,7
Spain	1,4
Developing Countries	0,3
Global	**1,1**

Source: P. Vellinga, during IPCC Climate Conference, February 1996

seen in the preceding section, the effects of climate change are not evenly distributed either. Neither is the potential for adaptation to these effects. The possibilities to adapt to the changes will to a large extent be decided by level of economic development. As seen in section 4.3, climate change will have the highest impact in areas in the developing world. These are generally also the most vulnerable countries, with the least potential for adaptation. We may conclude that, in general, countries that contribute most to climate change (up till now mainly the developed countries) will experience the least negative impact of the process while on the other hand, the impact will be greatest in the developing countries, which contribute least to CO2 emission in an absolute as well as a relative sense. IPCC Working Group III (summary for policymakers, p.6): "Many developing countries are in relatively hot climates, depend more heavily on agriculture, and have less well developed infrastructure and social structures; thus, they may suffer more than average, perhaps much more." There is thus a serious imbalance between causes and effects on a national (and macro-regional) level and this means that there are serious differences of interest in dealing with the problem. The fact that the developing countries are not only the most vulnerable to the potential effects of climate change but also, because of their limited economic and political power, lack the means to exercise tangible political pressure on the nations that are the main contributors to the process, only aggravates this imbalance and poses an extra barrier to a short term solution.

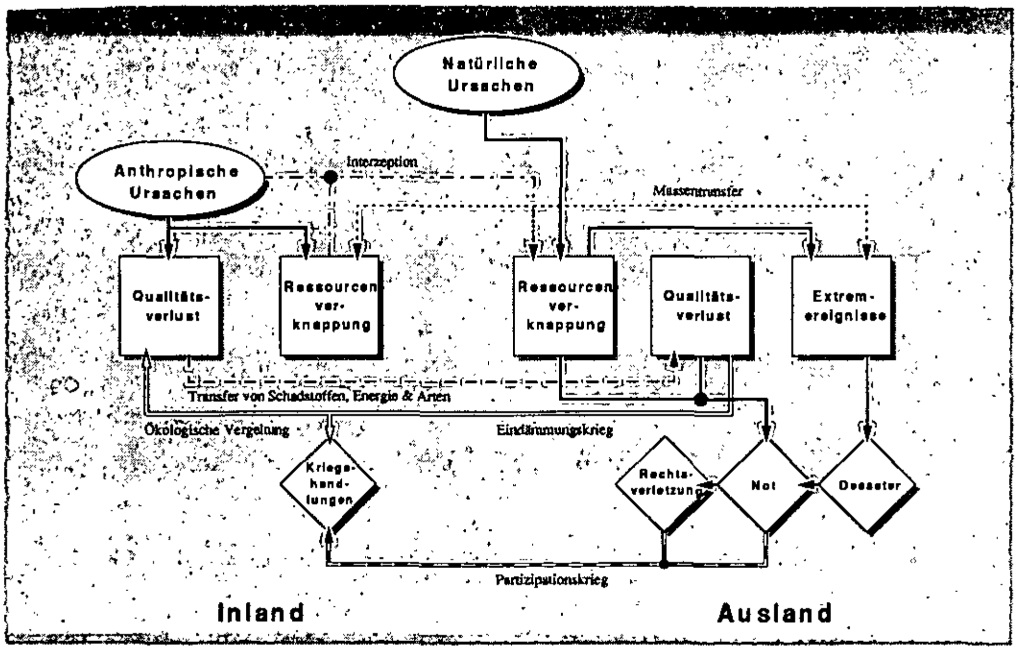
5. REGIONAL ARENAS AND ENVIRONMENTAL CONFLICT POTENTIAL

5.1 Introduction

Despite all changes in the direction of increasing interdependence at the planetary level, the mutual salience of most social actors is still much more restricted. Social conflict is therefore generally restricted to arenas that are much smaller than the global level. This does not preclude interventions by a few of the largest powers all over the world. It is our contention that this also applies to eventual conflicts that result from environmental changes after global change. In this section we first deal with the different ways in which environmental change may condition conflict (5.1). Social actors, however, are not merely passive accepting parties in dealing with environmental change. Some of them are better able to cope with such changes than others. We will argue that democracy and level of development are important factors in this context. Section 5.2. will provide a more detailed outline of this train of thought. Subsequently, section 5.3 will turn to the effects and conflict potential of gradual changes in freshwater availability, of the rising sea level and of weather extremities in relation to freshwater availability. In section 5.4 we turn to the gradual and 'weather extremities'-effects of climate change on food availability. Globally, both water and food supplies are sufficient. But freshwater and food are not evenly distributed around the world's countries and populations. Water shortages and food shortages are regional problems, already now, and this may be aggravated by changing climate. Finally, in section 5.5 we will turn to the issue of environmental refugees, as a potential climate change-induced cause for conflict. To cite the Intergovernmental Panel on Climate Change (1990): "The gravest effects of climate change may be those on human migration as millions are uprooted by shoreline erosion, coastal flooding and agricultural disruption. Geographical macro-regions of the world, individual countries and parts of countries differ as to susceptibility, vulnerability and consequently the probability that their populations and political leadership will take effective measures against (the consequences of) climatic change. Susceptibility refers to the likely physical and human changes as a result of a particular threat, when no adaptation or prevention measures are taken ('business as usual'). Vulnerability refers to the capacity of a social actor to take measures to prevent or cope with these changes. When there is a combination of a threat, on account of high susceptibility, and high vulnerability due to the inability to react, environmental insecurity of the first type grows (Buzan 1991). Increasing threats of this type may result in increasing chances of violent conflict (environmental insecurity of the second type) in several ways. First of all, environmental degradation decreases the resource base of social actors. They become anxious to compensate for their losses by conquest of neighbours' assets and/or vulnerable to threats of violence from other social actors. This may happen in the international arena, primarily between adjoining states (in security regions as they have been called, Buzan 1991) as well as in the intranational arena between organized groups. An example of intranational conflict of organized groups at least partly based on issues of resource distribution is the civil war in Rwanda. Obviously in both cases there is no evidence that environmental degradation originated in global change. A diminished resource base may also result from a change in flows of precious environmental assets across boundaries, e.g. international rivers or groundwater streams. We will deal with these situations in category four where we specifically focus on the consequences of external effects. Secondly, improvements of the environmental condition in which a social actor (a state or otherwise) finds himself, may in theory also increase the chances of violent conflict. This is because significant changes in the distributions of power increase uncertainty and thus create some of the prerequisites to go to war. When power grows, some of the barriers to resort to war subside and the uncertainty may drive in the direction of the sorting out of differences by violence. When the power of others grows, it may be deemed urgent, even vital, for longterm survival to start preventive action, so that expected future power disparities will not be misused by the rival. Such considerations are important in the interpretation of patterns of warfare (Goldstein 1988, Houweling & Siccama 198.). They have so far not been used in connection with differential environmental change, not to speak of possibly differentiated effects of global climate change. One can imagine such shifts in power distribution as a result of more gradual aspects of climate change or as a consequence of the incapacitating impact of weather extremities. As in the previous case, a stronger power position may also result from beneficial developments in transboundary flows. This again will be further discussed under external effects in category four. Thirdly, environmental change may also result in a collapse of the social order and thereby in violent conflict. In the short term this is the major risk resulting from weather extremities like hurricanes and droughts. Changing frequencies of such extremities result in changing probabilities of such collapses. In the longer term, if global change would slowly undermine major environmental conditions and social actors are slow to respond, similar social collapses might ensue. The most vivid example that comes to mind results from sea level rise. In general it is of course difficult to differentiate between conflicts over distributional issues and conflicts resulting from the collapse of order-maintaining mechanisms. In our view the distinction is nonetheless important. Finally, environmental degradation may condition violent conflict as a result of external effects. In one sense this is merely a specification of conflict over distributional issues. Where environmental resources are shared and one party is struck by environmental change that translates into diminution of the availability of precious assets for the other party (e.g. degradation in precipitation levels in the catchment area of the upstream part of an international river and decreasing quantities of water for the downstream country as a consequence) - and perhaps a relatively stronger position for the upstream part - a new round of conflict on the distribution of the remaining water may easily be touched off. In another sense this is a different causal chain altogether. Where environmental degradation on the territory of one actor results into negative consequences for other social actors, conflicts may arise over these external effects. This is the case when environmental refugees become a bone of contention between the sending and receiving countries. In addition, the settlement of environmental refugees in itself also results in different problems, some of them directly connected to distributional issues concerning the environment in their new settlement (how to allocate resources between the resident population and the newcomers), some of them connected with a collapse of the social order. In the case of the Rwanda refugees in the surrounding countries and particularly in Zaire, all these secondary consequences do occur at a large scale. In short, violent conflict may follow in several ways from environmental change. Parties may be moved towards a serious conflict mode through changing distribution of assets as a result of diminution or expansion of resource bases, or through the breakdown of order as a result of environmental degradation, or through the external effects of environmental degradation. Relevant social actors may be states, but also other social groups. Many of these assertions are based on general views in the literature on international relations and conflict behaviour, and still have to be studied for the environmental sector specifically. If, at the regional scale, one would try to build international regimes to cope with the conflictuous issues resulting from global change and the ensuing environmental damage, the same problems that we encountered at the global level would again come to the fore. Free-riding efforts would have to be encountered where a collective good definition of the situation would be proposed. When one would perceive the situation in terms of winners and losers it would be more difficult to find common ground in the first place. The regional level limits the scale and the number of parties and thereby makes free-riding more difficult. But the effects of a regime can not entirely be internalized (there are always arbitrary decisions about who is in and who is out given the partial overlap of politically and physically coherent entities) and there will therefore always be ground for conflict with outsiders. Some experience with international regimes in the environmental sector at the regional level has already been gained, e.g. as regards cross-border air pollution in Europe (Sjöstedt, 1993). The causal chain from global climate change to the assumed differential environmental degradation has still to be backed up by evidence. In the following paragraphs we skim the literature in search of bits and pieces of evidence for the preceding argument and of possible specifications and extensions of the argument itself. Tromp (1995), following Gleick (1991), groups potential threats to international security emerging from conflicts about resources or from other environmental factors, into four categories: resources as strategic goals, attacks on resources, the environment as a weapon and destruction of the environment. The first category concerns the denial of access to resources by others (states, regions, population groups) and attempts to gain these resources for oneself. Examples are the conflict-promoting role of accessibility to the water of the Jordan between Israel and its neighbours and that of the river Nile between Egypt and Ethiopia. Denial of access to particular resources may be following from already existing political tension on other subjects (e.g. caused by action as in category three), but it may also be the primary cause for political tension and conflict to develop. The second category, attacks on resources, refers to the possibility that the environment by the destruction of particular goals (e.g. dams, nuclear reactors, pipelines) becomes a strategic target during war. Environmental degradation or resource depletion in this context is thus not a cause of war but a result, possibly with consequent security impacts. Third, the environment as a weapon refers to manipulation of the environment to put pressure on a conflicting party. An often cited example is Turkey's indication that it would use the Atatürk Dam to restrict the flow of the Euphrates' water to

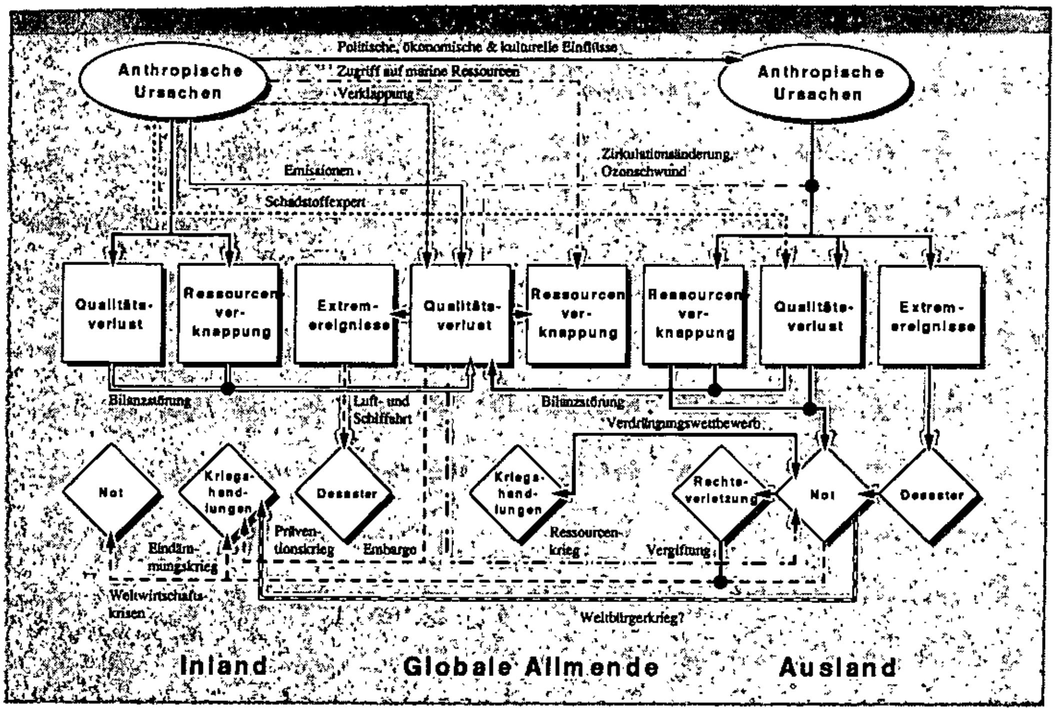
Syria, in order to press this country to withdraw its support for Kurdish separatists in Eastern Turkey. It seems that this category can hardly be separated from category one. Destruction of the environment is classified as a fourth category. The major difference with the preceding categories is that contrary to these three, destruction of the environment has no rationale but simply happens because of negligence, ignorance or short-run self interest (examples: acid rain, soil erosion, greenhouse effect). Environmental degradation will result in unrest, political disturbances, confrontation and revolutions and ultimately in some form of political violence. These four categories apparently extend our preceding repertoire of relations between the environment and violent conflict. They underline that resources - to deny the use to others, to appropriate them to oneself, to destroy them - are occasionally the target or aim of violent conflict (as in cases one and two). Environmental degradation may in this connection even be the consequence of violent conflict rather than the cause (case two). The conduct of war may result in serious environmental consequences thus reversing the causal arrow. In fact, this seems to be the main thrust in the literature. In Middleton's recent textbook on environmental issues (London 1995), for example, the chapter on war is 90% concerned with the environmental impact of war and 10% with the environmental causes of war. Because in this programming study we discuss environmental degradation as a potential cause of conflict rather than as a possible effect, this relation seems not in place here. Tromp's case three overlaps with our earlier case where external effects of resource degradation may result in conflict. It is now stressed, that these external effects can of course be manipulated to press a rival. The emphasis in all these cases is on the environment as one item in the deliberations of contenders, less on the environment as a general contextual factor that conditions their options. This is only addressed in case four that thereby recaptures our earlier, general perspective but does not add to it. Gleick (1993, pp.108-110) in addition mentions in this context inequities and new water developments (like the construction of dams) disturbing existing use patterns as conflictuous issues quoting examples from India, Egypt/Sudan and Mexico/US. Homer-Dixon et al (1993, p. 17) report on the relation between environmental change and violent conflict on the basis of a project with 30 comparative case studies. They argue that many of the currently threatened renewable resources like the atmosphere and the oceans are held in common and are therefore unlikely to be the object of straightforward armed clashes. In their view, scarcities of renewable resources often produce insidious and cumulative social effects, which can in their turn trigger clashes between ethnic groups or civil strive and insurgency. In other words, scarcities can set the stage for conflict but are not very likely to be the direct cause of the conflict themselves. In their description of the causal chain between resource depletion and conflict as a final outcome, Homer-Dixon et al. incorporate a number of intermediary factors and processes. In their view, a combination of decrease in quality and quantity of renewable resources, population growth and unequal resource access may - via consequences like migration and decreasing economic productivity - indirectly lead to weakened states, ethnic conflicts, deprivation conflicts and coups d'état. Decreasing availability of resources like water and food enhances the possibilities for political unrest and destabilization, which in its turn is a fruitful soil for potential tensions and conflicts of non-environmental nature to be mobilized and possibly escalate. Homer-Dixon et al. have produced a very useful outline for a model of resource related violent conflict. They stress the multivariate nature of such a model and the forces additional to resource-related factors that drive such a model. With respect to our earlier efforts at classification they particularly stress the importance of the breakdown of social order as an intermediate factor and thereby the importance of intra-national conflict plus the external effects of these (boundary-transgressing environmental refugees). However, there is in this overview hardly any link between the processes of global climate change and environmental degradation. Finally, the assertion that many of the threatened renewable resources are held in common can be questioned to some extent. The extension of state territories into the adjoining water incorporating a zone of up to 200 km. (according to the current Law of the Sea) has already resulted in conflict between neighbouring states and users of such waters. States are also adamant in protecting their airspace. These zones of contention may well give rise to 'straightforward' conflict, particularly with respect to property and use rights and consequently demarcation. Schnellnhuber and Sprinz (1995) also provide several schemes that try to analyze the causal relations between environmental changes and potential conflict. As mentioned (section 4.2) they make a distinction between crises that are the result of selfinduced environmental degradation; crises induced by external, boundary-transgressing effects caused by neighbours; and of crises induced elsewhere or on a more global scale, like the eventual consequences of global climate change. Regarding environmental problems caused by global factors, like climate change, they distinguish the (in their view all rather improbable) theoretical conflict possibilities of preventive wars (to forestall further damage by others), limiting war (Eindämmungskrieg; to keep damage to limited territories), and global civil war (Weltbürgerkrieg) as a result of a worldwide collapse of the state system and its social orders. They estimate the chances of such events as extremely remote. Tensions on account of reduced availability of water and food (partly following from water shortages) belong in these authors' classifications to self-induced or neighbour induced crises. The respective charts are reproduced as figures 5.1 and 5.2.

Figure 5.1 Transnational security risks as a result of environmental crises caused nearby



Two points require further comment. In both of the above figures, Schellnhuber and Sprinz have included 'extreme events' and concomitant hazards as a separate type of consequences of environmental change, with a different impact than the gradual resource depletion and degradation itself This recaptures the distinction we made in section 1.3 of this report. Although the crises modeled in these figures may to a large extent be ascribed to local factors or external effects imported from the neighbours, it should be repeated that in principle global climate change has different local ramifications and thus can also give rise to these conflict configurations. An inhibiting problem to the analysis of the precise nature of the relation between climate change and regional conflict formations is the lack

Figure 5.2 Transnational security risks as a result of environmental crises caused at a distance

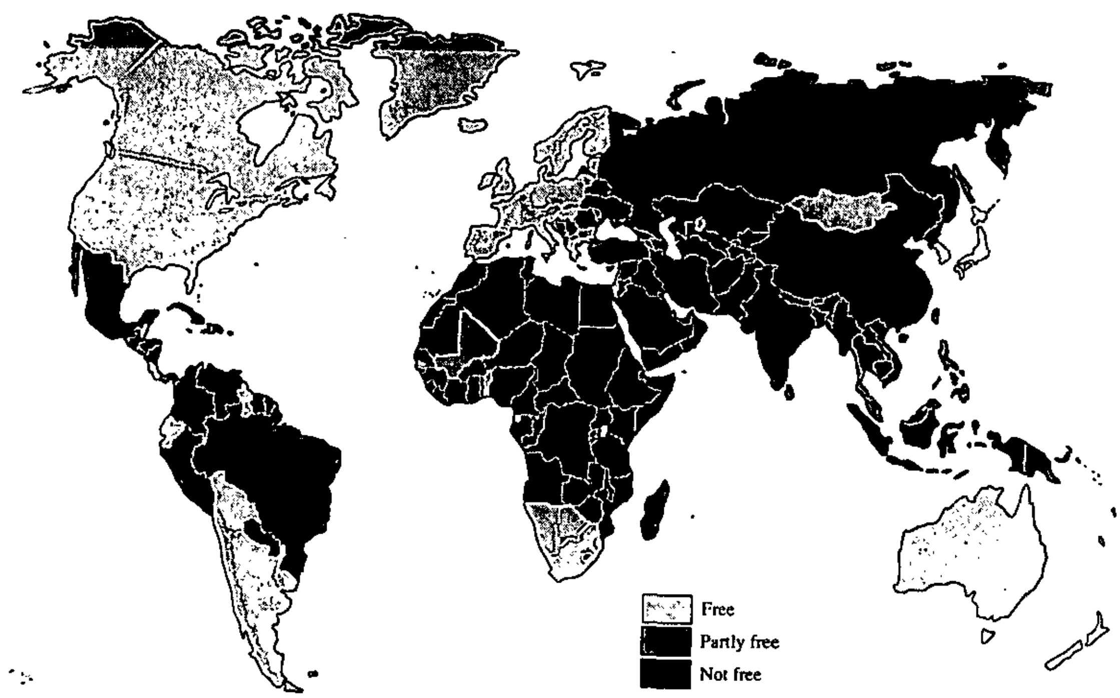


of detailed data. Not only data concerning the winners and losers in case of global warming (section 4.3) but, moreover, data and knowledge that enables us to separate the physical (and possibly: security-) effects of climate change per se, from that of other types of environmental decay. Climate change must to a large extent be regarded as an additional environmental factor, that may strengthen and aggravate (and in some places: soften, compensate) the environmental consequences caused by other environmental processes.

5.2 Democracy, development and the risk of violent conflict

In the preceding section we concentrated on the susceptibility of groups, countries and macro-regions to violent conflict that might ultimately emanate from global change through environmental degradation or improvement. In this section we indicate possible conditions of differential vulnerability. Vulnerability, not primarily as the lack of capacity to cope with the physical changes (these were already treated in chapters 2 and 3) but particularly as the lack. of capacity to cope with ensuing conflicts. We argue that governmental legitimacy, backed up by administrative capacity, plus a strong democratic ethos and the accompanying wide-ranging civil society, plus the international ramifications between pairs and larger groups of such states are the best conditions to prevent the deterioration of conflict into violence. In addition, it may well be that socio-economic development level has an additional, independent effect in this regard. Some caution is in order here, because socio-economic development is highly related to stable democracy. Nevertheless it makes sense to specify its potential contribution to the success of mechanisms for preventing and managing conflict: the empirical relation is by no means perfect (India is a democratic and developing country), and the current wave of democratization may diminish the relation between socio-economic development and democracy even further. First of all we deal with the chances of social order breakdowns, e.g. as a consequence of weather extremities and the concomitant disruptions of water and the loss of vital food supplies. Under such hazardous circumstances, the legitimacy of government is of great importance. Legitimacy provides mutually accepted frames for action. Under modern circumstances there is no alternative provider of such order available. The legitimate authority of state government may result from different sources (Weber distinguishes traditional, charismatic and rational forms of authority). In order to cope effectively with natural crises a large component of rationality from the side of the administrative authorities is indispensible. Particularly in cases of considerable and unanticipated stress this is not sufficient. Under these circumstances, it is necessary that in addition there are many centers of initiative within society that act at their own initiative and are able and willing to coordinate those initiatives with other citizen initiatives and with the efforts of state authorities. The continuous adaptations that occur under the circumstances can only be executed on the basis of an existing rich network of social relations and a basic trust to engage in common action with unknown people. These attributes describe civil societies. They are the necessary basis of a democratic polity (Putnam, 1993). Civil societies are based on widely shared value orientations in populations that are probably induced by the systems of rule under which they live. The more precise conditions for civil societies to flourish are still poorly understood. Social breakdowns result from sharply declining legitimacy (quite possibly by administrative failure) and by a lack of civic capability. Is there an additional relation of social breakdown to level of socio-economic development? Higher levels of socio-economic development are generally accompanied by more pronounced division of labour. As an overall relation one may assume that the less pronounced the division of labour, the larger the capacity to fall back to a survival strategy of a primary group (e.g. the family). This would imply that in poorer countries survival strategies by primary groups have more chances to succeed. The question in this paragraph, however, is to what extent such survival strategies limit the chances of violence. The answer is unclear. It is apparently connected to the form distributional conflicts take and these will be dealt with in the next paragraph. Severe shocks to the social pattern by sudden survival threats can be countered by common efforts to cope or by an at least temporary fall back to coping strategies of primary groups (e.g. families). It may well be that the political conditions mentioned in the preceding paragraph (civil society, democracy) primarily set the terms for common efforts to cope with the situation, while the degree of social division of labour indicates the capacity for (short term) primary group survival strategies. How this capacity translates into levels of violence remains to be seen. Secondly, we deal with the chances of violence resulting from distributional conflicts, that may emerge as the outcome of environmental degradation because of global change. In our view, a democratic polity provides the best chance to prevent bloodshed in intra-national troubles. This has one basic reason: in democratic polities issues tend to be solved by compromise, as no party can be sure of enduring predominance and actors can afford to lose. This assumes, however, that democracy is stable, which in particular in case of 'new democracies' is difficult to determine. Moreover, the relation between democracy and peaceful (intra-national) conflict resolution is not entirely unambiguous, because democracy also provides more opportunities for potential conflict formations to materialize. However, on balance the chances for peaceful settlement are probably greater in an 'open' democratic setting. As regards international conflict, one of the few regularities that has so far pretty well stood the test of the empirical record is the absence of warfare between two democratic polities (Gleditsch et al., 1992). The explanation for this statistical relation is still far from clear. It emphatically excludes pairs with one democratic polity (e.g. Israel and some of its Arab neighbours, a highly relevant combinations for this subject matter, leaving the question what party is to blame for the violence unresolved). It has been suggested that intensive, wide-ranging interaction between such democratic polities resulting in complex interdependence might act as an additional inhibiting factor. This seems also to be in accordance with the data (Gleditsch et al., 1992, Russett 1993). In some ways this thesis of a peaceful realm of democracies, connected by peace-enhancing international trade and other contacts, recuperates the old Kantian ideal of eternal peace. It also links up with the notion of a security community as a set of countries who have banned violence from their mutual repertoire of action (not necessarily against outsiders), inspired by shared value orientations (Deutsch, 1957). What about the relation between socio-economic development and distributional conflict? There are three views concerning this relationship. The first one argues from grievances and sees conflict as engendered by efforts to remedy those grievances. In that view, low socio-economic development enhances the chances for conflict and ultimately violent conflict. This basic view also comes in more sophisticated guises. Grievances are then considered not to be based on absolute properties (e.g. real scarcities) but are the result of comparisons. These feelings of relative deprivation may result from disappointed expectations in relation to a norm, in relation to one's own history or in relation to others. A second view argues from another position. It concentrates on parties' assets that are available to engage in conflict. Viewed from this perspective, socio-economic development provides increasing means of violence and thus heightens the risk of violence. However, socio-economic development also provides extra other means. It is by no means sure that parties will more frequently use violence as socio-economic development increases. They have a wider repertoire of actions at their disposal. This brings into play a third view, that considers this problem from a more clearly cultural point of view. As socio-economic development increases and the division of labour gets increasingly complex, people are forced into more civilized behaviour by the multitude of situations in which they have to engage with relative strangers and they learn to control their primary emotions. 'Civilized' in this context means 'more restrained' and this results in the renunciation of violence. This third view originates in a longterm perspective on the course of European history. It is ironic that it was first proposed by a German refugee (Norbert Elias) just before the outbreak of World War II. It is obvious that widely diverging perspectives have been brought forward concerning the relation between socio-economic development and the ability to control violence. We are not in a position to choose between these perspectives with respect to the chances of violence in environment-induced distributional conflicts. As regards democracy, an additional observation should be made. Democracy is probably not only more effective in peacefully dealing with the effects of environmental change (e.g. water or food shortages as a result of global change, i.e. solving the distributional problem), but also in preventing these effects to take an irreversable character. Fukuyama (1992, p.114-115) notes that as a whole, democratic political systems reacted much more quickly to the growth of ecological consciousness in the 1960s and 1970s than did the world's dictatorships. The legal right for local communities to protest, the freedom of watchdog organizations to monitor the behavior of companies, and the larger chance of whistleblowers from inside organizations thanks to a less repressive general climate of opinion, provides the necessary feedback for governments to balance the interests of different parties (companies, population) within its national borders. In particular the communist world's "truly abysmal environmental record" makes Fukuyama conclude that "what is most effective in protecting the environment is neither capitalism nor socialism, but democracy" (Fukuyama 1992, p. 114). This comparison should obviously not detract from the fact that democracies so far have not been particularly successful in preventing environmental degradation. A major problem with assessing the role of 'level of democracy' on the peaceful management of climate-indiced changes in water and or food availability or quality in given areas, is that these effects will occur at some future date. As we mentioned we have great difficulty to indicate the stability of democracy for current regimes, which is nonetheless indispensible to act as earlier indicated. We simply do not know whether and when particular countries or regions will be democratic or not, and to what extent. The present situation can only serve as a point of departure and indicate if there are allready well-rooted democratic values and institutions in particular countries at this juncture (figure 5.3). Finally it has been suggested that population density might be a violence inducing factor once conflict is underway. This factor has to be treated with caution. First, it may run counter to the idea of increasing restraint as a consequence of more civilization and its material conditions. Secondly, population density interpreted as a proxy for pressure on resources suffers from a high degree of imprecision. Resources are at best only very roughly indicated by land surface. Even in case of the resources that are primarily implicated in the environmental conflicts that are the issue here, land surface is only a very rough approximation of the variable that should apparently be measured. This does not preclude that further study might uncover significant relations, but the intended relation has to be specified, as is the unit of measurement.

Figure 5.3 The free and not-so-free world, 1993



Source: The Economist, 27 augustus 1994

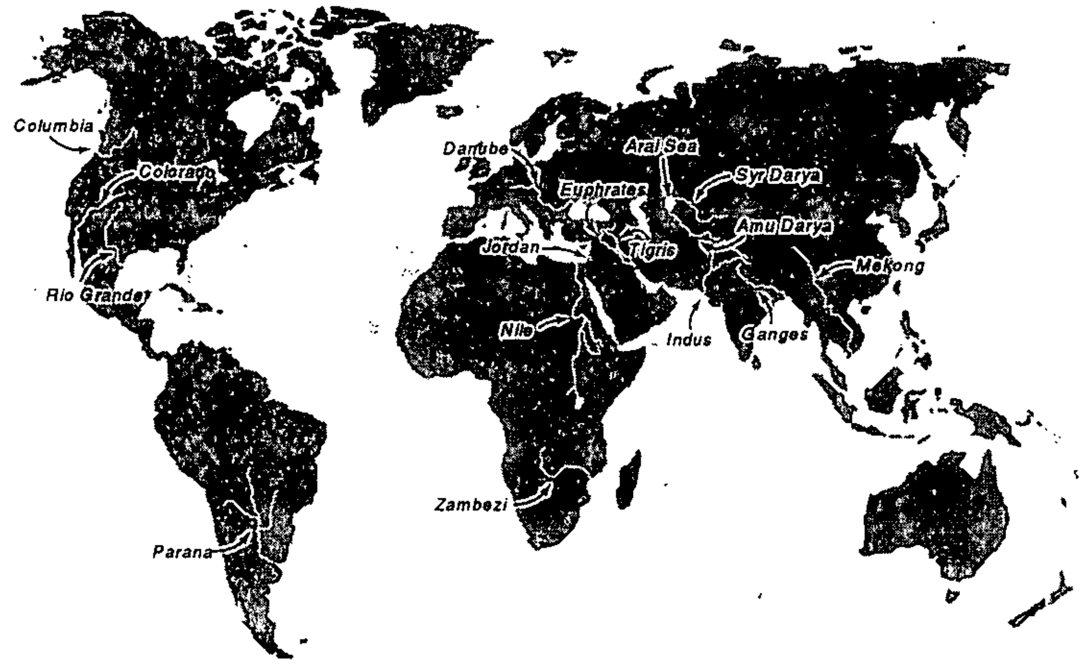
5.3 Water

The earth is a wet planet. A large part of the world's surface is covered with water. The global water cycle approximately involves 1380 million cubic kilometers of water (Yearly 1995, p. 217-218). Nearly 98% of this is salt water, held in the oceans. More than two-thirds of the remaining freshwater is retained in ice or permafrost and the remaining volume of fluid freshwater for almost 99 percent consists of groundwater (Natuur & Techniek 1996, p.17). The available freshwater thus amounts to only a very small part of the total water volume on this planet. However, precisely this part of the total water volume is and may increasingly become the subject of intra- and international competition and, ultimately, violent conflict. Global change may be one of the factors that contribute to a reduction of available freshwater and thus to the chances of this type of conflict. Under conditions of global change, several aspects of the water cycle may alter. The balance between evaporation and rainfall may change, with regional variation. This may particularly affect the conditions of agricultural production but also the availability of freshwater for human consumption and industrial purposes in certain locations. As discussed earlier, the change in water availability, and the effects of global change more in general, may regionally vary. They may be either advantageous or detrimental, referring to the issue of winners and losers (see section 4.3). Glaciers and polar icecaps may melt and as a consequence change the waterlevel and flow of glacier-rivers and cause a global rise of sea-level. In this section, we try to grasp the ways in which a change of water availability, caused by climate change, may contribute to national or in international political tension and, ultimately, violent conflict. First of all, we will discuss the possible security effects of a gradual change in freshwater supply in particular areas (section 5.3.1). Secondly, we will discuss the possible security impacts of a gradual rise of sea-level for coastal countries (section 5.3.2). Although both problems are related to a change of waterconditions and both concern a gradual process, changing freshwater availability and sea-level rise are obviously processes of a totally different nature. Both are unlikely to cause violent conflict themselves. They may, however, provide or strengthen the setting in which other issues or events become the 'trigger' for escalation, or act as the trigger in situations where other issues already provided the basis for conflict. After these two gradual phenomena and their potential security consequences we will turn to the security risks that follow from sudden changes of freshwater availability (5.3.3). These may occur as a result of weather extremities (droughts, hurricanes, floods), the frequecy of which will possibly rise in the wake of global warming.

5.3.1 Gradual changes in freshwater availability

Globally, fresh water is abundant. The World Development Report (1992, p. 48) states that each year an average of more than 7,000 cubic meters per capita enters rivers and aquifers. This is a substantial volume, as 1000 cubic meters per capita is commonly regarded as the level below which water scarcity is regarded a severe constraint. In this context, the World Development Report rightly notes that water "does not always arrive where and when it is needed. Already now, freshwater scarcities in some parts of the world are the subject of political stress and conflict. On the national scale, regions and economic sectors sometimes compete for use of the available water supply. Globally, 66 percent of the freshwater supply is used by agriculture, 25 percent by industry and 9 percent for human consumption (Mansbach 1994, p.521). Industrial and agricultural interests already now compete with the use of water for human consumption in such diverse areas as Israel and California. During the severe drought that struck California early in the 1990s, cities like Los Angeles had to compete with influential agricultural interests for diminishing water supplies. Only after a long struggle were limitations placed on agriculture's extravagant consumption of water (Mansbach 1994, p. 521). This kind of intra-national problem of sectoral distribution will in many cases also have a regional/geographical dimension. Freshwater may also be the subject of international competition and conflict. When freshwater availability for several countries is dependent upon one or more shared riverbasins or underground waterflows, any change of water supply, whether by 'natural' causes (change in rainfall, rising temperature) or by human action (building of upstream dams, drilling wells, diverting the waterflow by upstream states) puts the issue of water distribution on the political agenda. Population growth and increasing irrigation are major factors behind the water scarcities that, according to a common perception, will become increasingly serious in the next century. According to the World Bank, an amount of 600 billion US Dollars must be invested in developing countries between 1995 and 2005 to avoid severe water shortages (The Economist, february 24th 1996, pp. 69-70). Current water shortages are not caused by climate change but they could well be aggravated by increasing droughts in the wake of global warming (Myers, 1995, p. 42). A possible decrease of the volume of freshwater supply as a result of global warming will aggravate existing scarcity problems in some places and may contribute to new scarcities in other places. A change in the availability of shared freshwater brings differences of (sectoral, regional, national) interest immediately to the fore and puts the distribution issue (again) on the political agenda. Changing water conditions - whether detrimental or advantageous - may also affect the international distribution of power and thus destabilize international relations in a particular area. In short, a change in the (international) availability and distribution of water may cause political conflict and ultimately violent conflict, along the lines set out in section 5.1. As regards international rivers, several cases are the subject of international dispute already. Donkers (1994, p.22) lists fifteen international rivers in Asia, Europe and the America's that are or have been the subject of serious conflict. Thus far, these disputes have not reached the violent stage. On the other hand, many authors have cited the Six Day War in

Figure 5.4 Conflicts concerning international rivers



Source: Donkers 1994, p.22

1967 as an example of a violent conflict that was at least partially triggered by water problems, i.e. the dispute regarding distribution of the water of the Jordan River basin, shared by Israel, Syria, Lebanon and Jordan (Falkenmark 1986, Homer-Dixon et al. 1993). More in general, controversial water issues have helped to block any peace agreement in this area since 1947. Rivers were also said to be involved in the Lebanon conflict and the Israeli incursion of Lebanon in 1982-85 (Falkenmark 1986). The Jordan is not the only Middle East river that is the subject of dispute. The conflict between Syria, Iraq and Turkey over water from the Euphrates River is also very volatile, as is the dispute between Egypt, Ethiopia and Sudan, which with six other countries share the waters of the Nile River basin. Many observers and politicians have stated that water shortages are increasingly likely to stir political tension or crisis in the near future. The World Bank vice-president Ismail Serageldin predicted that the wars of the next century will be fought over water instead of oil or politics (The Guardian; Dutch translation in de Volkskrant, August 12th 1995). UN secretary general Boutros Ghali, then deputy minister of foreign affairs of Egypt, remarked that if there would be another war in the Middle

East it will probably be over the River Nile (ibid.). More recently, preceding the 1996 Habitat Conference the UN stated that water crises 'will increasingly loom' (International Herald Tribune, March 20th, 1996). Where and when such crises will occur and if water shortages and disputes around internationally shared river basins will indeed escalate into violent conflict, remains a matter of speculation. We can however, on the basis of the preceding arguments, indicate where the chances for water conflict, partly induced by global change, are highest: in areas whose water supply is dependent on an internationally shared river basin, where freshwater is already scarce and where global warming is expected to have a substantial deteriorating effect on the water balance (rainfall, evaporation). A so far rarely discussed case in this context is that of Bulgaria, under increasing pressure for fresh water, and the other users of the Danube (GeoJournal 1997). The chances of escalation of water conflict into violent conflict are probably highest in regions that lack a stable and well-rooted democratic tradition and where the level of economic development is low. The chances of peaceful settlement of such water conflicts are highest in places where these conditions are present. At least 214 of the world's rivers flow across more than one country (United Nations; cited in Donkers 1994 and Falkenmark 1986). 155 of these are shared between two countries, 36 among three countries and the remaining 23 among four to twelve countries. Competition for water will be most intense around river basins that are located in arid areas, where evaporation is highest and where the population grows at a fast rate. Falkenmark (1986, p. 98), has selected a number of developing countries with at least 75 percent of their area in international river basins and a populations that will double in 25 years or less, or a population density of at least 100 persons per square kilometer. A selection of this type remains rather arbitrary when predictions of serious conflict are the purpose, because political conditions are not taken into account (economic condition are, as Falkenmark limits her selection to developing countries), but it nevertheless provides some insight in the broad location of potential problem areas. Of the sixteen countries mentioned in the selection (see Table 5.1), eleven are in Africa, two in Asia, one in the Middle East, and two in South America. It is difficult to predict if, where and when water conflicts will really emerge. We can, however, identify regions and countries that face water shortages already now, at least at the general (national) level. In the wake of increasing drought, caused by climate change, these countries are the most susceptible to serious scarcities.

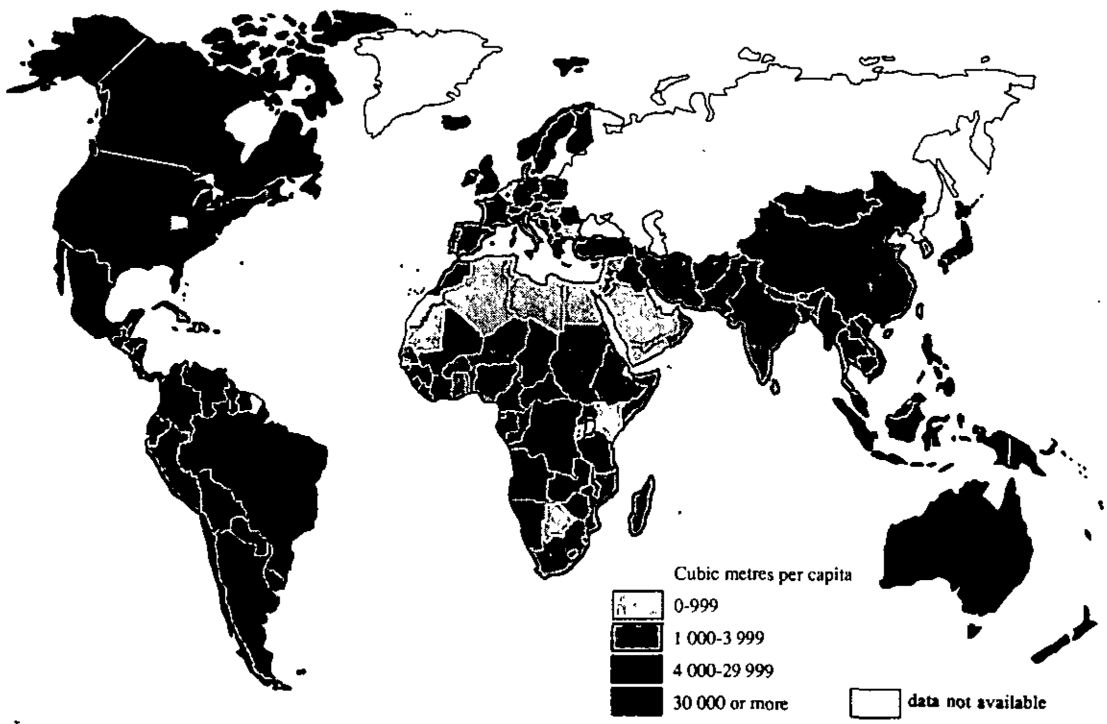
Table 5.1 Selected countries domained by international river basins

Country	Number of international river basins	Area in international river basin(s) (per cent)	Population density in 1980 (persons/km^2)	Cereal production in 1980 (kg/capita)	Population doubling time (years)
Bangladesh	3	86	613	246	24
Burundi	2	100	146	73	44
Ghana	3	75	48	54	22
Iraq	2	83	30	168	19
Malawi	2	96	50	222	24
Nepal	2	100	104	259	29
Nigeria	5	87	87	121	20
Paraguay	1	100	8	224	21
Rwanda	2	100	195	51	21
Sudan	5	81	7	157	22
Swaziland	3	100	32	188	24
Uganda	2	100	56	82	21
Venezuela	6	80	17	105	20
Zaire	3	99	12	28	24
Zambia	2	100	8	185	22
Zimbabwe	5	100	19	269	21

Source: Falkenmark 1986, p.98

Where are water scarcities already apparent? According to the World Resources Report 1990-1991 (Table 22.1, pp.330-331) twenty-seven countries already have renewable water resources of less than 1,000 cubic meters per capita per year. This level is commonly taken to indicate that water scarcity is a severe constraint. Of these twenty-seven countries, fifteen (nearly all situated in North Africa and the Middle East) have less than 500 cubic meters per capita, which according to Falkenmark & Lindh (1993) indicates that these are suffering absolute scarcity. In addition to these countries with chronic water problems, another eighteen countries have less than 2,000 cubic meters per capita on average. This is dangerously little in years of rainfall shortage (World Development Report 1992). Obviously, these measures indicate only average yearly supply and in

Figure 5.5 Annual renewable water resources, 1000 m3 per capita, per country



Source: Mansbach 1994, p. 522 [original source World Dev Report 1992]

addition they refer to a high level of aggregation, i.e. countries. Some of the figures are also disputed (e.g. those on Bulgaria as set out in GeoJournal 1997). Detailed knowledge of the geographical distribution of rainfall as well as the distribution of rainfall over time (seasons) is indispensable when serious evaluations of water conditions in particular countries are to be made. Keeping these reservations in mind, we may nevertheless draw some important general conclusions from the above material. Most of the countries with limited renewable water resources are in the Middle East, North Africa and Sub-Saharan Africa. As indicated above, these are also the regions where many countries are dominated by international river basins (Falkenmark 1986). In addition, these are also the regions where populations are growing fastest, which means that under conditions of 'business as usual', pressure on the scarce resource is growing relatively fast. According to the World Development Report, water scarcity elsewhere is less of a problem at the *national level, but it is nevertheless severe in certain watersheds of northern China,* west and south India, and Mexico. Where is global change expected to have the largest effect

Table 5.2 Availability of water by region

Region[a]	Annual internal renewable water resources: Total (thousands of cubic kilometers)	Per capita (thousands of cubic meters)	Percentage of population living in countries with scare annual per capita resources: Less than 1.000 cubic meters	1.000-2.000 cubic meters
Sub-Sahara Africa	3.8	7.1	8	16
East Asia and the Pacific	9.3	5.3	<1	6
South Asia	4.9	4.2	0	0
Eastern Europe and former USSR	4.7	11.4	3	19
Other Europe	2.0	4.6	6	15
Middle East and North Africa	0.3	1.0	53	18
Latin America and the Carribean	10.6	23.9	<1	4
Canada and United States	5.4	19.4	0	0
World	**40.9**	**7.7**	**4**	**8**

[a] Regional groups include high-income economies. Sub-Saharan Africa includes South Africa.

Source: World Resources Institute data: World Bank data. World Development Report 1992, p.48

on water availability and thus on the potential development of water-induced conflict formations? The precise effects of global warming on freshwater availability are unknown and dependent upon a large number of intertwined climatic processes. IPCC (1996) notes that in attempting to quantitatively analyze the direct effects of global warming on water resources demands, we are confronted by an increasing array of uncertainties and analytical difficulties. General Circulation Models only provide outputs on a large geographical scale and do not agree on a likely range of changes in average annual precipitation for any given basin or watershed (IPCC 1996, Summary for Policymakers, p.12). Some areas of the world may be suffering from increased drought while on the other hand others may experience an increase of rainfall. For example, a recent study of the prospects for rainfall in the Netherlands, concludes that a temperature rise of 2 degrees Celsius will cause an increase of rainfall of 22% (Reuvekamp & Klein Tank 1996). The regional effects of global warming on water availability thus remain largely speculative. IPCC (1996) concludes that predicting where water resources problems will occur due to global warming, can only be generalized on a sub-continental scale at this time. High latitude regions may experience increased runoff due to increased precipitation, but lower latitudes may experience decreased runoff due to the combined effects of increased evapotranspiration and decreased precipitation. Water resources in arid and semi-arid zones are particularly sensitive to climate variations because the volume of total runoff and infiltration is low, and because relatively small changes in temperature and precipitation can have large effect on runoff. Expectations are that in particular these areas of the world could experience some of the largest decreases in runoff - hence posing the greatest challenge to water resources management (IPCC 1996). Falkenmark (1986, p. 109) foresees that "the highest levels of frustration that will arise from increasing water scarcities can be expected to develop in Africa (where populations are increasing dramatically and where most of the rivers are international) and in south-western Asia (where populations are also increasing rapidly and where dry-season flow is scarce). Arid or semi-arid regions in lower latitudes are generally also the regions where in many cases democratic traditions and institutions are only weakly developed, if at all (see Figure 5.3). In addition, most countries in these regions are developing countries, which poses an extra (financial) barrier to an effective solution and hence an increased risk to escalation of water-related conflicts. Water can be the trigger that lightens an already existing but latent conflict of another kind or be the main subject of conflict itself. A peaceful solution will generally be more difficult to achieve in an already conflict-prone area. In this context, IPCC 1996 significantly notes that a number of countries in conflict-prone areas are highly dependent on water originating outside their borders (e.g. Cambodia, Syria, Sudan, Egypt, Iraq). To avoid water conflicts, rules and institutions to practice these rules must be available. Water resources must be governed by a doctrine that transcends the exclusively nationalistic approach, on the basis of equity, fairness and peaceful relations. Based on the general principles of international law of international rivers, such as furnished by the rulings of the International Court of Justice in for example the case of the Oder River in 1929, the traditional tool in sharing multinational water resources is a formal agreement among the countries concerned. The practical application of such agreements may be controlled and carried out by a joint river commission (Falkenmark 1986). Falkenmark also adds some problems that may be a barrier to a solution. The most important of these is the problem of defining what is a reasonable or equitable share of an international water resource, in such a way that the disputing nations wil accept this definition. The basic problem is to transcend the conflict between national self-interest and international equity. In Europe, around 175 international water treaties have been established to settle the distribution of the water of several rivers (Donkers 1994). In the Middle East, only one such treaty has been established, i.e. between Egypt and Sudan regarding the Nile River. This indicates that peaceful settlement of potential water conflicts is not equally probable in all regions of the world, and seems to support the democracy-thesis.

5.3.2 Gradual changes in sea level

Global change has a potential impact on the ocean water level as polar icecaps and continental glaciers start to melt when temperature rises. Several models have been developed to predict the impact on sea level of a particular rise in temperature. The outcomes are slightly different but all in all, sea level rise is the one potential effect of climate change for which reasonably robust predictions can be made. Because the location and altitude of coastal areas in the world is known, it is possible to predict what, ceteris paribus, the effect in terms of landloss and affected inhabitants will be when sea level rises with a given amount. Figure 5.6 shows that most of the areas that are susceptible to sea-level rise are in the developing world, although many coastal areas in the United Sates are also potentially threatened. What are the effects when no adaptive measures (e.g. construction of dykes) are taken and where are the most serious effects to be expected? Relevant factors in this context are the size of the flooded area, the presence of economic activities, of cities and of human inhabitants in general. Based on case studies, IPCC (1996) has estimated the number of people affected and the quantity of land at loss, for a selected number of countries, assuming a sea level rise of one metre (see Table 3.1, section 3.1 of this programming study). Small islands, deltaic settings and coastal ecosystems appear particularly susceptible to sea level rise. More than ten percent of the total land surface of Bangladesh, Kiribati and the Marshall islands would be lost. Measured

Figure 5.6 Coastal areas vulnerable to sea-level rise

Source: Delft Hydraulics, The Netherlands

in absolute terms, i.e. in square kilometres, large areas in Bangladesh, China, Japan and the Netherlands would be flooded. In terms of the number of people affected, Bangladesh, China, Japan and the Netherlands would be hard hit. Measured as a proportion of the total population, Antigua, Bangladesh, Guyana, Kiribati, the Marshall Islands and the Netherlands are particularly heavily threatened (more than 50 percent). As mentioned earlier, there is an important difference between susceptibility and vulnerability to sea level change and other climate induced environmental changes. Which of the countries that may expect some part of their surface to flood when temperature rises are the most vulnerable? In other words, what is the probability that effective measures against the damaging effects of sea level rise will be taken? Again, democracy and level of socio-economic development are probably highly important independent variables. Contrary to the case of gradually growing freshwater scarcity (section 5.3.1), level of development is in the case of sea level rise probably of primary rather than secondary importance. Unlike a gradual decrease of freshwater supply, losing a coastal area - in some countries much more - to the ocean is not so much a distributional problem, concerning sectoral of regional differences of interest, but rather a problem of national proportions. In most countries, coastal areas are the centre of trade and other economic activities and some of the world's largest urban zones are in coastal areas. Not only the coastal area itself is threatened but the economy and society as a whole will suffer when the ocean takes its part. On a national and international scale, sea-level rise has no winners (particular companies or economic sectors may benefit). Under these circumstances, serious direct conflicts (of interest) are far less probable than in the case of changing freshwater availability. The problem is less likely to be neglected, even by non-democratic regimes. Barriers against effective measures to counter the effects of sea-level rise will probably be of an economic rather than a political nature. The most likely security impact of sea level rise, when no measures are taken, is social and political destabilization because of refugees fleeing the threatened areas (see section 5.5), either to a national or international destination. The (gradual) inflow of large numbers of refugees will contribute to an increasing pressure on the remaining national physical resources in these settlement areas, and may thus induce distributional conflicts and other types of tensions in these places (see section 5.5). Additional distributional issues in the countries affected by sealevel rise may emerge because of a salinization of freshwater supplies. When effective measures are taken, the costs of these will limit the availability of financial resources for other purposes. At least in theory this may indirectly cause political strain of some kind. This is, however, unlikely to cause violent conflict.

5.3.3 Weather extremities and freshwater availability

The chairman of the Intergovernmental Panel on Climatic Change, professor Bert Bohlin, has stated that "most of the damage due to climate change is going to be associated with extreme events, not by the smooth global increase of temperature that we call global warming" (cited in Myers 1995, p.47-48). Weather extremities like floods, heat waves, droughts and hurricanes cause direct damage (human casualties, destroyed harvests, infrastructure, houses) and may have a concomitant destabilizing impact on the social and political order. National authorities may be under strain and the chances of violent conflict (chaos, plunder, civil war, international war) may increase (see section 1.3). An increase of frequency and severity of this type of events could also affect the freshwater supply because of the destruction of purification installations, the salinization of water supplies after floods, spreading diseases and other events. A decrease of freshwater supply would thus pose an extra strain on the country and population at stake, in addition to the direct impact of the extreme weather event itself. This may possibly enhance the chances for violent conflict. Predictions of the changes in frequency of extreme events are still very tentative. In fact, even consensus as to the possible direction (in- or decrease) of such changes is still missing. IPCC (1996, chapter 12) considers small islands, the lower reaches of big rivers (e.g. Missisipi, Yellow River, Nile) and delta regions in South and Southeast Asia particularly vulnerable to floods. The countries most affected by tornadoes are the United States, Canada and Russia, while tropical cyclones commonly affect South, Southeast and East Asia, and Oceania, as well as Central America, the Caribbean and parts of Mexico and the United States. Agricultural settlements in regions such as Sub-Saharan Africa, Australia, China, Southern Europe and mid-continental North America "are projected to be sensitive" to drought conditions (ibd. p.16). Settlements in the Middle East and North Africa may be particularly vulnerable to drought. As indicated already, the effects of global warming on the frequency and geographical distribution of this type of events are still largely unknown. The arguments that we have already discussed regarding the role of democracy and socio-economic develoment for preventing violent conflict, also apply here. Democracy and socio-economic development are the primary conditions in scenario's that indicate the chances for either peaceful management of the problems at hand or violent escalation.

5.4 Food

Globally, sufficient food is available (Kuyvenhoven 1996). Distributing it to those who need it proves, however, very difficult. Famines in Somalia, Ethiopia and the Sudan have recently shown this to be the case. The per capita consumption of food differs by region and country. In some parts of the world food consumption is outstripping production while in others, a large part of agricultural production is exported. According to Wallensteen (1986, p. 156) food adequacy is at the heart of national security. A threat to the supply of the basic staple food requirements of a country is in this view "likely to lead to conflict". In recent history food prices have regularly led to political turmoil (Poland 1980, Morocco

1984, Tunisia 1983-84) and the overthrow of regimes (Sudan 1985). This underlines the relevance of food supply, whether by domestic production or imports, for political stability. In addition, food can also be used as a political weapon (Wallensteen 1986). Those who have food may extract a political prize from those who need it, and may withhold it from rivals, national or international (Kodras 1993). As is the case with freshwater availability, a gradual decrease of food availability increases the uncertainty of (the quality of) life, stimulates social and political instability and may thus provide or strengthen the setting for (violent) conflict (of interest) to develop. Other issues or events may act as the 'trigger' for escalation or, the other way around, provide the basis on which food shortages can be the trigger for violent escalation of latent tensions. As Wallensteen (1986, p. 153) puts it: "In all societies there exist additional cleavages that relate to food production in only a secondary or derivative sense. To these belong relations between capital and labour, among different businesses, among political organizations, among ethnic groups, and among regions. Such incompatibilitites could become activated or accentuated during a food crisis." The same argument holds for the international stage.

5.4.1 Gradual changes in food availability

Where will agricultural production diminish as a consequence of global warming? In the course of years, many studies have been conducted to estimate the effect of a doubled level of greenhouse gases on agricultural production. However, most of these studies concerned (parts of) developed countries. For countries in Sub-Saharan Africa, the Middle East and North Africa, Eastern Europe and Latin America, the number of studies is far lower. In addition, for most regions, studies have focused on one or two principal grains only. IPCC (1996, chapter 3, p.20) notes that "the studies that have been done strongly demonstrate the variability in estimated yield impacts among countries, scenarios, analytical methods and crops, making it difficult to generalize results among areas or for different climate scenarios". In addition to the limited range and reliability of these studies, the possibilities for substitution, introduction of new varieties, for importing food and other means of adaptation are not included either. This hampers a realistic estimate of where and what will be the impact of global warming on food production, let alone the impact of global change on the chances for a food-related violent conflict (see chapter 2). In which of the countries or regions where agricultural production may be negatively affected by global change, is the availability of food (by production, imports) already

Table 5.3 Basic regional agricultural indicators[a]

	Sub-Saharan Africa	Middle East/ North Africa	South Asia	Southeast Asia	East Asia	Oceania	Former USSR	Europe	Latin America	USA, Canada
Land Area(106h.)	2390	1167	478	615	993	845	2227	473	2052	1839
Agric. Land (%)	41	27	55	36	51	57	27	47	36	27
Crop Land (%)	7	7	44	13	11	6	10	29	7	13
Irrigated (%)	5	21	31	21	11	4	9	12	10	8
Climate	tropical; arid, humid	subtropical, tropical; arid	tropical sub-tropical humid, arid	tropical; humid	sub-tropical temp. oceanic conti-nental; humid	tropical, temp. oceanic subtropical; arid, humid	polar, conti-nental, temp. oceanic humid, arid	temp. oceanic some subtro-pical; humid, arid	tropical, subtropical; mostly humid	conti-nental, subtro-pical, polar, temp. oceanic; humid, arid.
Pop. (10^6)	566	287	1145	451	1333	27	289	510	447	277.
Agric. pop (%)	62	32	63	49	59	17	13	8	27	3
Pop/h. cropland	3.6	3.4	5.4	5.7	12.6	0.5	1.3	3.7	2.9	1.2
Agric. Prod. (10^6t.)										
Cereals	57	79	258	130	433	24	180	255	111	388
Roots and tubers	111	12.5	26	50	159	3	65	79	45	22
Pulses	5.7	4.1	14.4	2.5	6.3	2	6	7	5.8	2.2
S. cane and beet	60	39	297	181	103	32	62	144	494	56
Meat	6.7	5.5	5.7	6.4	39.6	4.5	17	42	20.5	33.5
Ag. (% of GDP)	>30	10-19	>30	20 to >30	20-29	<6	10-29	<6	10-19	<6
GNP/cap. (USA $)	350	1940	320	930	590	13780	2700	15300	2390	22100
1980-91 growth (%/annum)	-1.2	-2.4	3.1	3.9	7.1	1.5	N/A	2.2	-0.3	1.7

[a] Computed from data from FAO Statistics Division except GNP per capita, GNP growth rates, and agriculture as a share of the economy are from World Bank, World Development Indicators *1993* and temperature and climate classes from Ritter, et. al., *1995*. Note: East Asia GNP excludes Japan. Also, regional GNP data generally include only those countries for which data are given in Table 1 in World Development Indicators. Countries with more than 4 million population for which GNP data are not available include Vietnam, Democratic Republic of Korea, Afghanistan, Cuba, Iraq, Myanmar, Cambodia, and Zaire, Somalia, Libya, Angola; land areas are in hectares, production is in metric tones, GNP is in 1991 USA dollars, growth rate in percent per annum.

Source: IPCC, 1996

under strain and/or in which of these countries does agriculture account for a large part of the economy? Because of the relatively high vulnerability of countries with these characteristics, these are, in a very general sense, in combination with the conditions and possible trains of events discussed in earlier sections, the potential conflict areas. According to current IPCC-estimates, many of the populations in Sub-Saharan Africa appear to be the most vulnerable to an eventual global warming and decrease of agricultural production. The region is already hot, large areas are arid or semi-arid, average per capita income is low, over 60 percent of the population depends directly on agriculture, and agriculture generally represents more than 30 percent of the GDP. IPCC also considers populations in South Asia vulnerable, due to heavy dependence on agriculture, i.e. more than 30 percent of GDP in most countries in the region. Many of the at risk populations are also found in Southeast and East Asia, the tropical areas of Latin America and in some Pacific island nations. The earlier discussed arguments regarding the role of democracy and socio-economic develoment for preventing violent conflict, also apply here. The chances for peaceful management of food-related conflict are highest in democratic countries, with a well-rooted civil society and democratic tradition and a relatively high level of socio-economic development. The chances of escalation into violent conflict of food-related tensions are highest in areras where these conditions are lacking. As was the case with freshwater, most of the countries that may be considered susceptible to a deterioration of the food supply belong this category.

5.4.2 Weather extremities and food availability

As changes in food production are to a large extent related to changes in fresh water supply, the impact of weather extremities on food supply, if this can be assessed, runs parallel to that on water supply, which were briefly discussed in section 5.3.3.

5.5 'Environmental refugees'

Among the possible negative consequences of global change, attention has focused on the possibility of huge migration waves set in motion by environmental disasters: "The gravest effects of climate change may be those on human migration as millions are uprooted by shoreline erosion, coastal flooding and agricultural disruption" (IPCC 1990, quoted in

Myers 1995, p. 134). The notion of 'environmental refugee' has been coined to refer to the people struck by such a fate. There are three difficulties with this concept in our present context. The first is the problem, already encountered on earlier occasions in this report, to relate environmental degradation unequivocally to global climate change. We will quote some very tentative forecasts, relevant to the issue of migration, at the end of this section. The second is the relative importance of environmental degradation in the conditions that set the terms for certain migration flows. The third is the use of the term 'refugee'. Migration is as a rule the outcome of complexes of push and pull factors. There is hardly any migration without any pull whatsoever and completely dominated by one overwhelmingly important push factor. It is extreme cases of abrupt, clear and present danger that force people to flee their homes, that come to mind here as approximations of this extreme type. In our context they are the consequence of weather extremities, floods etc., or they result from social order breakdowns and fights in distributional conflicts caused by environmental degradation. Obviously difficult judgments have to be made in less extreme cases as to the relative importance of environmental factors in the decision to move. Similar categorizations have nonetheless been made elsewhere in the migration literature e.g. labour migration. One might in addition consider the possibility that migration flows are moving towards regions struck by positive consequences of global change. In such instances, pull factors would be dominant. The notion of refugee - already disputed in the former example as we will presently see - would be inappropriate altogether. It should be stressed that this theoretical possibility has not been put forward in the literature so far. The term 'refugee' has been introduced to underline the urgent and unavoidable nature of the migration. It is clear that a 'refugee' is a certain category of persons in international law. As codified in the UN Convention of 1951 and the additional Protocol of 1967, refugees are persons who are persecuted, or have a well-founded fear to be persecuted in their homeland, therefore stay in another country and have a right to be protected there. Refugee is also a colloquial term that can be given a broader definition in which fleeing one's home is the key notion. Specified as 'environmental refugee', the agent that causes the flight is indicated. Those who defend the use of the notion of environmental refugee tend to underline that refugee is an evocative, colloquial term and will therefore be readily comprehensible to policymakers and the public. In addition, however, the already existing legal and restricted definition of refugee and the similarities between refugees under international law and environmental refugees, that are pressed by the use of the term, suggest the suitability of similar reactions and policy responses in the two cases. The ensuing debate re-captures the same arguments as those used to defend and attack the introduction of the notion of environmental security set out in chapter 1 of this report (Myers, 1995, pp. 22-23). How can we more specifically imagine the relations that possibly connect global climate change and environmental refugees, and what role could violent conflict play in this instance? We may again start with the assumption of negative environmental consequences of different kinds resulting from global change. They are to be categorized as either sudden catastrophic changes in the physical basis of existence or its gradual deterioration. The outflow of people may be either by trickling out in different directions or by concentrated flows to a single destination, or by combinations of these. There are two possible causal paths connecting degradation to migration. The first is migration as the immediate consequence of degradation. Gradual shifts tend to result in trickles of outmigration as no clear thresholds can as a rule be indicated. A good example is soil erosion by too intensive use that gradually undermines the base of existence of agricultural communities, possibly over generations. Sudden deterioration results in outbursts of migrants. A good example is in some circumstances the lack of rain in a semi-arid environment in the growing season. Immediate consequences of environmental deterioration in terms of outmigration have been dealt with in chapter 3. The second possible causal path connects degradation and migration via the intermediary of violent conflict. Here the idea is that degradation results in either distributional conflict or social order breakdown. We have dealt with this sequence in earlier sections of this chapter. As a consequence people flee the area. This is the train of events especially relevant in this section. There is a follow up to such episodes, that should also be mentioned at this juncture. Particularly when people flee massively (either directly after environmental degradation or via violent conflict) to certain destinations, the chances are that new rounds of conflict emerge. These are first of all touched off by implicated governments as migration flows pass borders. Such flows may set in motion international conflict (e.g. the war between Honduras and El Salvador in 1969, the war between Somalia and Ethiopia in 1978. Either government may also find itself immersed in a massive public order problem caused by the flight of people, that it feels inclined to solve by force (e.g. the efforts to act of what remains of the state of Zaire at the border with Rwanda recently). Once more or less settled, an extensive conflict potential between newcomers and home population may well develop, that encompasses distributional as well as social order issues (this may also happen when people have been displaced within their own country, e.g. China and India). Where state regulation is important, the state again is a party in such conflicts. The way in which they develop is also affected by the presence of democratic means of conflict regulation and by the stakes at issue in distributional conflicts and the means available to fight such conflicts. The structure of these conflicts is highly similar to the clashes between new immigrants and the home population in western cities that have been extensively studied. Some of these incoming migrants can be considered as environmental refugees under a relaxed interpretation of the terms of the concept. There are, however, also important differences with the nature of conflicts encountered in the settings of developing countries where most of the 'environmental refugee' flows now occur. The first is the overwhelming presence of the state in the western situation. The state provides most of the rules as well as many of the stakes that are at issue. In developing countries the state may set some of the rules but it provides definitely less of the stakes. The second is the presence of formal democratic means of conflict regulation that enable parties to mobilize around disputes and finally to come to some sort of often temporary solution to their contradictory claims. The third is the smaller stock of assets over which distributional conflicts are fought and the fewer means available for such fights. This has contradictory implications. Rivalry may be sharper in the case of environmental refugees in developing countries because of smaller pool that can be distributed, but fewer means are available to express such differences of opinion. This may lower the chances of serious conflict. In the remainder of this section we will take a closer look at some recent literature concerning this issue, in particular Myers' (1995) wide-ranging survey of the evidence. We are particularly interested in the train of events proposed in that literature with an eye to the role of serious social conflict as a trigger or an outcome of massive migration, and also to an understanding of the concepts and their measurements used in this connection. We will finally show the distribution of regions of the world now thought to be the candidates for serious disruptions of this kind. Myers' (1995) recent report is an extensive treatment of the emerging issue of environmental refugees. In his view there is a steep increase of environmental refugees since the early 1980s and the chances are that the numbers will grow quickly. He estimates at least 25 million such refugees at present, that should be compared to 22 million refugees of the traditional kind. The total number of environmental refugees may well double by the year 2010 if not before. If predictions of global warming are borne out, eventually 200 million people may be put at risk of displacement by environmental degradation due to global change (Myers 1995, p.1) Myers (1995, pp. 17-19) operates with a wide definition of what an environmental refugee is (e.g. the first wave of what were so far called labour migrants from the South Mediterranean countries towards Western Europe would largely qualify under his terms) and provides unashamedly rough guesstimates of the current and future numbers. This is not meant to be criticism in the sense of a faulty procedure that should be replaced by another, that is readily available. There is probably at this moment in time no way to get a better approximation of the phenomenon once it has been defined in this way. The preceding remarks have to be read as consumer advise not to take the numbers too seriously as yet. Additional work on concept formation has to be done, a few well-chosen in-depth case studies would be necessary to provide more reliable and valid ways of making guesses on numbers. Myers (1995) proposes that the question of environmental refugees will become overwhelmingly important in quantitative terms, marginalizing the more circumscribed notion of refugees on the basis of persecution. This view is flawed as he does neglect to provide an assessment of the dynamics of 'traditional' refugee numbers. He considers the issue of environmental refugees as already of prime importance even without global climate change. In his view global climate change will seriously aggravate an already desperate situation. Over-exploitation of resources is already a serious problem in many parts of the world and tends to get worse due to the related dynamics of population growth and resource depletion. What about violent conflict? This is definitely not a major focus of Myers' analysis but he gives it some attention. In his opening chapter he briefly discusses the situation of Ethiopia and Eritrea where in 1994 3,5 million people were considered refugees of all kinds. Many of them had apparently fled military activities and civil violence. Many too were fleeing environmental degradation. "One category reflects the other. Often enough, they are inextricably mixed together, and to distinguish between them is to some degree, to try to separate the inseparable" (Myers 1995, p. 15). Then he sets the number of environmental refugees at 1,5 million. One has to conclude that the causal chains have not been considered very precisely. In chapter 3 of Myers' report dealing together with a number of causes of migration, governmental shortcomings are mentioned and also conventional conflicts. The governmental shortcomings are the last in a series of mostly physical factors indicating environmental degradation. They recapture our earlier discussion of social order breakdown and back this up with an example from Ethiopia suggesting that in this case government by its akward handling of a situation of environmental degradation induced further hardship in regions where it acted most 'vigorously', thus inducing more people to flee their homes (Myers 1995, pp.51-52). The conventional conflicts are mentioned in conjunction with the ethnic and cultural factors that now provoke so much of the organized violence in the world. These are of course the major driving forces behind the increase in traditional refugee numbers. The civil wars in Myanmar fought around these issues result in environmental degradation and refugees (Myers 1995, p.52). Again, it is very difficult to get a sense of the relative importance of the various relations on the basis of this account. Myers also restates Westing's count of 50 ongoing wars in 1994, about 20 of them environmentally induced (half of these in arid lands). Many of these wars result in refugee movements. "In Sudan the decade-long war has not only killed more than half a million people ., it has caused three million people to be uprooted whether temporarily or permanently - and at a time when the country is host to one million foreign refugees, mostly from Ethiopia and Eritrea" (Myers 1995, pp.52-53). However telling the example, it has in addition to be mentioned that the Sudan war can again not merely be considered a resource or environmental conflict, but that ethnic and religious factors play a major role as they did in the conflict concerning Ethiopia and Eritrea. On pp. 8 and 151-152 dealing with policy responses, Myers also shortly considers the impact of refugee flows on host societies and the chances of new rounds of violent conflict. There is, however, no discussion of the conditions that will either hamper or induce such conflicts to occur. One has to be content with a warning by a former UNHCR commissioner. This is perhaps related to Myers' repeated assertion that refugees tend to be constrained to re-establishment in increasingly marginal lands, where problems are perhaps less focused on relations with host societies than on an uninviting new physical environment that quickly becomes engaged in a new round of environmental degradation (e.g. on the Philippines, Myers 1995, pp. 65-67). In sum Myers' treatment of the issue is overwhelmingly predicated on the chain of events where environmental degradation immediately produces environmental refugees. Violent conflict is definitely a concern but it is in this analysis of secondary importance. The chain of events leading to environmental refugees through violent conflict or to violent conflict as the outcome of the outpouring and new establishment of environmental refugees is still unclear. The currently estimated 25 million environmental refugees are mainly located in Subsaharan Africa (notably in the Sahel and the Horn), the Indian sub-continent, China, Mexico and Central America (Myers 1995, p.1). In what is called a greenhouse-affected world where the predictions of global change have been realized, the extra numbers of people at risk of becoming environmental refugees are set out in the following table:

Table 5.4 People at risk in a greenhouse-affected world

Country or region	Total people at risk (millions)
Bangladesh	13
Egypt	16
China	73
India	20
Island States	1
Agriculturally-dislocated areas	50
TOTAL	**173**

Source: Myers (1995)

A large effect is ascribed to changes in river regimes and sea level change, accompanied by salinization of fresh water supplies etc.. They particularly put people at risk in coastal zones. One of the major worries is the large proportion of the world's largest urban concentrations in these coastal zones. The agriculturally-dislocated areas would particularly suffer from climate change directly and the most vulnerable region is Africa. The number of 173 million in the table is misquoted in the text as 182 million (Myers 1995, p.148) and then further upped until 212. The final number retained is 200 million. Again, it is very obvious that we deal with very provisional orders that are still open to considerable debate. Lonergan (1996, pp. 15-16) in his scoping report on human security for IHDP proposes 'environmental change, population displacement and human security' as a first key research topic in this area. From his reading of the literature he has found this to be one of the widest discussed topics in the field. He also mentions a dearth of good research but some amount of anecdotal evidence and a keen policy interest. We do not disagree with this recommendation but want to stress the necessity of more succinct conceptualization and a serious discussion of possible ways to handle the measurement and data acquisition problems. On a substantive note, we feel that the role of conflict should not be neglected in further research on this topic. Here in particular we have not moved beyond the anecdote to make our points (further discussion in DeMars 1996, pp. 81-89).

6 CONCLUSIONS AND RESEARCH PRIORITIES

The final chapter of this report contains two parts. The first sections deal with the socio-economic impacts of climate change (section 6.1), the conclusions (section 6.2) and the research priorities (section 6.3). The second part deals with violent conflicts (sections 6.4) and towards a research agenda for environmental insecurity involving violent conflict (section 6.5).

6.1 Socio-economic impacts

Economic progress has long been recognized to involve potential adverse environmental side effects at the local, regional and even the global level. In recent years it has become increasingly clear that expanding economic activity can also impose environmental damage that is irreversible over long time horizons. The central theme of this part of the report is to study the socio-economic impact of climate change. Therefore a literature review is made in order to get an overview of the present state of knowledge and to identify the most urgent and challenging research topics. The assessment of policy options for climate change requires detailed information on the cost and benefits of the various alternative policy options. This study is focussing on the order of magnitude estimates of impact on 17 different sectors associated with a doubling of atmospheric CO_2 concentration. In section 3.9 six types of the rich dynamic nature of the climate change damage costs are distinguished: valuation of damage over time, socio-economic vulnerability, higher order impacts, knowledge and uncertainty, non-equilibrium climate change, irreversibility and other accumulation. IPCC predicts that $2 \times CO_2$ will lead to an (equilibrium) increase in global mean surface temperature of 1.0 to 4.0^{0}C by 2100. The adjusted Business as Usual scenario (IS92a) will lead to $2 \times CO_2$ around 2050 and an increase in temperature of 1.0 to 3.5^{0}C around 2100. By 2100, sea level is projected to increase by 10 - 75 cm, with a best estimate of 50 cm, as a result of climate change. This increase comes on top of the present trend of 20 cm/century. Attempts at a monetary quantification of the impacts have started to emerge only recently. The impact of the enhanced greenhouse effect on agriculture is ambiguous, despite the large research efforts in the past decade. All impacts strongly depend on the adaptability of the farmers, and on the reaction of markets and politics. Together with the costs of sea level rise the effects on agriculture are probably the most studied aspect of the enhanced greenhouse effect. Climate change scenarios exerted (in most cases) a slight-to-moderate negative effect on simulated world cereal production, even when the beneficial effects of CO_2, farm-level adaptations and future technological yield improvements were taken. Estimates of damage costs of agriculture in the US lay between 0.6 billion and 15.2 billion dollars. For the OECD-E, OECD-P, CEE&fSU and S&SEA there are some benefits to gain for agriculture. Scientific studies will tend to overestimate the damage if no adaptation is assumed. Climate change was found to increase the disparities in cereal production between developed and developing countries. Cereal prices and thus the population at risk from hunger, increased despite adaptation. The extent to which forests and woodlands will be affected by climate change depends on various factors like, for example, the species and age of trees, possibilities for forests to migrate and the quality of forest management. The impact of global warming on wood production is therefore ambiguous. Although net primary productivity may increase, the standing biomass may not increase. As a consequence of $2 \times CO_2$ the world-wide forest area could reduce by about 3.5 per cent. Temperate and boreal forests would decline more, by about 9.6 per cent, whereas tropical forest areas would expand by some 5.2 per cent. Several studies indicate a total global increase in forested area from 1 to 9%, and another study calculates a decline of 25%. Estimates of damage costs of forests in the US lay between 0.564 billion and 38.0 billion dollars. The figures, however, are inexact in several ways. Climate change impacts are likely to exacerbate existing effects on fish stocks, notably overfishing, diminishing wetlands and nursery areas, pollution and UV-B radiation. Globally, saltwater fisheries production is hypothesized to be about the same and significantly higher if management deficiencies are corrected. Also, globally, freshwater fisheries and aquaculture at mid to higher latitudes should benefit from climate change. While the biological relationships are not well understood, positive effects should be offset by negative factors such as a changing climate which alters established reproductive patterns, migration routes, and ecosystem relationships. National fisheries will suffer if institutional mechanisms are not in place which enable fishers to move within and across national boundaries. Subsistence and other small scale fishermen, lacking mobility and alternatives, are often most dependent on specific fisheries and will suffer disproportionately from changes. Of particular importance for the fishing industry could be the loss of coastal wetlands. A reduction in total catches of 8 per cent in the US is estimated. Adaptations options can provide large benefits irrespective of climate change. The two uses of energy which are most sensitive to climate change are: a) space heating and air conditioning in residential and commercial buildings; and b) agricultural applications such as irrigation pumping and crop drying. Supply companies will adapt by changing the amount of new investment and the composition of investment. All the relevant studies conclude that the use of fossil fuels, which are used as space heating fuels, will decline. Adjusted to the assumption of 2.5^{0}C warming, an average increase in US electricity demand of about 3.2 per cent for $2 \times CO_2$ is estimated. It is estimated that energy cost in the US increased by 6.8 billion dollars. The regional differences in the US are, however, considerable. The limitation to electricity may lead to an overestimation of the total expenditures increase. Another limitation is the assumption of constant price. Other estimates of damages to the US energy sector are 7.1 and 9.0 billion US dollars. There is a strong connection of the costs of increased energy demand with the amenity value of climate. Heating or cooling expenditures are adaptation or defence measures. The supply of water will be affected, mainly through the change in precipitation patterns and, in coastal areas, through the intrusion of saline water into freshwater reservoirs. Higher temperatures are likely to cause an increase in water demand. Salinity damage for Holland is estimated at $6 million a year. In all developing countries with a high rate of population growth, future *per capita* water availability will decrease. Large discrepancies may be noted among results obtained for some countries. Assumptions for a reduction in water availability for the United States as a whole are between 7 and 10 per cent. Several studies estimate the damage costs to the water sector in the United States between 6.1 and 13.7 billion US dollars. There are different water prices in each region. For the US, one study estimates the damage costs of water pollution to be in order of $28.4 billion dollars for a 4^{0}C temperature rise. The problem of assessing the impacts of likely climate change on construction falls into distinct parts: the assessment of the likely impacts of climate change on existing constructions and of how current design practices might require modification. It is often assumed that climate change would benefit the construction sector because 'lengthening of the construction season' would be 'likely to increase productivity'. However, the increased incidence of heat waves would seem likely to eliminate some summer construction days. More important, although construction is adversely affected by frost, it is also inhibited by rainfall. In general, risks are created by extremes values and events (e.g., very high winds) rather than average conditions. The construction industry will be called on to implement adaptation options associated with sea-level rise. One study estimates that about 2600 km^2 of low-lying land in the United States may need to be protected from sea-level rise. The cost would be $5-13 billion for a 50 cm rise, approximately the current best estimate for the year 2100, and $11-33 billion for a 100 cm rise. It has been estimated that protecting Japanese ports, harbours and adjacent coastal areas against sea-level rise cost $92 billion. An even greater amount of construction activity might be required in Africa, where industry tends to be concentrated in capital cities, many of which are seaports. Existing assesssments of transport impacts have recognised the potential significance of changes in geographical patterns of economic activity on the transportation network. Climate change will have some direct effects on transportation infrastructure and the operation of transportation systems. These may be divided into the effects of sea-level rise on coastal facilities, the effects of climate on infrastructure and the effects of climate on operations. The cost of raising vulnerable streets in Miami was put at $237 million for 410 km of road. Environmental external costs amount to $0.02 to $0.1 per km driven by cars. Damage costs of transport in OECD countries associated with global climate change are estimated by Quintet (1994) at 1 to 10 per cent of GDP, which is very high in comparison to other estimates. The transport sector is affected by cold weather, snow and ice, and might thus profit from a warmer climate, particularly through reduced disruptions and lower winter maintenance costs. On the other hand, heatwaves can be similarly disruptive. Probably more importantly, the transport sector is also negatively affected by rainfall, and precipitation is likely to increase under $2\times CO_2$. Given that Americans spend approximately $240 per capita annually on wildlife related recreation or a total of $54.4 billion, the market component of tourism is not trivial. Summer tourism would generally benefit from a longer season. Although only to the extent that activities are not hindered by excessive heat or increased rainfall. A monetary estimate for the United States has been predicted as a loss from leisure activities in the order of $1.7 billion per year. The overall effect for a country as large as the United States would probably be negligible, though specific regions could experience adverse or favourable effects. In general, global warming might be expected to reduce the length of the skiing season in many areas and to affect the viability of some ski facilities. The downhill ski season in the South georgian Bay Region could be eliminated with an annual revenue loss of $36.55 (Canadian dollars). A 50-70% decrease is projected in the number of skiable days in Southern Quebec. On the other hand, the summer recreation season in many areas may be extended. Tourism could also be affected in areas where coral reefs are attractions. The cost of sand required to protect major US recreational beaches from a 50 cm sea-level rise would be $14-21 billion. In addition, elevating infrastructure would cost another $15 billion on the Atlantic coast alone. The costs of sea level rise divide into three types: Capital costs of protective constructions, and the costs of foregone land services, conveniently split into dryland and wetland loss. The estimated damage depends strongly on the projected policy. Small islands, deltaic settings and coastal ecosystems appear particularly vulnerable. It has to be noted that there are differences in outcomes between the estimates of several different studies. The estimated damage on dryland loss depends strongly on the projected policy. Valuing coastal lands is rather difficult and figures differ by several orders of magnitude, depending on the use and location of the piece of land in question. Values are ranging from 0.5$ to 200$ m/km^2. The possible amount of wetlands loss depends mainly on the possibility of the systems to migrate inland, and therefore on the amount of coastal protection measures taken. The more comprehensive the defence measures, the more difficult backward migration becomes and the more coastal wetlands will be lost. One study estimates that for the United States a complete protection of all coastal zones would lead to a loss of one-half of all remaining wetlands. The value of coastal wetlands is ranging between $0.5 m/km^2 and $13/km^2, including all quantifiable benefits. Most studies on the impacts of climate change predict an increased loss of species and ecosystems. The impact of climate change on species and ecosystems has been paid relatively little attention to by economists, primarily so because the physical impact is still to large extent unknown, but also because the value of an ecosystem or a species cannot be easily estimated. Several studies are ranging values between $2 and 107$ per person and year for the preservation of entire habitats. Estimates of the loss for OECD-America are between $4,000 and $20,810 million. The global value is between $25,620 and $40,530 million US dollars.

Value erosion is subject to manipulation. Both memory effects and cohort effects lead to successive generations rarely valuing losses cumulatively and in perpetuity. The overall effect of global warming on human amenity is ambiguous, the impact being positive in colder and negative in warmer regions. The monetary value of a benign climate is still largely unknown. A careful distinction between winning and losing regions would further require fairly accurate information about regional and seasonal temperature patterns. For purposes of establishing an order of magnitude, if people were willing to pay just 0.25 per cent of personal income to avoid the sharp increase in heat waves and other effects of a benchmark $2\times CO_2$ warming in outdoor comfort, the damage of such disamenity would stand at some $10 billion annually for the United States. Global climate change over the coming decades would have various effects, mostly adverse, upon the health of human populations. The health effects would be both direct and indirect. Studies in large urban populations in North America, North Africa and China indicate that the annual number of heat-related (summer) deaths would increase by a mean of 2-3%. This heat-related increase in deaths may be partially offset by fewer cold-related deaths, although the balance would vary by location and would also depend on adaptive responses. Most economic valuation studies lead to an increased mortality of 27-40 persons per million for the benchmark climate change. This estimates is based on the impact of heat waves in US cities. Several studies estimate the damage costs from mortality in the US due to climate change between >$5,000 and $9,963 million dollars. One study estimate the loss from increased mortality in the world at $49,182 million US dollars. An approximately 25% increase in the rate of occurrence of malaria in Indonesia by 2070 is predicted. One study indicates an average global temperature increase of 3 degrees in the next century could increase the range of malaria-carrying mosquitoes and result in 50 million to 80 million new malaria cases per year. Adaptive options to minimise health impacts include: improved and extended medical care services; environmental management; disaster preparedness; protective technology; public education directed at personal behaviours, and appropriate professional and research training. Global warming will affect the quality of air in two ways. The first has to do with what is called secondary benefits. Secondly, many chemical reactions depend on temperature. Global monitoring of urban air quality in cities indicates that nearly 900 million people are exposed to unhealthy levels of SO_2 and more than 1000 million are exposed to excessive levels of particulates. Warming can exacerbate the formation of smog. The estimates for NO_x range from about $0.10 to $15 of damage per kg emitted. Excluding acid deposition, SO_2 causes a damage of $0.6/kg to 3.5/kg, mainly through health effects and corrosion. Several studies estimate the damage costs of air pollution in the US due to climate change between >3.0 and 23.7 billion dollars. One study estimates for the world as a whole these costs at 15.4 billion dollars. It is assumed that under a worst-case scenario as many as 100 million people could be displaced world-wide. One study estimates of 72 million people displaced in China, eight million in Egypt and half-a-million in Poland. In Bangladesh 11.4 million people could be affected. Conflict between groups in society can be exacerbate the effects of climate. Several studies estimate the damage costs of migration in the US due to climate change between 0.4 and 0.58 billion dollars. The estimates for the world as a whole are between 4.0 and 7.27 billion dollars. To the costs would have to be added the costs of hardship and stress suffered by migrants. There are two types of costs: utility sacrificed by the migrant, and cost on the target host country. Outside the United States, there are indications that concern about increased immigration induced by global warming is especially high in Europe, where immigration problems already have intensified in the past decade as the consequence of political change in Eastern Europe and North Africa. As semi-arid African states are among those expected to be seriously affected by global warming, such concern would appear well founded. Increased frequency of extreme events will potentially have more impact than mean changes in climate. On the basis of meteorological data, however, there can be no determination of an systematical increase in stormactivities. Windstorms cause several types of harm to socioeconomic systems - property damage, lost production, macroeconomic disruption and personal death, injury or stress. Research results of damage costs from tropical storms in US are between 0.2 and 13.3 billion dollars. For the world as a whole these estimates are between 2.7 and 45.6 billion dollars. Over the last 40 years, US hurricanes have caused an annual average of $ 1.5 billion in damages at 1989 prices. It is concluded that a 10% increase in winter precipitation could lead to a rough doubling of annual average damage from Dfl. 21.8 million in the Limburg Meuse Valley. Both droughts and floods are related to outbreaks of vector-borne diseases and agricultural pests.

6.2 Conclusions socio-economic impacts

This report has attempted to provide an overview of recent research results on the impacts of climate change associated with an atmospheric CO_2 concentration of twice the preindustrial level ($2 \times CO_2$). Together with the costs of sea level rise the effects on agriculture are probably the most studied aspect of the enhanced greenhouse effect. The order of magnitude estimates of impact on 17 different sectors are not all negative, depending on which sector, region and/or adaptation is included. For the OECD-E, OECD-P, CEE&fSU and S&SEA there are probably some benefits to gain for agriculture. The best guess negative impact, in economic terms, of a rise of the global mean temperature of 2.5 degrees centigrade ranges from about 1.5 percent of Gross Domestic Product in Western Europe and North America to about 8.5 percent of GDP in Africa and South Asia (Tol *et al.*, 1995). Fankhauser's estimates are slightly higher than those of Cline (1992; for the US) and Nordhaus (1991a, b; US extended to the world), which both come up with a best guess of about 1 per cent of GNP, but are below Titus (1992), who estimates a $2 \times CO_2$ damage of 2.5 per cent of GNP, again for the US. This latter estimate however assumes a 4^0C temperature rise and is thus not directly comparable to Fankhauser's results. Tol (1995b) estimates world-wide greenhouse damages at 1.7 per cent of GNP. These figures are little more than a first guess, being based on an incomplete overview, and hence highly uncertain. The situation could be further aggravated by a failure to implement the cost efficient adaptation response (e.g. coastal protection), something which is quite likely to happen if the necessary funds are not made available. Although the data are weaker in the case of non-OECD countries, it seems therefore fair to say that global warming will have its worst impacts in the developing world. Regional differences can, however, be substantial. The figures do indicate that the poor regions are more vulnerable than the rich. We should also remember that several greenhouse impacts have not been quantified. These are probably predominantly harmful, with the possible exception of climate amenity. Lack of data made it sometimes necessary to resort to some fairly *ad hoc*, and thus possibly subjective, assumptions. This has in particular affected the results for developing countries, and the confidence in these results is substantially lower than in those for developed regions. On the whole, the 1 per cent to 2 per cent damage range for industrialized countries and the world as a whole is fairly robust, however, and the same appears to be true for the relative ranking of the different regions. A word of caution is required with respect to the policy implications of the results. While the figures indicate a rather low damage with which at least the industrialized world should be able to cope, they do not necessarily imply that greenhouse policy action is unwarranted, for two reasons. First the analysis has shown that, relative to their income, developing countries will be far more affected than their wealthy counterparts. Arguable, the destiny of the least well-off should be of particular concern to policy-makers, and the damages to developing countries should therefore be given additional weight in the decision process. Second, the estimates only concern one single point in time, i.e. shed light on the impacts of $2\times CO_2$ only. However, global warming will not stop there. $2\times CO_2$ could be reached as early as 2050, and what happens afterwards is as yet still unclear.

6.3 Research priorities on socio-economic impacts

1. **A more detailed analysis of agricultural impacts in developing countries in addition to the already intended study on semi-arid regions in West Africa.**
   The study should specific pay attention to the various options to adjust to changing climatic conditions, the role of risk and uncertainty and the secondary impacts on prices of agricultural products. In particular, to credibly deal with the cost of adjustment of which there is significant disagreement, the process of socio-economic adjustment must be modeled to treat key dynamic issues such as how the expectations of farmers change, whether they can detect climate change, and how current investments in equipment, education, and training may lead to a system that only slowly adjusts, or adjusts only with high costs and significant disruption (IPCC, 1996, Chapter 13, pp 2). Change in crop is a powerful form of adaptation, but, as any other form of adaptation, little is known of the driving processes. How fast farmers will adapt, and under which circumstances adaptation will be succesful is a crucial but largely unknown determinant of the damage costs (IPCC, 1996, Chapter 13, pp 1). Climate effects on soils and plant pests, and consideration of other environmental change should also be an integrated part of the models rather than treated on an ad hoc basis or as a separate modeling exercise (IPCC, 1996, Chapter 13, pp 2). Omitting variables are the effect of extremes and ranges in climatic variables as well as the effect of changes in irrigation. Another bias arises in the

production-function approach, because it fails to allow for economic substitution as conditions change (Mendelsohn *et al.*, 1995). The capability to readily simulate agricultural impacts of transient climate scenarios should also be developed. The impact on welfare is hard to assess, as food is an essential input to most people. From a dynamic perspective, much is left to be desired. *In abstracto* the damage costs of climate change are based on limited, partly outdated information, inconsistent combination of models, uncontrolled up- and downscaling, gross inter- and extrapolation, and non-expert interpretation (Tol *et al.*, 1995).

2. **A more detailed analysis on the influence of climatic scenarios on water availability in sensitive regions.**

   The study should focus on the availability and consumption of water and the required storage for consideration of effects of climate variations on the design and operation of water resource projects. There also is a need to study the effects of climate change on large international river basins, as a collaborative effort of riparian countries and on the effects on water quality parameters of aquatic systems (IPCC, Chapter 10, pp 17). There is an absence of information on future climate variability - a basic element of water management, and on precipitation data to runoff and basin water budgets. The future demands by each water sector and the socio-economic impacts of response measures also need to be studied (IPCC, 1995, Chapter 14, pp 1).

3. **A further analysis of the socio-economic impacts of sea level rise.**

   The study should particularly focus on vulnerable and densily populated deltas, paying attention to various options for adaptation, the required funds for it and the resulting impact on economic activity, housing and direct effects of resettlement and migration. Also needed are scientific classifications of coastal types for climate change analysis, based on geomorphological, ecological and/pr socio-economic criteria. Other research needs are improved coastal processes data (especially in developing countries) based on socio-economic trends in coastal areas such as population changes and resource utilization, taking into consideration differences in socio-cultural characteristics of countries and etnic groups (IPCC, 1996, Chapter 9, pp 31).

4. **A more detailed analysis of socio-economic impacts of changes in human health and mortality.**

Numerical estimates are now available for the expected spread of malaria after climate change. Recent speculation about a link between climate change and the spread of diseases such as cholera and dengue fever suggest that health impacts of climate change may have been underestimated so far. The study should provide insight in the socio-economic consequences of changes in human health and mortality in regions when these changes can be expected to be most relevant. There is immediate need for improved and internationalised monitoring of health-risk indicators in relation to climate change (and other associated global and regional environmental stresses). Existing global monitoring activities should encompass health-related environmental and bio-indicator measurements, and, where appropriate, direct measures of human population health status. Monitoring activities should interact with ongoing health risk research and assessment activities (IPCC, 1996, Chapter 18, pp 2).

5. **A detailed study on the socio-economic impacts of migration because of environmental degradation and flooding.**

Climate change is expected to lead to additional migration and environmental refugees. The study should provide scenarios that indicate in which areas these events may occur and what the expected socio-economic impacts will be in costs of adaptation and resettlement. There is also a research need for studying the question of how conflict between groups in society can exacerbate the effects of climate change (IPCC, 1996, Chapter 12, pp 6).

6. **A more elaborated study on the possible impacts of extreme weather events based on risk assessment.**

Further research on the effects of variability rather than changes in the "mean' climate is needed. The causal relationship between sea surface temperature and the formation of tropical cyclones suggests that the intensity and frequency of tropical cyclones will increase in future. The evidence from models is however conflicting (IPCC, 1996, Chapter 8, pp 13). Extreme events have the most severe effects on crops, livestock, soil processes, and pests. The problem of droughts and floods under instationary hydroclimatic conditions is an area that needs additional research efforts in future (IPCC, 1996, Chapter 10, pp 8). The more serious human consequences of climate change also are likely to involve extreme events such as drought, flooding, heat waves, and storms and do not only determine a large share of the damage, but also drive adaptation. Climate change will be felt through events, and not through gradual changes (Tol, 1994b). The macroeconomic impacts of weather extremes has to be studied. The changes in the frequency distributions of parameters of extreme events has to be estimated before and beyond the benchmark. In addition research on the impacts of extreme weather events on non-OECD countries should be extended substantially.

7. Socio-economic impacts of changes in ecosystems and biodiversity.

The study should analyse which socio-economic impacts are related to the projected changes in ecosystems and biodiversity as a result of climate change. Climate economists face a double problem, i.e., how to derive a total value of something which is unknown in quantity and price (Tol, 1996). The aim of the study is to improve impact and damage assessment that can be used in integrated assessment models that analyse the cost and benefits of climate change. There are hardly any valuation studies of a species or an ecosystem available for the middle income countries like those of the former Soviet Union (Fankhauser, 1995). The implied change in landscape value has not been assessed, with a main reason that these value changes are local and hence cannot be predicted (Tol, 1996).

6.4 Violent conflicts

In 1987 the concept of 'environmental security' was officially introduced in the General Assembly of the UN. Before that time it had occasionally been used by politicians and academics. Afterwards it has become a regular password in academic and political discourse (PRIO/UNEP 1989). More recently, global climate change as one manifestation and cause of environmental degradation has been added to this debate. In this paper we focus on the possible connections between global climate change and 'environmental security'. At present 'environmental security' is a fuzzy concept. The mutual connections between the environment and security are perceived in two different ways (Westing, 1986, 1988, 1991, Myers 1989, 1993, Prins 1993). Security refers to risks and threats. In the first sense of 'environmental security' the adjective 'environmental' refers to the origin of the threat itself (i.e. the degradation of the environment threatens the existence of a population, compare food security as a risk of a shortage of food). In the second connotation 'environmental' refers to an agent that sets in motion a train of events that eventually increases the risk of violent conflict (it is a specification of the ultimate cause of violence - as the infliction of intended immediate bodily harm - which is the basic threat in one highly influential understanding of what 'security' is about). It is this second sense of environmental security, where the concept is directly linked to violent conflict, that will inform the discussion in this paper (latest data on current patterns of violence in Wallensteen & Sollenberg 1996). In tracing the links between global climate change and environmental security we have to indicate the impact of global climate change on other aspects of environmental degradation. All studies in this field are, however, hampered by the lack of reliable, detailed data on the scale of nations and smaller regions (IPCC 1996). Global climate change has two dimensions that result in different consequences from the perspective of their impact on social life. One dimension is the gradual longterm change of climate parameters and concomitant changes in bio- and geosphere. Within limits there is a significant element of choice in societal response options, however disputed they may be (recall the political battles on the responses to CO2 reductions). The other type is a gradual change in frequency and severity of peak events. Response time for these peak events is very short or non-existent. Some preparations are possible - they might even be encouraged by increasing frequency and severity. Societies differ in their capability to respond to these peak events and every peak event may significantly alter the history of the affected society. The causes and consequences of global climate change are unevenly and differently distributed. Those parts of the globe that contribute most to global climate change are not the ones that suffer most of the consequences. But contributions change over time and consequences may be severe for all in the long term.

Environmental security in the global arena

Because of its global nature and its perception as a collective 'bad', countering the process of climate change necessitates collective action by sovereign states. But the nature of the issue at the same time provides sovereign states with the potential for 'free riding' (Olson 1965). States may benefit from the, perhaps costly, measures to be taken by other states. The unbalanced mix of national and collective interests provides a potential basis for international political tension and conflict. In addition a number of specific national economic interests for some individual countries provide extra incentives to 'free riding' and thus an extra barrier to effective, common action. On top of this, not all countries will equally suffer from global climate change. Climate change is thus not really a collective good/bad (Buzan, Waever & de Wilde 1995). Collective action in this field is not completely impossible. Negotiations concerning the ozone issue have given rise to a viable and more or less effective international regime (Benedick 1991, Gijswijt 1995). Power, knowledge and interests decide whether an international regime, that sets norms in international interaction backed by shared convictions and social control but lacking the authority of an overarching power, can be established (Young 1994). Powerful states are necessary to force weaker states to comply with the terms of the regime. Learning by transnational groups of scientists and policy-makers enable the formation of the knowledge base that is necessary to craft a regime. Mutually agreeable deals that respect the interests of significant individual parties are the motivating force underlying regime formation. Climate change as a subject of regime formation differs in important respects from the ozone question. This is the case as regards the time frame and the size of the effects (longer and less certain in the case of global change), the significance and the number of actors controlling the response mechanisms (a handful of chemical companies versus all interests connected with energy use), the less even distribution of effects of global change ('winners and losers' in the case of global change). These factors result in less favourable circumstances for regime formation (Payne 1996). Although climate change is commonly perceived as a collective global threat ('no winners') it is at least in the short run also a distributional problem with winners and losers. This last view has long been ignored. There is a striking difference with reactions to the prospect of a global cooling around 1970 that stressed the differential impact for various regions and countries (Glantz 1995). In fact, environmental security is not one, but a bundle of issues that can not be solved in the setting of one clearcut rank order of states. Because of differences in interests and strategic positions of states, every issue has to be considered on its own merits. In every instance the cooperation of one or even several groups of states is essential and they wield effective veto power in that particular instance. As a consequence every issue has to be negotiated in a differently structured arena, that often will be less than truly global. Spillovers and tradeoffs are difficult to achieve (Buzan, Waever & De Wilde 1995, Sjöstedt 1993). While it is clear that there will be initial winners and losers of global climate change if it materialises, their precise enumeration is still difficult. IPCC (1996) is notably cautious in this regard. Many of those especially at risk are probably low-income populations in low-latitude regions depending on isolated, dryland agricultural systems in semi-arid and arid areas. However, studies so far have only considered a limited number of adaptation measures and limited numbers of sites. It is curious that much scientific and political attention for the climate change problem comes from those who have no special reason to fear, on the contrary (Scandinavia, Canada). Their concern has among other things to do with the basic uncertainty concerning the longterm overall consequences of climate change. Paradoxically, the lack of precise knowledge concerning the regional consequences of climate change may also have beneficial effects for the emergence of global cooperation. Global level arenas where the consequences of global climate change are treated among the members of the state system are in the short run hardly likely to deteriorate into theatres of violent conflict. The interests at issue are still insufficiently seen as matters of life and death by the most important participants to make such courses of action very likely. Of course this may well change over time.

Regional arenas and environmental conflict potential.

Most conflicts ultimately emanating from global climate change and possibly violent, will materialise within the macro-regions of the world. Geographical macro-regions, individual countries and parts of countries differ as to susceptibility, vulnerability and consequently the probability that their populations and political leadership will take effective measures against (the consequences of) climatic change (Kasperson 1995). Susceptibility refers to the likely physical and human changes as a result of a particular threat, when no adaptation or prevention measures are taken ('business as usual'). Vulnerability refers to the capacity of a social actor to take measures to prevent or cope with these changes and their consequences e.g. in terms of violent conflict. High degrees of susceptibility and vulnerability result in environmental degradation. This may in its turn lead to more violent conflict. How might this happen? A decreasing resource base may cause anxiety and efforts to make up for the losses elsewhere, or it may cause an increased vulnerability to armed attack that indeed results in aggression by others. An expanding resource base (the 'winning' side in global change) may give rise to efforts of territorial expansion. There is evidence in the general literature that this in general tends to happen, though there is none in this particular context. Environmental decline may also result in a collapse of the social order and thereby in violent conflict. Finally, environmental degradation may condition violent conflict as a result of external effects. This may happen when environmental refugees cross international borders and cause tensions between the two countries involved. Violent conflict may thus follow in several ways from environmental change. The relevant social actors need not always be only states, but states are definitely often involved, increasingly as one party in a civil war. Many of the preceding assertions considering environmental factors as conditions for violent conflict are based on general views in the literature on international relations and conflict literature and still have to be studied for the environmental sector specifically. In the literature on environmental questions the reverse relation has been emphasized: the environmentally negative consequences of war. Homer-Dixons et al. (1991, 1993) project of thirty case studies results in the view that scarcity of renewable resources often produces insidious and cumulative effects, which can trigger violent conflict; it is ony rarely the direct cause of that conflict. The multivariate nature of their explanatory model has however hardly been specified and global climate change has no special place in it. Schnellnhuber & Sprinz (1995) have assessed the available evidence and conclude that the chances of a direct connection between global climate change and different kinds of violent conflict are for the time being extremely remote. However, the ramifications of global change at the regional and local level may well create the conditions for such conflicts. They stress the destabilizing effect of extreme weather events as earlier mentioned. What could be the possible conditions of different vulnerability, first to cope with environmental degradation, but more importantly in this context, with the ensuing chances of violent conflict? We suggest the importance of a democratic polity and probably an advanced level of socio-economic development, though some arguments for the opposite relationship are available. The chances of violent conflict as a result of social order breakdowns (e.g. due to weather extremities) are limited by the legitimacy of government, by rational response patterns from the side of the authorities, and by the availability of independent action centers in civil society (Putnam 1993). The relations with socio-economic development are in fact less clear due to the advanced levels of division of labour that high development implies and that may result in effects either way. The chances of violence as a result of distributional conflict are again limited by a democratic polity. This applies to domestic conflict due to the cautious nature of democratic politics (decision-makers have to compromise and can afford to lose) and to international relations (pairs of democracies for whatever reason hardly wage war with each other) (Gleditsch a.o. 1992, Russett 1993). The relations of distributional conflict and socio-economic development are differently assessed. If one stresses grievances as conducive to conflict low development engenders violence. If one stresses capacities to engage in conflict, high development engenders violence. If one stresses the civilizational impact of development due to division of labour and interdependence, high development reduces the chances of violence. Reduced fresh water availability, sea level rise, diminishing food production and environmental refugees are the subjects frequently encountered in the context of possible global change impacts. Changes in these factors or their emergence are also referred to as potent causes of future violent conflicts. When fresh water availability for several countries is dependent upon one or more shared riverbasins or underground waterflows, any change of water supply, whether by 'natural' causes or by human action puts the issue of water distribution on the political agenda. Population growth and increasing irrigation are major factors behind the increasing water scarcity, that could be seriously aggravated by global warming. The chances for water conflict are highest in areas whose water supply is dependent on an internationally shared water basin, where fresh water is already scarce and where global warming is expected to have an especially deteriorating effect on the water balance. One expert (Falkenmark 1986) foresees the highest level of frustration from increasing water scarcities in Africa and south-western Asia. Arid and semi-arid regions in lower latitudes are generally also the regions where democrastic traditions are weak and socio-economic development in many cases modest at best. In these regions there are hardly any international treaties instituting a regime for the peaceful allocation of water from shared rivers (Kliot 1994, Donkers 1994, Gleick, 1993). The consequences of sea level rise would be most serious in a number of flat, densely populated coastal areas around the world. In various cases not only is the coastal area itself threatened but the national economy as a whole. At the intra-national level there is hardly a distributional conflict, and social order breakdowns might be prevented by responsive action on account of the gradual nature of the rise. The most likely security impact of sea level rise when no measures would be taken, e.g. due to low degree of socio-economic development, is thus social and political order breakdowns because of refugees in a national or an international context. IPCC (1996) estimates indicate that many of the populations in sub-Saharan Africa are the most vulnerable to eventual global warming and the concomitant decrease of agricultural production. To an extent this is also true for South Asia and other parts of the developing world though for slightly different reasons. The arguments concerning democracy and socio-economic development again apply (also Wallensteen 1986). As in the case of fresh water it is generally in areas highly susceptible to the risk of diminishing food production where democracy, certainly stable democratic conditions, are lacking to inhibit the emergence of violent conflict. An impact of socio-economic development is likely as mentioned though its direction is disputed. The notion of 'environmental refugee' has recently been coined to indicate the plight of those uprooted by environmental degradation. There are some problems with this notion in the current context. As in earlier parts of this report the connection between environmental degradation and global climate change is often hazardous in the literature. It is also uncertain how important environmental degradation contributed to the migration decision. The term 'refugee' has a well circumscribed meaning in international law and there are pros and cons in extending the definition (Kaplan 1994, Myers 1995, DeMars 1996). In spelling out the possible connections between environmental degradation and migration two different causal paths have to be considered. The first is migration immediately induced by degradation of natural resources as in migration as a consequence of a lack of rain in the growth season in semi-arid conditions. The second causal paths links degradation and migration through violent conflict. Here the idea is that degradation results in distributional conflict or social order breakdown which in its turn gives rise to outmigration. This is the train of events especially relevant here. It may have a further sequence when newly arrived outmigrants have to settle amongst an established population with a full potential of a new round of distributional and social breakdown conflicts. When borders, in particular international borders are crossed, political authorities both sides of the line get involved, which may result in further extension of conflict. Myers' recent report on environmental refugees produces staggering numbers of people on the move at the current time for environmental reasons (25 million) and a large chance of extremely high numbers some decades from now due to further deteriorating conditions including the effects of global climate change (the consequences of current predictions of global climate change would induce possibly 200 million environmental refugees in 2010). These numbers are extremely hazardous due to difficulties with the definition of the concept of environmental refugee and with the modes of guesstimating. Myers mentions some instances of violent conflict in this connection but his main focus is on the immediate effects of environmental degradation.

6.5 Towards a research agenda for environmental insecurity involving violent conflict

The ideas concerned with the link between global climate change and security address a number of urgent and difficult issues that need to be studied. The notion of environmental security is at the same time in danger to become a cover term for all sorts of risks somehow connected with the environment. Consequently we propose a study on:

1. **A proper conceptualization of 'environmental security' taking into account the theorizing done so far.**

In addition empirical work should be done to assess the presumed links in the causal chains linking global climate change to different forms of security.

2. **The environmental factor in past inter- and intranational armed conflicts**

Provide an overview and analysis of the role of environmental factors as a cause of violent conflict. Particular attention should be paid to the role of food and water scarcities. Westing (1986, Appendix 2) has prepared a list of twentieth century <u>inter</u>national wars and skirmishes that involved natural resources (in general). This selection should be updated and, where necessary, completed. A complete overview and analysis of environmental causes of historical <u>intra</u>-national armed conflicts is still lacking. With existing databases (SIPRI, PIOOM, DPCR Uppsala, AKUF Hamburg, John Laffin's Annual of War, Correlates of War, Ted Gurr's Minorities at risk data, and recent updates like Wallensteen & Sollenberg 1996) and literature as a point of departure, such a selection should be made. In the analysis of these conflicts, attention should be focused on the (political, economic) factors that decide whether 'environmental' tensions or conflicts of interest (international or intranational) are solved or managed by peaceful means, or escalate into violent conflict. Economic factors: level of development. Political: the existence of other 'hot' policy issues between the quarreling parties, democracy or not.

3. **International conflict prevention: managing environmental or resource related tension**

How have international frictions or differences of interest regarding environmental issues or the availability of natural resources so far been managed peacefully? By ad hoc negotiation? By institutionalized, regular consultation and negotiation in special committees or permanent intergovernmental organizations (e.g. Rhine Commission, Organization for the Development of the Senegal River; regimes)? By supranational legislation (European Union)? Attention should be focused on the (political, economic) factors that decide if international environmental conflicts are solved by peaceful means, and by what means. Economic factors: level of development. Political: other relevant policy issues, democracy or not.

- overview of international geographical arenas of environmental strain (water, food)
- comparative case studies of environmental conflict regulation (e.g. river commissions) in several areas of the world

4. Intranational conflict prevention: managing environmental or resource related tension

How have intranational frictions or differences of interest regarding environmental issues or the availability of natural resources so far been managed peacefully? By ad hoc negotiation? By institutionalized, regular consultation and negotiation in special committees or public bodies? By national legislation? Attention should be focused on the (political, economic) factors that decide if intranational conflicts are solved by peaceful means, and by what means. Economic factors: level of development. Political: other relevant policy issues, democracy or not, type of administration (federalist, central), legal tradition.

- overview of states having problems of environmental strain (water, food)
- comparative case studies of environmental conflict regulation in countries in several areas of the world

5. Typology of types of political environmental friction, the way in which these frictions are managed (or not) and decisive factors in this respect

Studies b., c. and d. should provide the basis for a typology of types of environmental conflict (scale, level of 'organization') and of the circumstances (economic, political) under which such conflicts either escalate or are managed peacefully (and how). Study will thus be based on the results of the first three studies.

6. The possible political effects of sea-level rise in coastal areas

Knowledge concerning the physical effects of sea-level rise is readily available (e.g. Delft Hydraulics). Scenarios might be designed to speculate on the question in which areas this will possibly lead to serious political tension, and what the chances are for peaceful settlement of these conflicts? Potentially decisive factors:

- size of flooded area
- population density: (inter)national refugees?
- economic factors (level of development, main economic activity in vulnerable coastal area)
- political factors (democracy or not, other policy issues)

7. Governmental reaction to environmental disaster in the past

One of the main effects of global warming will probably be a higher frequency of extreme weather conditions (hurricanes, floods, droughts). What have been the political effects of such extreme events in the past. How have governments reacted? This study should focus on the ways and circumstances under which governments can maintain or restore a certain level of (social) order, after this order has (at least in parts of the territory) been seriously weakened or destroyed.

8. 'Environmental refugees'

The policy debate on environmental security is to a considerable extent focused on the issue of environmentally induced emigration. This is a highly charged political affair because of the consequences in case migrants cross international borders. Despite the abundant migration literature there is still a scarcity of studies linking the expertise on migration with the emerging field of environmentally induced population movement. In addition there is a newly emerging literature on the assessment of relief efforts that takes into account the conditions that propelled the population movement and the impact on local resources in the new locations. A careful non-partisan overview of these bodies of evidence with an eye to the possible causal chains affecting different versions of 'environmental security' as set out in chapter 5 would be a first step in the direction of more insight. This should be followed by a few properly selected case studies that would enable systematic comparison following the logic of the project by Homer-Dixon et al. (1993) reported elsewhere in this study.

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