The GEO-3 Scenarios 2002-2032

Quantification and Analysis of Environmental Impacts

by

Jan Bakkes *(National Institute for Public Health and the Environment (RIVM), the Netherlands)*
Thomas Henrichs *(Center for Environmental Systems Research (CESR), University of Kassel, Germany)*
Eric Kemp-Benedict[1] *(Stockholm Environment Institute (SEI), USA)*
Tosihiko Masui *(National Institute for Environmental Studies (NIES), Japan)*
Christian Nellemann *(UNEP GRID Arendal, Norway)*
José Potting[2] *(National Institute for Public Health and the Environment (RIVM), the Netherlands)*
Ashish Rana[3] *(National Institute for Environmental Studies (NIES), Japan)*
Paul Raskin *(Stockholm Environment Institute (SEI), USA)*
Dale Rothman[4] *(International Centre for Integrative Studies (ICIS), the Netherlands)*

Edited by José Potting and Jan Bakkes*

---

[1] currently KB Creative, USA
[2] currently University of Groningen, the Netherlands
[3] currently Winrock International India, New Delhi, India
[4] currently Macaulay Institute, United Kingdom
* corresponding author

ISBN: 92-807-2384-7

For bibliographic and reference purposes this publication should be referred to as:
UNEP/RIVM (2004). José Potting and Jan Bakkes (eds.). The GEO-3 Scenarios 2002-2032: Quantification and analysis of environmental impacts. UNEP/DEWA/RS.03-4 and RIVM 402001022.

Division of Early Warning and Assessment (DEWA)
United Nations Environment Programme (UNEP)
PO Box 30552, Nairobi 00100, Kenya
Tel: +254-20-624299
Fax: +254-20-624269
E-mail: geo@unep.org
http://www.unep.org/geo/geo3/index.htm

National Institute for Public Health and the Environment (RIVM)
PO Box 1, 3720 BA Bilthoven, Netherlands
Tel: +31 30 2743728
Fax: +31 30 2744464
E-mail: jan.bakkes@rivm.nl
http://www.rivm.nl/env/int/geo

Reproduction

Disclaimer

The views expressed in this volume are those of the authors and do not necessarily reflect the views of UNEP or RIVM. The designations employed for geographical entities and their presentations in this report are based on the classification used for UNEP's Global Environment Outlook 3 and do not imply the expression of any opinion whatsoever on the part of UNEP or RIVM concerning the legal status of any country, territory, city or area or its authority, or concerning the delimitation of its frontiers or boundaries.

Contributing institutes

Center for Environmental Systems Research (CESR)
University of Kassel, Kurt Wolters-Strasse 3, D-34109 Kassel, Germany.
Tel: +49 561 804 3266; Fax: +49 561 804 3176;
Email: cesr@usf.uni-kassel.de; www.usf.uni-kassel.de
Contact person: Joseph Alcamo

International Centre for Integrative Studies (ICIS)
University of Maastricht, PO Box 616, 6200 MD Maastricht, The Netherlands.
Tel: +31 43 388 2662; Fax: +31 43 388 4916;
E-mail: icis@icis.unimaas.nl; www.icis.unimaas.nl
Contact person: Jan Rotmans

National Institute for Environmental Studies (NIES)
16-2 Onogawa, Tsukuba-Shi, Ibaraki, 305-8506, Japan.
Tel: +81 298 50 2422; Fax: +81 298 50 2422;
E-mail: mikiko@nies.go.jp; www.nies.go.jp
Contact person: Mikiko Kainuma

National Institute for Public Health and the Environment (RIVM)
PO Box 1, 3720 BA Bilthoven, The Netherlands.
Tel: +31 30 274 3728; Fax: +31 30 274 4464;
E-mail: jan.bakkes@rivm.nl; www.rivm.nl
Contact person: Jan Bakkes

UNEP GRID-Arendal
Fakkelgården, Storhove, N-2628 Lillehammer, Norway.
Tel: +47 61 287916; Fax: + 47 61 287901;
E-mail: christian.nellemann@nina.no; www.globio.info
Contact person: Christian Nellemann

Stockholm Environment Institute - Boston (SEI)
11 Arlington Street, Boston MA 02116-3411, USA.
Tel: +1 617 266 8090; Fax: +1 617 2668303;
E-mail: praskin.at.tellus.org; www.tellus.org
Contact person: Paul Raskin

Preface

UNEP's third Global Environment Outlook (GEO-3), published in 2002, presented four scenarios of sharply contrasting futures, looking ahead over the next thirty years.

The scenario story-lines were developed in close collaboration with a range of experts, from different regions of the world. These story-lines and subsequent quantitative analysis led to estimates in the GEO-3 Outlook Chapter of the scenarios' impacts on a range of human and environmental concerns, from hunger to climate change.

This technical report provides background information to the Outlook Chapter of GEO-3. On the one hand, it elaborates some of the regional detail in the scenarios and provides analyses of the regional significance of the impacts. On the other hand, it explains the methods used for the quantitative impact analysis by the various teams that contributed to the chapter.

'Learning by doing' has been the motto of the GEO process, simultaneously developing its flagship report series and the network of collaborating centres. In support of this endeavour, this technical report also formulates recommendations for work on outlooks in future GEO reports.

I would like to thank the authors of this technical report, some of whom have already moved on to other responsibilities since their work on GEO-3, for their diligence and hard work and for their perseverance in completing the report. I also thank the reviewers in the various regions.

Dr. Klaus Töpfer
Executive Director, United Nations Environment Programme

Acknowledgements

This report was written with the collaboration of a large number of individuals, who were involved at various stages of the production – from initial drafting to reviewing. This list serves to acknowledge their work. However, the responsibility for the assessment rests with the authors. Mirjam Schomaker (consultant, France) carried out substantive editing of various parts of the report in various stages of the compilation and handled the review.

Joseph Alcamo	Center for Environmental Systems Research (CESR) at the University of Kassel, Germany
Johannes Bollen	National Institute for Public Health and the Environment (RIVM), the Netherlands
Lex Bouwman	National Institute for Public Health and the Environment (RIVM), the Netherlands
Ben ten Brink	National Institute for Public Health and the Environment (RIVM), the Netherlands
Marion Cheatle	Division of Early Warning and Assessment (DEWA) of the United Nations Environment Programme (UNEP)
Jacquie Chenje	Division of Early Warning and Assessment (DEWA) of the United Nations Environment Programme (UNEP)
Munyaradzi Chenje	Division of Early Warning and Assessment (DEWA) of the United Nations Environment Programme (UNEP)
Rutu Dave	National Institute for Public Health and the Environment (RIVM), the Netherlands
Ruth de Wijs	National Institute for Public Health and the Environment (RIVM), the Netherlands
Bas Eickhout	National Institute for Public Health and the Environment (RIVM), the Netherlands
Junichi Fujino	National Institute for Environmental Studies (NIES), Japan
Michael Gould	Translator / Editor, the Netherlands
Mirjam Hartman	Desk editor, the Netherlands
Henk Hilderink	National Institute for Public Health and the Environment (RIVM), the Netherlands
Mikiko Kainuma	National Institute for Environmental Studies (NIES), Japan
Yasuko Kameyama	National Institute for Environmental Studies (NIES), Japan
Kees Klein Goldewijk	National Institute for Public Health and the Environment (RIVM), the Netherlands
So-Joung Lee	Intern Division of Early Warning and Assessment (DEWA) of the United Nations Environment Programme (UNEP)
Ton Manders	Netherlands Bureau for Economic Policy Analysis (CPB), the Netherlands
Toshihiko Masui	National Institute for Environmental Studies (NIES), Japan
Bert Metz	National Institute for Public Health and the Environment (RIVM), the Netherlands
Johan Meijer	National Institute for Public Health and the Environment (RIVM), the Netherlands

Jiahua Pan	Xuanwu District Academy of Social Science, China
László Pintér	International Institute for Sustainable Development (IISD), Canada
Remko Rosenboom	National Institute for Public Health and the Environment (RIVM), the Netherlands
Kenneth Ruffing	Organisation for Economic Cooperation and Development (OECD), France
Mirjam Schomaker	Consultant, France
Khageshwar Sharma	Asian Institute of Technology (AIT), Thailand
Sudhir Sharma	Asian Institute of Technology (AIT), Thailand
Ram Shrestha	Asian Institute of Technology (AIT), Thailand
Subrato Sinha	Regional Office A&P, UNEP
Nicolette Star	National Institute for Public Health and the Environment (RIVM), the Netherlands
Kiyoshi Takahashi	National Institute for Environmental Studies (NIES), Japan
Tonnie Tekelenburg	National Institute for Public Health and the Environment (RIVM), the Netherlands
Sara Vassolo	Center for Environmental Systems Research (CESR) at the University of Kassel, Germany
Hans Visser	National Institute for Public Health and the Environment (RIVM), the Netherlands
Detlef van Vuuren	National Institute for Public Health and the Environment (RIVM), the Netherlands
Jaap van Woerden	UNEP-GRID, Geneva, Switzerland

Abbreviations

AIM	Asian-Pacific Integrated Model
ANZ	Australia and New Zealand
AOS	Atmospheric Ocean System
CCs	Collaborating Centres
CHP	Combined Heat and Power
CESR	Centre for Environmental Systems Research
DCW	Digital Chart of the World
EMF	Energy Modeling Forum
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GEO	Global Environment Outlook
GHG	Greenhouse gas
GLASOD	Global Assessment of Soil Degradation
GLCCv2	Global Land Cover Characteristics version 2
GLOBIO	Global Methodology for Mapping Human Impacts on the Biosphere
GSG	Global Scenario Group
ICIS	International Centre for Integrative Studies
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
NCI	Natural Capital Index
NCI-pb	Pressure-based NCI
NIES	National Institute for Environmental Studies of Japan
NINA	Norwegian Institute for Nature Research
OECD	Organisation for Economic Co-operation and Development
PPP	Purchasing-power parity
RIVM	National Institute for Public Health and the Environment
SEI	Stockholm Environment Institute
SRES	Special Report on Emissions Scenarios
TIMER	TARGETS-IMAGE Energy Regional model
UNEP	United Nations Environment Programme
UNEP_GRID	UNEP Global and Regional Integrated Data centres
UNEP_WCMC	UNEP World Conservation Monitoring Centre
UNU	United Nations University
USBC	United States Bureau of the Census
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VMAP	Vector Smart Map
WaterGAP	Water - Global Assessment and Prognosis
WIDER	World Institute for Development Economics Research
WRI	World Resources Institute
WWV	World Water Vision

Abstract

The four contrasting visions of the world's next three decades as presented in the third Global Environment Outlook (GEO-3) have many implications for policy – from hunger to climate change, from freshwater issues to biodiversity and from waste generation to urbanization. Quantitative implications of the worldwide GEO-3 scenarios 2002-2032 are presented in this Technical Report.

GEO is UNEP's flagship report series. It delivers modern environmental assessments based on broad and active participation by a large number of expert organisations. A key role is played by the GEO network of collaborating centres, carefully spread over the regions of the world. In fact, the development of this network is considered as important as the GEO reports.

Presenting a deeper analysis than the original GEO-3 report, this Technical Report quantifies the impacts of the scenarios for all 19 GEO 'sub-regions', such as Eastern Africa, South Asia and Central Europe. Regional impacts are discussed in the context of sustainable development. The report summary compares the impacts of the four scenarios across regions – and for the world as a whole - in the light of internationally agreed targets including those in the Millennium Declaration where applicable.

The report details the analytical methods applied to the GEO-3 scenarios – *Markets First, Policy First, Security First, Sustainability First* – and records the results of the analyses. It also provides an account of key assumptions, models and other tools, along with the approaches used in the analyses.

Based on the methods and results, the report looks back on the process of producing the forward-looking analysis for GEO-3. Were all analytical centres on the same track? Did the approach adopted for GEO-3 contribute to the overall GEO objective of strengthening global–regional involvement and linkages?

The report is intended for those interested in the background of the GEO scenarios, for experts interested in using region-specific findings of forward-looking studies on the environment and sustainable development, and for practitioners carrying out worldwide and regional assessments, like future GEO reports.

Contents

1. Introduction

1.0 Introduction

As part of its third Global Environment Outlook (GEO-3), the United Nations Environment Programme (UNEP) developed a set of four alternative scenarios depicting developments for the 2002-2032 period. These scenarios were intended to stimulate thinking on different possible trends in the environment at the global and regional level. The fours scenarios, together with their environmental implications, were presented in the Outlook chapter of GEO-3. During and after the work on this chapter, it became evident that there was strong interest in a more detailed description of the scenarios, as well as in the analytical work done for the GEO-3 Outlook chapter. Interest was also expressed in the process that was followed to describe and quantify the GEO-3 scenarios. This technical report was written to meet that demand.

1.1 The GEO Project

The UNEP Global Environment Outlook (GEO) project was initiated in response to the environmental reporting requirements of *Agenda 21* and a UNEP Governing Council decision of May 1995, which included a request to produce a comprehensive global state-of-the-environment report. The GEO project has two parts – the GEO process itself and the GEO outputs, which include the GEO report series. Many outputs are available, both in printed and electronic format. The various components are presented below, with particular emphasis on the Outlook chapter of the GEO-3 report.

1.1.1 The GEO process

This is a consultative, cross-sectoral global environmental assessment process. Within the context of sustainable development, it aims to bring environmental issues into the mainstream and integrate them into the knowledge centres and decision-making of people in public and private organizations

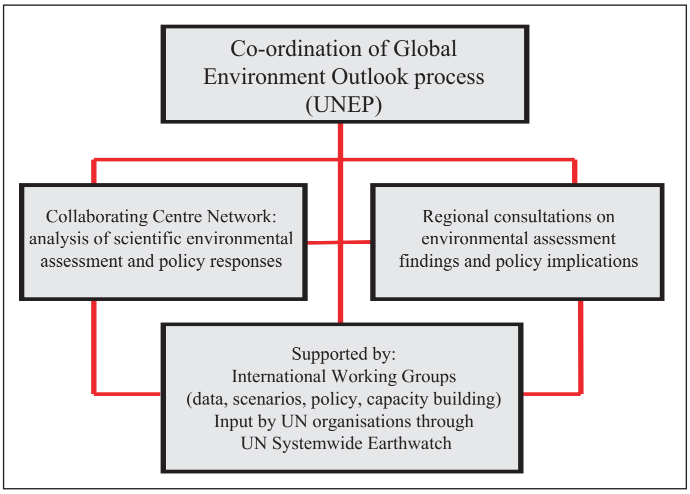
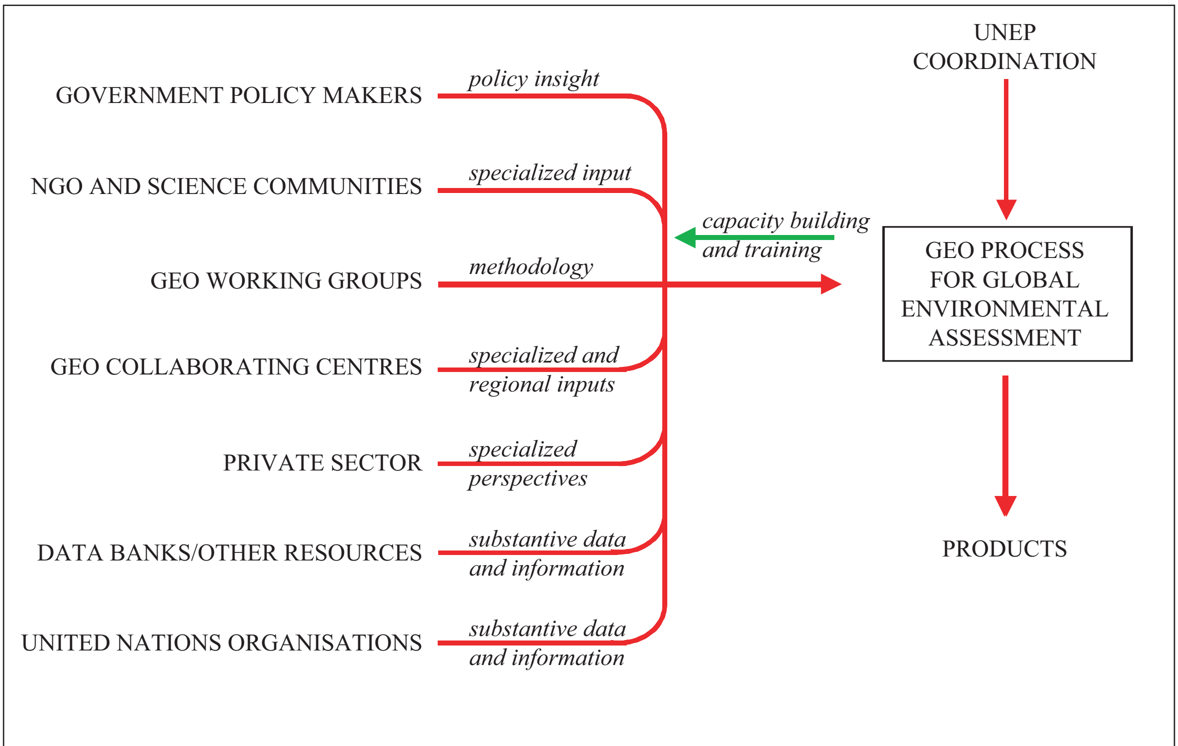


Figure 1.1 The GEO process

as well as those in other sectors of civil society. Furthermore, this process is geared to stimulating action by providing options for improving the state of the global environment. It incorporates regional views and stimulates consensus building on priority issues and actions through dialogue between policy-makers and scientists at the regional and global level. It also aims to strengthen the environmental assessment capacity in the regions through training and 'learning-by-doing'.

The GEO process is co-ordinated by UNEP but it involves numerous partners (see Figures 1.1 and 1.2). The GEO Co-ordinating Team is based at the UNEP office in Nairobi – with representation in the regional offices – and at its core there is a co-ordinated global network of collaborating centres (CCs) (see Table 1.1). These centres have played an increasingly active role in preparing GEO reports. Collaborating centres are now responsible for almost all of the regional inputs, combining top-down integrated assessment with bottom-up environmental reporting. Other institutions provide specialized expertise on crosscutting and thematic issues. Working together with the GEO Co-ordinating Team, the CCs research, write and review major parts of the GEO reports. Specific working groups provide advice and support. Other UN and international agencies also contribute, mainly by providing substantive data and information on the many environmental and related issues that fall under their individual mandates. They also participate in the review process.

Each of these partners provides special expertise. At the same time, the learning-by-doing process leads to a strengthening of capacity at these institutions and within UNEP. The particular areas emphasized in capacity building are training in integrated environmental assessment and reporting, training of trainers at the regional and sub-regional level, specialized technical training in relevant areas, and the provision of equipment and basic funding to Collaborating Centres.



Adapted from GEO-2000

Figure 1.2 The GEO partners (adapted from GEO-2000)

Table 1.1: GEO-3 Collaborating Centres

Arab Centre for the Studies of Arid Zones and Drylands (ACSAD)	Syria
Arabian Gulf University (AGU)	Bahrain
Asian Institute of Technology (AIT)	Thailand
Association pour le Developpement de l'Information Environnementale (ADIE)	Gabon
Bangladesh Centre for Advanced Studies (BCAS)	Bangladesh
Brazilian Institute of the Environment and Natural Renewable Resources (IBAMA)	Brazil
Central European University (CEU)	Hungary
Centre for Environment and Development for the Arab Region & Europe (CEDARE)	Egypt
Commission for Environmental Cooperation of the North American Agreement on Environmental Cooperation (CEC of NAAEC)	Canada
Earth Council	Costa Rica
European Environment Agency (EEA)	Denmark
GRID-Christchurch/Gateway Antarctica	New Zealand
Indian Ocean Commission (IOC)	Mauritius
International Centre for Integrative Studies (ICIS)	The Netherlands
International Global Change Institute (IGCI)	New Zealand
International Institute for Sustainable Development (IISD)	Canada
Island Resources Foundation	US Virgin Islands
Moscow State University (MSU)	Russia
Musokotwane Environment Resource Centre for Southern Africa (IMERCSA) of the Southern African Research and Documentation Centre (SARDC)	Zimbabwe
National Environmental Management Authority (NEMA)	Uganda
National Institute for Environmental Studies (NIES)	Japan
National Institute for Public Health and the Environment (RIVM)	The Netherlands
Network for Environment and Sustainable Development in Africa (NESDA)	Côte d'Ivoire
Regional Environmental Centre for Central and Eastern Europe (REC)	Hungary
RING Alliance of Policy Research Organizations	United Kingdom
Scientific Committee on Problems of the Environment (SCOPE)	France
Scientific Information Centre (SIC)	Turkmenistan
South Pacific Regional Environmental Programme (SPREP)	Samoa
State Environmental Protection Administration (SEPA)	China
Stockholm Environment Institute (SEI)	Sweden and United States
Tata Energy Resources Institute (TERI)	India
Thailand Environment Institute (TEI)	Thailand
University of Chile, Centre for Public Policy Analysis (CAPP)	Chile
University of Costa Rica, Development Observatory (OdD)	Costa Rica
University of the West Indies, Centre for Environment and Development (UWICED)	Jamaica
World Conservation Union (IUCN)	Switzerland
World Resources Institute (WRI)	United States

1.1.2 GEO outputs

The GEO report series – GEO-1 (UNEP, 1997), GEO-2000 (UNEP, 1999) and GEO-3 (UNEP, 2002) – are flagship UNEP publications. This series presents periodic reviews on the state of the world's environment and guidance on decision-making processes, such as the formulation of environmental policies, action planning and resource allocation. The reports are typically underpinned by sound scientific data and information. They use an integrated assessment approach, in which an analysis of both the current state of the environment and environmental policy is made. They present global and regional perspectives, are developed in a participatory and multi-stakeholder manner, and identify priority issues. Moreover, the reports are forward looking, policy-relevant, and oriented towards action and sustainable development. Further output of the GEO project includes regional, sub-regional and national environmental assessments, as well as technical and other background reports, a website (http://www.unep.org/geo/), products for young people (*GEO for Youth*), and a core database (the GEO Data Portal).

The forecasting approach applied to the three GEO reports produced so far evolved markedly from report to report.

In the Outlook Chapter in GEO-1 (UNEP, 1997) and the accompanying technical report (UNEP/RIVM, 1997) a single 'business as usual' scenario was analysed, portraying the effect of a further convergence of the world's regions towards Western style production, consumption and resource management. A fairly broad range of environmental issues was considered in the analysis, although difficult-to-model issues such as fisheries or 'industrial risks' were not covered (nor have they been included in subsequent GEO Outlooks). The GEO-1 impact analysis was already based on a system of interrelated world regions. Computational tools used were an earlier version of PoleStar providing regionalized assumptions and an earlier version of IMAGE producing spatially explicit impact estimates. Rudimentary estimates of the effect of applying Best Available Technology to all investments gradually over all regions was added to, though not integrated with, the GEO-1 scenario analysis.

The Outlook Chapter in GEO-2000 (UNEP 1999) shifted focus towards region-specific analyses of alternative policies, up to 2015, contrasted with a baseline scenario. Each considered a specific issue, for example fresh water in West Asia, urban air quality in Asia and the Pacific and forests in Latin America and the Caribbean. A six-step methodology, applying a baseline-cum-variant set-up was followed in these studies and described in a technical report (UNEP/RIVM, 1999).

In GEO-3, the Outlook was designed to cater for a more strategic approach, beyond the policy-optimization questions investigated by GEO-2000. Thus, GEO-3 looked further into the future than GEO-2000 did. As will be elaborated in this technical report, the GEO-3 analysis explored consequences and implications of alternative, comprehensively defined pathways into the future. It considered four starkly contrasting, yet all plausible scenarios for society, with a strong narrative component. The scope of the quantitative impact analysis was widened, in the style of GEO-1, but this time around included estimates of the number of people living with hunger._

GEO-3 was published 10 years after the first Earth Summit in Rio de Janeiro (1992) and 30 years after the Stockholm Conference on the Human Environment (1972). Since it was closely linked with the Rio+10 preparatory process, it helped set an action-oriented environmental agenda at the World Summit for Sustainable Development in Johannesburg (2002) and other relevant forums.

The time-frame adopted for the report is 1972 – 2032. *The State of the Environment* and a 30-year *Policy Retrospective* (1972-2002) are complemented by a 30-year *Outlook* (2002-2032). The four scenarios produced depict general developments during this period, viewed with an eye to the environmental implications at the global and regional and sub-regional (local) levels. Although none of the scenarios are intended to be predictions, the alternative futures provide insights into the direction in which events might lead in this period (2002-2032).

A Core Scenario Group and regional scenario workgroups were instrumental in producing the Outlook chapter of GEO-3. The teams involved in the development and analysis of the quantitative aspects included the Stockholm Environment Institute (SEI), the National Institute for Public Health and the Environment of the Netherlands (RIVM), the National Institute for Environmental Studies of Japan (NIES), the Centre for Environmental Systems Research at the University of Kassel, Germany (CSER), and the GLOBIO project at the Norwegian Institute for Nature Research (NINA). Finally, the International Centre for Integrative Studies at the University of Maastricht, the Netherlands (ICIS) and the RIVM assisted UNEP in co-ordinating the overall production of the chapter.

1.2 The structure of the report

This report is meant for professionals involved in environmental assessment and policy-making who are interested in obtaining more insight into the process and tools used as well as the quantitative results obtained during the preparation of the GEO-3 Outlook chapter. The report is not meant to provide full details of the input data, assumptions or tools used. Specialists in quantitative modelling of environmental/economic/social interactions who require more specific information are referred to existing scientific publications and websites on the various analytical tools used. The contact addresses of the main institutes which contributed to the production of the GEO-3 Outlook chapter are included in the preliminary pages. Readers are invited to contact the individual institutes for specific information on data input and the technical models.

As for the GEO reports in general, the GEO-3 Outlook chapter focuses on global and regional perspectives, showing sub-regional differentiation wherever possible. The GEO regional classification was used as much as possible for the regional and sub-regional perspectives presented in the report. However, for various reasons, variations were necessary in some cases; these were always noted (see Table 7.1 for details). Some discussion is included on the issue of regional classification in the Summary and Concluding Recommendations.

The analytical tools used (AIM, GLOBIO, IMAGE, PoleStar and WaterGAP) and the impact variables provided by each tool for the GEO-3 Outlook Chapter are listed in Table 8.1. However, several of these tools can also be used to analyse comparable (or even identical) variables. And indeed, several ‘overlapping’ variables were analysed during the preparations for the GEO-3 Outlook chapter (see Table 8.2). While not all of the results were included for all regions in the GEO-3 report itself, these will be presented here; the overlaps will make it possible to carry out some interesting cross-comparisons between the various tools and interpretations from different analytical teams.

The report is divided into an introductory chapter (Chapter 1) followed by seven specific chapters. Chapter 2 describes the development of the GEO-3 scenarios, documenting the various steps taken to develop the narratives and the quantitative aspects of the four GEO-3 scenarios, including some details on efforts to harmonize input data and assumptions for major driving forces among different tools and teams. Each of the subsequent five chapters deals with one of the five analytical tools used in the GEO-3 Outlook chapter and each presents the quantitative results for the environmental implications of the four GEO scenarios (see Table 8.1). Chapter 8 cross-compares scenario interpretations, tools and processes. Each chapter contains a discussion section that is specific to the subject discussed. The Summary and Concluding Observations (see the end of the report) include a traffic light-style comparison of the estimated impacts of the four scenarios (Table S.2), for the six regions and for the world as a whole. The chapter provides an overall discussion of the approach, lessons learned, and suggestions for future GEO scenario activities.

References

United Nations Environment Programme (UNEP), 1997. *Global Environment Outlook*. Nairobi: United Nations Environment Programme.

UNEP, 1999. *Global Environment Outlook 2000*. Nairobi: United Nations Environment Programme; London: Earthscan.

UNEP, 2002. *Global Environment Outlook 3*. Nairobi: United Nations Environment Programme; London: Earthscan.

UNEP/RIVM, 1997. Bakkes, J.A. and J.W. van Woerden eds. *The Future of the Global Environment: A model-based Analysis Supporting UNEP's First Global Environment Outlook.* Bilthoven: RIVM. Nairobi: United Nations Environment Programme.

UNEP/RIVM, 1999. Detlef van Vuuren en Jan Bakkes. GEO-2000 Alternative Policy Study for Europe and Central Asia: Energy-related environmental impacts of policy scenarios. Bilthoven: RIVM. Nairobi: United Nations Environment Programme.

2. Scenario description and quantification

This chapter describes the process, focusing on issues related to the desire to achieve global–regional integration, and coherence and consistency of the narrative and quantitative elements of the scenarios. As with any scenario development process, improvisation was, at times, required in the creation of scenarios for the GEO-3 Outlook chapter.

2.0 Introduction

The intention of the GEO-3 Outlook chapter was to meet certain criteria. These criteria, specified below, will be dealt with in this chapter. It should:

- complement a 30-year retrospective on the environment, as presented in the preceeding GEO-3 chapters;
- view future developments with an eye to environmental implications;
- be relevant to the forming of environmentally relevant policy;
- demonstrate global–regional integration in process and content; and
- present scenarios comprising coherent and consistent narrative and quantitative elements.

On the basis of previous GEO work and other similar activities, it was decided that an iterative process of scenario analysis, consisting of storytelling and quantitative scenario evaluation, could satisfy these criteria. The value of using such a combination is that it builds on the strengths of both approaches. Narrative scenarios can explore relationships and trends for which either few or no numerical data are available, e.g. shocks and discontinuities. These scenarios can also more easily incorporate human motivations, values and behaviour, and create images that capture the imagination of the group targeted. Quantitative scenarios can provide greater rigour, precision and consistency. Assumptions are explicit, and conclusions can be traced back to the assumptions. The effects of changes in assumptions can be easily checked and important uncertainties indicated. Quantitative scenarios can provide order-of-magnitude estimates of past, present and future trends in, for example, population growth, economic growth or resource use.

This chapter focuses on: (1) global-regional integration and (2) narrative-quantitative coherence and consistency. This report will emphasize the process rather than the product, i.e. to what extent were these two forms of integration successful, given the way in which the scenarios and the GEO-3 Outlook chapter as a whole were developed? Section 2.1 provides a history of the GEO-3 scenario development, highlighting key events and decisions. Given this background, the two process issues relevant to the narratives are addressed in section 2.2; this section briefly describes the resulting GEO-3 scenario narratives. Sections 2.3 and 2.4 move on to quantitative aspects and harmonization among the analytical teams. Primary emphasis is on the development of driving assumptions specific to population and overall economic development, while the environmental impacts themselves are the focus of Chapters 3 to 7.

2.1 Developing the GEO-3 scenarios: the first steps

The concept of developing and using scenarios as a major component of GEO-3 arose early in the planning process, which started with a meeting of GEO Collaborating Centres in November 1999.

Table 2.1: A temporal overview of the production of the GEO-3 outlook chapter

Date	Location	Event
Nov 1999	Nairobi	GEO-3 Start-up Meeting
Feb 2000	Nairobi	First UNEP Internal GEO-3 Meeting
Apr 2000	Bangkok	GEO-3 First Production Meeting
June 2000	Nairobi	Expert Group Meeting for the GEO-3 Outlook Chapter
July 2000	Boston, USA	GEO-3 Core Scenario Group Meeting (in the text mainly referred to as “Planning Meeting”)
Sept 2000	Cambridge, UK	Working Meeting for the GEO-3 Outlook Chapter
Oct-Nov 2000	various	Regional consultations on the GEO-3 Outlook Chapter
Dec 2000	Geneva	Drafting Meeting for the GEO-3 Outlook Chapter
April 2001	Hidalgo, Mexico	GEO-3 Second Production Meeting
May 2001		First draft
October 2001		Second draft
Nov 2001	London	UNEP/Shell Meeting of Scenario Experts for the GEO-3 Outlook Chapter (in text also referred to as Scenario Experts Meeting)
March 2002		Final draft
May 2002		Launch of GEO-3 report

As was the case for other aspects of the envisaged new GEO, a ‘game plan’ was drafted. The use of scenarios was a key issue at both the first UNEP Internal GEO-3 meeting in Nairobi in February 2000 and the first Production Meeting in Bangkok from 4-6 April 2000 (see Table 2.1). The first meeting devoted specifically to the Outlook chapter was the Expert Group Meeting hosted by UNEP in Nairobi from 13-14 June 2000. Here, a number of internal and external experts were brought together to discuss the conceptual framework for the chapter and the process for developing both the qualitative and quantitative aspects of the scenarios.

The underlying premises of the process and themes of the scenarios for the GEO-3 Outlook chapter were laid out at this Expert Group Meeting. There was prolonged discussion on the process, focusing on the questions of global versus regional, and centralized versus decentralized, development of the scenarios. The necessity of ensuring global consistency was also raised. At the same time, the need for regional flexibility and the full involvement of the regions was highlighted. Regional participation would be needed to promote ownership of the scenarios, but global coherence would also need to be maintained. It was decided that the process should fully incorporate regional views and participation, while maintaining a general global framework building on the extensive global research work that had already been undertaken. It was agreed that there should be ‘mutual conditioning’ where globally consistent themes have been developed; the regions would then be given the flexibility to take these issues further (UNEP, 2000). In the initial game plan for the GEO-3 report production, the theme on ‘vulnerability of human beings and ecosystems to environmental changes’ had been suggested as a possible discussion thread running through the report. This is the reason for considering vulnerability in the scenario development for GEO-3. At the regional level other sub-themes would be chosen as possible points of entry into the discussion on many other issues.

A Planning Meeting, held at the Stockholm Environment Institute in Boston, USA from 17-19 July 2000, was attended by representatives of Regional Outlook and global scenario focal points, along with UNEP experts exploring possibilities to assess in GEO-3 the changes in human vulnerability in function of environmental change, and a representative from the GEO UNEP HQ, in Nairobi, collectively known as the Core Scenario Group. Several key decisions were made at this time. First, it was agreed that four scenarios would be presented in the Outlook chapter. Second, as described in Box 2.3, the starting point for the specific scenarios would be the work of the Global Scenario Group (Raskin and others, 1998); however, their further development would also draw on other exercises, such as the IPCC SRES (Nakicenovic and others, 2000) and the World Water Vision (Cosgrove and Rijsberman, 2000) exercises.

The experiences with these two large, theme-oriented assessments formed an important background for the GEO-3 scenario exercise (see Boxes 2.1 and 2.2 for details on the IPCC-SRESS and WWV Scenarios).

Box 2.1: The IPCC-SRES Scenario Development Process

The development of the most recent set of emission scenarios for the IPCC is described in detail in a Special Report on Emission Scenarios (IPCC, 2000). This report simply refers to the emission scenarios as IPCC-SRES, or SRES scenarios.

The SRES process began with a general description of four global story-lines, each of which came to define a single scenario family. The story-lines emphasized general developments in areas such as the degree of globalization and the relative emphasis on economic growth and environmental concerns; no explicit climate policies were included in the story-lines.

Six modelling groups were invited to further implement and develop quantitative scenarios based on these narratives. Notably, there was no formal effort to feed the results of the quantitative exercises back into the narrative storylines once the basic features and driving forces were determined. This process ultimately resulted in a total of 40 quantitative scenarios. Within each family, the quantifications, one per family, were defined as the representative, or ‘marker’, scenario. Other scenarios within the family were classified as either harmonized or non-harmonized, vis à vis those of the marker scenario, depending on their assumptions for specific key drivers: population, gross domestic product and energy consumption.

In the SRES process, each modelling group provided a complete set of results for each quantitative scenario produced. This theoretically allowed for the exploration of uncertainties arising from different characteristics of these models (i.e. comparisons across scenarios within a family) and uncertainties from looking into the unknown future (i.e. comparisons across scenario families). However, this necessitated an important sacrifice. Since the models employ different regional classifications, all were required to aggregate their results to four regions: OECD90, Africa & Latin America, Asia, and countries undergoing economic reform. Even with this aggregation, Van Vuuren and others (2002) identified a number of systematic differences between scenarios. They were unable to trace these differences back to either model structure or specific assumptions in quantifying the story-lines.

Box 2.2: The World Water Vision (WWV) Scenario Development Process

The development of the WWV scenarios is described in Cosgrove and Rijsberman (2000) and Gallopín and Rijsberman (2000).

The WWV process began with the development of three qualitative story-lines. These normative story-lines, focused on water futures, postulated three general patterns of development: ‘Conventional World’, ‘Water Crisis’ and ‘Sustainable World’. After an initial review, including some quantitative comparisons, the storylines were refined into a first set of scenarios.

These scenarios were presented to four modelling teams and widely circulated at regional and sectoral fora for expert and public feedback. The feedback from the modelling teams and fora was used to revise the scenarios, which were then again circulated for further quantitative analysis and comments. In all, three rounds of iteration took place before the scenarios were finalized. Notably, the water problems posed by the ‘Conventional World’ scenario were significant enough to allow them to drop the ‘Water Crisis’. Two variations of ‘Sustainable World’ were developed instead, resulting in the final set of three scenarios: ‘Business as Usual’, ‘Technology, Economics and the Private Sector’, and ‘Values and Lifestyles’.

Within the WWV process, the four modelling teams worked independently and in close consultation so as to provide consistent and coherent results. They met three times and shared information, often with output from one modelling team providing input to other modelling teams. This was particularly significant in understanding the relationships between food and water security.

In the IPCC-SRES process, the scenarios were all viewed as exploratory. Apart from prescribed developments for population size, gross domestic product and energy intensity, the only constraints placed on them were the exclusion of any policy actions specifically related to the issue of climate change. For the WWV, two of the three scenarios were defined as normative. Specifically, these WWV scenarios had a vision of future conditions with respect to water resources, and how these were to come about. Interestingly enough, the nature of the normative scenarios changed in the process of developing the scenarios. Originally, the normative scenarios were to be ‘Water Crisis’ and ‘Sustainable World’ scenarios. The initial commentary and quantification made it clear, though, that the ‘Conventional World’ scenario was problematic enough, so it was decided to drop ‘Water Crisis’ and instead have the scenario set include two sustainability-oriented scenarios. This resulted in the final set of three scenarios: ‘Business as Usual’, ‘Technology, Economics and the Private Sector’, and ‘Values and Lifestyles’.

A more detailed specification of the characteristics of the GEO-3 scenarios is given below:

- Each scenario was to be differentiated at the regional level (according to the GEO regional breakdown), with some sub-regional differentiation where warranted.
- The scenarios were to have a holistic approach to sustainable development but provide an environmental window by emphasizing environmental descriptions and policies.
- The narratives were to have the following descriptive dimensions (be based on the following categories of driving forces): demographic, economic, social, technological, environmental, cultural and political (governance) drivers; some variables could not be quantified (e.g. social, political) but only described qualitatively.

- The same environmental themes would be used throughout the report, both in retrospective and prospective chapters.
- The narratives were to include the current state (drawn largely from GEO 2000 and the draft GEO-3 State of the Environment chapter), driving forces, a story-line into the future and a vision of the future.
- Possible impacts of the story-line and future vision were also to be described and used as a way of describing vulnerability of humans to environmental change in each scenario.

Box 2.3: Parentage and evolution of the GEO-3 scenarios

As noted in Section 2.1, the development of the GEO-3 scenarios was built on other existing and ongoing scenario exercises. In the Nairobi meeting in June 2000, the three archetypal scenario families and variants used by the Global Scenario Group were introduced. These are Conventional Worlds (Reference, Policy Reform), Barbarization (Breakdown, Fortress World), and Great Transitions (Eco-communalism, New Sustainability Paradigm). At the same time, parallels were drawn between these scenarios and those developed by the IPCC (IPCC, 2000), the World Water Forum (Cosgrove and Rijsberman, 2000) and the World Business Council on Sustainable Development (WBCSD, 1998).

The initial narrative scenarios presented in Boston in July 2000 were, in effect, the original GSG scenarios: Reference (renamed Conventional Development), Policy Reform, Fortress World and the New Sustainability Paradigm (renamed Great Transitions). As the GEO-3 scenarios evolved, however, they began to assume a character of their own. To some degree, this evolution began almost immediately, with initial attempts made to provide quantitative underpinning to the scenarios. Whereas this relied in part on previous work by the Stockholm Environment Institute to quantify the GSG scenarios, it also began to draw upon efforts by RIVM and NIES to quantify the IPCC SRES scenarios and by the University of Kassel to quantify the WWV scenarios. The efforts of the regional partners at the Cambridge meeting in September 2000, and especially during the regional consultation meetings later that year, further enhanced the scenarios. Over the next year, the evolution of the scenario narratives, while maintaining the spirit of the originals, took them further down their own paths. This was also seen in the further quantification of the narratives, as described in this chapter and in Chapters 3 to 7 of this report. One result of this process was that the scenarios in their final form received new designations: *Markets First*, *Policy First*, *Security First*, and *Sustainability First*.

It was also agreed in Boston that although the narratives would be backed up by quantitative data, there would be little time to compile new data, so the best available and credible global data would be used for the global level and, where possible, data would be provided at the regional level. This was a step backward from the original goal of creating full coherence between the narrative and quantitative elements of the scenarios, but it was felt to be a more pragmatic choice. It also implied that the narratives would have precedence over the quantification, i.e. the onus would be on the quantification to show clear problems with narrative stories before these were changed. This is not to say that quantitative information would not be used in developing the narrative stories, but only that this information would not drive the process.

This point marked the start of the actual development of the global and regional narratives and the quantitative aspects of the scenarios, with enormous efforts being made by individual contributors.

Parallel but periodically intersecting paths were followed in the development of these two aspects. The nature of the process makes it useful to distinguish these paths.

2.2 Further development of the narratives

Based primarily on comments formulated during the Planning Meeting, the scenario narratives were revised and presented at the GEO-3 Scenario Working Group Meeting on the Outlook chapter held in Cambridge, UK from 11-15 September 2000. During the meeting, regional working groups began the process of developing regional-level versions of the global narratives, focusing on regional driving forces, environmental and social implications and policy dimensions (note that work in Africa had begun earlier at a meeting in August). At the Cambridge meeting it became clear that all four scenarios should be fully developed, as opposed to concentrating on *Markets First* and *Policy First*, and only sketching the other two by way of backdrop.

More detailed work was therefore undertaken during a series of regional consultations held in October and November 2000. More complete regional narratives were developed, both during and after these meetings. Parallel to this, the global narratives were further revised, primarily on the basis of comments received during the September meeting in Cambridge. A background document prepared by SEI was used in several of these meetings; subsequently, this document was converted into a GEO Technical Report (Raskin and Kemp-Benedict, 2004).

The global narratives and summaries of the regional narratives were brought together at a Drafting Meeting of the GEO-3 Outlook chapter in Geneva, Switzerland in December 2000. This produced a 0-order draft of the Outlook chapter, including the scenario narratives. This draft was offered for review and presented at the second GEO-3 Production Meeting in Hidalgo, Mexico, 2-6 April 2001. During and shortly after this meeting, revisions were made, resulting in a first- order draft of the chapter, which was then subjected to wider review.

At this point, a number of concerns were raised about the scenario narratives and the Outlook chapter in general. Firstly, whereas the regional narratives had done a good job in most cases of summarizing driving forces, and social and environmental implications in each scenario, they did not tell dynamic stories. In other words, they did not depict the path by which regions moved from the present to a situation 30 years on. Secondly, a clear and unnatural separation between global and regional narratives remained, with little of the detail in the regional narratives represented in the global narratives, and little of the global context and the importance of relationships between regions reflected in the regional narratives. Thirdly, the environmental content and quantitative support for the narratives was limited, inconsistent across the regions, and not fully consistent with the scenario narratives.

In order to solve these problems the choice was made to fundamentally reorganize the narratives and the chapter itself. The global and regional narratives were integrated to present more holistic stories of the next three decades. Separate sections were developed specifically to present and compare the social and environmental implications across the different scenarios on global and regional scales. These sections presented more detailed quantitative analysis than had been undertaken in support of the scenario narratives. The regional sections also added a separate sub-component, looking at the implications of the different scenarios for specific events or developments within each region. This work, done in consultation with the regional writing and modelling teams, resulted in a new draft of the chapter in October 2001. This draft received thorough review and was presented at the Scenario Experts Meeting in London, UK on 1 November 2001. Based on the results of this meeting and the review comments received, the scenario narratives, along with the quantitative analysis undertaken in support of these, were revised once more, resulting in the final versions presented in the published GEO-3 report. The driving forces considered for the four GEO-3 scenarios are described below (copied from the GEO-3 Outlook chapter). For detailed scenario descriptions, the reader is referred to GEO-3 itself. Summaries of the GEO-3 scenarios are presented in Box 2.4.

Driving forces

There are many socio-economic factors driving environmental change. How these factors evolve will shape global and regional development and the state of the environment far into the future. Trends may continue as they have in the past or change speed and direction — perhaps even going into reverse. Trends may lead to convergence or divergence between circumstances in different regions of the world. Trends in one region or responses to one driving force, may oppose others that originate elsewhere, or they may run up against absolute physical limits.

The scenarios explored in the pages that follow are based on certain assumptions about how these driving forces will evolve and interact with developing situations, potential future shocks and human choices. This section briefly describes the assumptions made about driving forces underlying the scenarios and, in particular, how these assumptions differ from scenario to scenario.

The seven driving forces under consideration are demography, economic development, human development, science and technology, governance, culture and environment. The environment is included as a driving force because it is more than a passive receptacle for change. Just as the assumptions about human and societal behaviour shape the scenarios, so do the assumptions about pressures exerted by the environment.

Developments arising from each of the driving forces will not unfold in isolation from one another. Issues will interweave and chains of cause and effect are likely to be hard to trace back to individual sources. Finally, any number of possible future trends could be constructed from the available array of variables. Narrowing down this range to a small, yet richly, contrasting set of futures that is consistent, plausible, recognizable and challenging, will depend on the extent to which one starts out with an intelligent set of assumptions.

Demography

Population size, rate of change, distribution, age structure and migration are all critical aspects of demography. Population size governs to a great extent demand for natural resources and material flows. Population growth increases the challenge of improving living standards and providing essential social services, including housing, transport, sanitation, health, education, jobs and security. It can also make it harder to deal with poverty.

Rapid population growth can lead to political and social conflict between ethnic, religious, social and language groups. Increases in the number of people living in towns and cities are particularly important because urbanization means large changes in lifestyle, consumption patterns, infrastructure development and waste flows. Population structure — the relative proportion of children, persons of working age and elderly people within a population — has important repercussions for future population growth as well as for matching the provision of education, health care, incomes and pensions to predicted needs. Finally, internal and international migration, whether voluntary or forced, can sometimes ease and sometimes worsen the pressures that other demographic factors and other forces place on society and the environment.

Because so many of the people who will have children over the next 30 years have already been born, much can already be said about population over that period. All of the scenarios assume continued growth in global population, tailing off at the end of the period, as more countries pass through the demographic transition. Nearly all the growth occurs in developing countries, with North America as the only developed region with noticeable growth. Slightly lower population levels are foreseen in *Policy First* and *Sustainability First*, reflecting the idea that policy actions and behavioural changes speed up the transition to slower growth. In *Security First*, lack of effective policy, and much slower economic and social development, combine to slow down the transition. This leads to significantly higher population levels in this outlook, regardless of devastating demographic trends or events such as the HIV/AIDS pandemic in Africa that might be expected to have the contrary effect.

Urbanization increases or remains stable in almost all regions in all the scenarios, with the greatest increase in those regions currently least urbanized — Africa and much of Asia and the Pacific. In all regions, much of the development occurs in large coastal cities, a shift with serious implications for the coastal environment.

Apart from the Antarctic sub-region, which has no permanent resident population, current and future population structure differs markedly from region to region. North America, Europe and Japan have significantly larger shares of elderly people, a pattern that persists and increases in all scenarios. This trend is less marked in *Security First*, where advances in medical science (and hence in life expectancy) make less headway in all regions. Other areas, particularly Africa, West Asia, Latin America, and the Caribbean and South Asia, are dominated by youth. Their share of the population in these regions — but not their absolute population size — gradually decreases over the next 30 years in all scenarios.

In terms of migration patterns, *Markets First* and especially *Security First* are likely to have more conflicts and inequality, provoking more and more movements of refugees and economic migrants. Whereas more openness is assumed under *Markets First*, barriers to migration are expected in *Security First*. *Policy First* and *Sustainability First* also assume more open migration, especially for refugees and displaced communities. At the same time, more equitable sharing of resources for economic development and international assistance reduce the need for migration.

Economic development

Economic development encompasses many factors, including production, finance and the distribution of resources, both between regions and across sectors of society. Although the pattern varies conspicuously, there has been a general trend towards more service-based economies. Product, financial and even labour markets are becoming increasingly integrated and interconnected in a worldwide economy with global commodity chains and financial markets. Similar trends are appearing at regional level in several parts of the globe. These trends have been spurred on by advances in information technology, international pacts designed to remove trade barriers or liberalize investment flows and the progressive de-regulation of national economies. The same advances have also allowed wealth produced by national and transnational mergers to become concentrated in fewer and fewer hands. There has also been an increase in inequality in terms of income and resource use across — and often within — nations. For many nations the problem of inequality is made worse by debt burdens that seriously constrain growth. As transnational enterprises respond to global business opportunities, the traditional prerogatives of the nation-state and the capacity for macro-economic intervention by the state are challenged anew.

In *Markets First*, most of the trends noted above are assumed to persist, if not accelerate. Economic development outweighs social and environmental concerns in most international discussions. Resistance continues, but no radical changes in policy result. Recognition that maintenance of environmental and social conditions is important for ensuring economic development slows economic growth down over time, but not very noticeably.

In *Security First*, trends towards global integration continue for some parts of the economy, yet come to a halt or even go into reverse for others. Over time, more and more activity takes place in the grey or underground economy.

Integration trends persist in *Policy First* and *Sustainability First* but are tempered by the introduction of new policies and institutions to tackle social and environmental concerns. This reflects improved understanding of the crucial roles of human, social and natural capital in determining economic health. Changes in attitudes and behaviour in *Sustainability First* affect these trends more than in the other scenarios as the whole notion of economic development becomes increasingly subsumed in the broader concept of human development.

The effect of these changes on per capita income shows a strong variation across regions and scenarios. Average income growth in all regions is lowest in *Security First,* but is also very unevenly distributed due to the greater inequality within regions. In the other scenarios, average growth at the global level is similar but there are key differences between and within regions. In *Policy First*, the more equitable distribution of growth allows average incomes of the wealthy to grow slightly slower than in *Markets First*, whereas incomes rise more rapidly among the poor. The most dramatic increases in income growth are seen in Africa, but also in parts of Latin America and the Caribbean, Asia and the Pacific, and West Asia. The convergence in per capita incomes is even greater in *Sustainability First*, especially as wealthier persons shift their emphasis away from market-oriented production and consumption. However, large differences remain at the end of the 30-year period.

Human development

Health, education, security, identity and freedom are aspects of human development that are all clearly related to economic development, yet go well beyond it. Dramatic differences in access to these important human needs comprise a feature of the contemporary global scene. Impoverishment and inequity are critical problems for the poorer countries but conspicuous pockets exist, even in the richest countries. As the world grows more interconnected, these forces affect everyone directly or indirectly, through immigration pressure, geopolitical instability, environmental degradation and constraints on global economic opportunity.

The United Nations, World Bank, International Labour Organization (ILO) and International Monetary Fund (IMF) recently set out specific international development goals for poverty reduction, universal primary education, gender equality, infant and child mortality, maternal mortality, reproductive health and the environment. Achieving these goals depends on: ‘Stronger voices for the poor, economic stability and growth that favours the poor, basic social services for all, open markets for trade and technology, and enough development resources, used well' (IMF and others, 2000).

Among obstacles to achieving these goals are 'weak governance, bad policies, human rights abuses, conflicts, natural disasters and other external shocks. The spread of HIV/AIDS, the failure to address inequities in income, education and access to health care, and the inequalities between men and women. But there is more. Limits on developing country access to global markets, the burden of debt, the decline in development aid and sometimes inconsistencies in donor policies also hinder faster progress' (IMF and others, 2000).

Policy First and *Sustainability First* place emphasis on meeting basic needs and providing the resources to meet them, even where this may hinder short-term economic growth. In *Sustainability First*, relatively more basic needs' provision comes from groups outside the public sector, both businesses and non-governmental organizations.

In *Markets First*, these issues are not addressed to the same extent, as it is taken for granted that economic development naturally leads to social improvement. In addition, more of the facilities that have traditionally been provided as public services are privatized. These trends are even more pronounced in *Security First*, accompanied by greater inequality in terms of access. Where new funds, whether public or private, are invested in development, physical security increasingly takes precedence over social welfare.

Science and technology

Science and technology continue to transform the structure of production, the nature of work and the use of leisure time. Continuing advances in computer and information technology are at the forefront of the current wave of hi-tech innovation. Biotechnology galvanizes agricultural practices, pharmaceutical development and disease prevention, though it raises a host of ethical and environmental issues. Advances in miniaturized technologies transform medical practices, materials science, computer performance and much more. The importance of science and technology extends beyond the acquisition of knowledge and how it is used. Continuing concerns over the distribution of the benefits and costs of technological development provoke much national and international debate. Such concerns include technology transfer, intellectual property rights, appropriate technologies, trade-offs between privacy and security, and the potential for information-poor countries to find themselves on the wrong side of a 'digital divide'. The ultimate resolution of these matters influences the future development of science and technology, as well as their impacts on society and the environment.

In *Markets First*, it is assumed that the rapid technological advances of recent years continue, but are increasingly driven by profit motives. Over time this may actually slow down development as basic research is given less priority. Technology transfer, intellectual property rights and other issues are tackled, but mainly to the advantage of those with greater power in the marketplace. Environmental benefits largely come about as side-effects of efforts to improve the efficiency of resource use. These patterns are even more pronounced in *Security First*, where — in addition — the diversion of more and more public funding into security provision, coupled with social, economic and environmental crises, means slower progress all round.

Rapid advances in science and technology are also assumed in the *Policy First* and *Sustainability First* scenarios, but these are driven by different factors. Direct investment by governments, subsidies and regulation — for example, pollution taxes — play a dominant role in *Policy First*. In *Sustainability First*, these levers are overshadowed by changing preferences of both consumers and producers. In both scenarios, greater caution on the part of governments and society at large may slow down technological development in some areas but also helps to head off serious side-effects. Greater efforts are also made to share the benefits of science and technology.

Governance

Governance refers to actions, processes, traditions and institutions by which authority is exercised. It is most often associated with governmental bodies at the national level and with regional or global institutions such as the United Nations, but this need not always be the case. Private institutions, such as corporations and non-governmental organizations, also play an important role in governance. In all cases, developments that affect participation, accountability, transparency, corruption and civil strife have an important influence on the shape of the future.

Although the forms and effectiveness of governance differ markedly around the world, various tendencies can be identified. One tendency is towards greater individual autonomy and the devolution of authority. This shift is expressed at the personal level in terms of a growing emphasis on individual rights, especially women's rights. It is also noticeable in the devolution of governmental authority to smaller and more local units, and in separatist movements. The private sector, too, has moved towards 'flatter' corporate structures and decentralized decision-making. A second and somewhat opposite tendency is towards forms of greater regional integration and global governance through such mechanisms as international trade and environmental agreements. Another tendency is towards greater integration and the growth of networks within and across private and public institutions. This is seen, in part, in the rise of global public policy networks and the emergence of civil society as an important voice in decision-making in many regions.

In *Markets First*, present trends are assumed to continue but with heavier emphasis on ensuring the smooth functioning of markets. Efforts are focused on the development of international institutions that will encourage free markets for resources, finance and products. In *Policy First*, greater coordination is assumed, particularly at the level of international governance. This includes the development of new institutions and more cooperation between the public and private sectors. Significantly, these changes are driven from the top – by governments, corporations or large non-governmental organizations (NGOs).

In *Sustainability First*, the shifts in governance are assumed to be driven much more from the bottom up. Reflecting the changing values and making use of the trends towards greater participation, in general, individuals and grassroots organizations become more and more involved in setting the agenda, a lead that larger organizations then follow. Governments continue to govern but do so in a fashion that involves more power sharing.

As with other aspects in the *Security First* scenario, assumed trends regarding governance differ over time and across groups more than in the other scenarios. Corruption, ineffective governance and reactions against both contribute to breakdown in parts of society. As societies regroup, governance among the 'haves' is assumed to become more centralized and autocratic, but largely effective. International coordination also bolsters the relative stability of these groups. The nature and effectiveness of governance is mixed among the 'have-nots'.

Culture

Culture includes the set of values and institutions that enables a society to develop and maintain its identity. Cultural signatures differ around the globe and reflect, for instance, conflicting ideas about the worth of economics as an integrating system of values or about the importance of technology and technological change as springboards for human progress. Cultural signatures also hinge on differing concepts of justice and fairness, and on differing beliefs about the relationship between people and the natural and spiritual world.

Recent history, particularly where racism, colonialism and genocide have been present, cannot be overlooked. Much has been said about the expansion of Western culture to the detriment of other cultures, about reactions to this spread and about possible clashes of civilizations as a result. To some, it is clear that many individuals aspire to Western lifestyles, while others see Western values permeating societies and associate them with selfish individualism and excessive consumption. This spread represents both a cause and an effect of economic globalization, aided by the far-reaching penetration of information technologies and electronic media. At the same time, there have been clear signs of nationalist and religious reaction against it, sometimes resulting in terrorist activities and in open warfare within or between nations.

Among the four scenarios, *Sustainability First* assumes the largest shift from current trends in terms of culture. The ascendancy of the values of solidarity, reciprocity, sufficiency and stewardship is at the heart of this scenario. To the extent that these core values are not violated, tolerance is also a key aspect of culture in this scenario.

In *Markets First*, little change in current trends is assumed. As befits the basic notion of a market, the trend towards individualism accelerates, as does a trend towards homogenization of culture. At the same time, so does passive and active resistance by particular groups and regions. In *Security First*, these and other trends lead to clashes that undermine many elements of society. *Policy First* assumes a middle path between *Markets First* and *Sustainability First*; efforts to encourage some of the trends of the latter compete with tendencies to follow the trends of the former.

Environment

Though the focus of this section is on the importance of socio-economic change in triggering environmental impacts, it is clear that environmental change is a potent driving force in its own right. Countries and regions must contend not only with unequal environmental endowments, but also with acute environmental problems. Human impacts on the environment have aroused growing anxiety. Atmosphere, land and water resources have been spoiled. Persistent organic pollutants and toxic substances have accumulated in living organisms. Species have been lost and ecosystems degraded. In addition, social and ecological systems are vulnerable to natural and human-influenced hazards and catastrophes.

The way natural systems react to these pressures (the rate, for instance, at which climate patterns change as a result of higher concentrations of greenhouse gases, or the response of coastal ecosystems to pollution) can have a large impact on social, economic and other natural systems. The realization that individual states cannot shield themselves from environmental change is already changing the basis of geopolitics and global governance.

The scenarios presented here do not differ greatly in their assumptions about the environment as a driving force. Most significantly, it is assumed that natural systems are in a more fragile condition in *Security First* than in the other scenarios. This implies that ecosystem collapses and curbs on the capacity of certain natural systems to provide goods and services are more likely, even when facing the same pressures. In *Policy First* and especially in *Sustainability First*, the values of stewardship and caring for the environment play a greater role in guiding science, technology and governance, as well as in shaping economic and social development.

Box 2.4: Summaries of the GEO-3 scenarios

Markets First

Most of the world adopts the values and expectations prevailing in today's industrialized countries. The wealth of nations and the optimal play of market forces dominate social and political agendas. Trust is placed in further globalization and liberalization to enhance corporate wealth, create new enterprises and livelihoods, and in doing so, to help people and communities afford to insure against — or pay to fix — social and environmental problems. Ethical investors, together with citizen and consumer groups, try to exercise growing corrective influence but are undermined by economic imperatives. The powers of state officials, planners and lawmakers to regulate society, economy and the environment continue to be overwhelmed by expanding demands.

Policy First

Decisive initiatives are taken by governments in an attempt to reach specific social and environmental goals. A coordinated pro-environment and anti-poverty drive balances the momentum for economic development at any cost. Environmental and social costs and gains are factored into policy measures, regulatory frameworks and planning processes. All these are reinforced by fiscal levers or incentives such as carbon taxes and tax breaks. International 'soft law' treaties and binding instruments affecting the environment and development are integrated into unified blueprints and their status in law is upgraded, even though fresh provision is made for open consultation processes to allow for regional and local variants.

Security First

This scenario assumes a world of striking disparities where inequality and conflict prevail. Socio-economic and environmental stress gives rise to waves of protest and counteraction. As such, troubles become increasingly prevalent and the more powerful and wealthy groups focus on self-protection, creating enclaves akin to the present day 'gated communities'. Such islands of advantage provide a degree of enhanced security and economic benefits for dependent communities in their immediate surroundings but exclude the disadvantaged mass of outsiders. Welfare and regulatory services fall into disuse but market forces continue to operate outside the walls.

Sustainability First

A new environment and development paradigm emerges in response to the challenge of sustainability, supported by new, more equitable values and institutions. A more visionary state of affairs prevails, where radical shifts in the way people interact with one another and with the world around them stimulates and supports sustainable policy measures and accountable corporate behaviour. There is a much fuller collaboration between governments, citizens and other stakeholder groups in decision-making on issues of close common concern. A consensus is reached on what needs to be done to satisfy basic needs and realize personal goals without beggaring others or spoiling the outlook for posterity.

2.3 Development of the quantification

As noted above, the quantification of the scenarios followed a parallel but periodically intersecting path to the development of the scenario narratives. At the Planning Meeting in July 2000, the Stockholm Environment Institute presented initial quantification for two of the proposed scenarios: Conventional Development (predecessor of *Markets First*) and Policy Reform (predecessor of *Policy First*). This was based on previous work of the Global Scenario Group using the PoleStar software tool (Raskin, 2002). Whereas PoleStar offers a flexible and easy-to-use accounting framework for organizing economic, resource and environmental information for alternative scenarios (see Chapter 3 for more detail on PoleStar), it was agreed that this needed to be complemented by further information on environmental impacts. These could only be provided by other, more spatially explicit, and process- oriented modelling tools.

Thus, prior to the Working Meeting in September 2000, RIVM undertook an exercise to provide quantitative insights drawn from related global scenario studies (Bakkes and others, 2000). These were derived principally from RIVM's quantification of the IPCC SRES scenarios using the IMAGE model (see Chapter 7 for more on the IMAGE model) and CSER's quantification of the World Water Vision Scenarios using the WaterGAP model (see Chapter 5 for more on the WaterGAP model). Boxes 2.1 and 2.2 briefly describe the WWV and IPCC-SRES scenario developments.

During the Regional Meetings in Autumn 2000, further efforts were made to quantify the scenarios, particularly the regional aspects. Following a number of the regional consultations, the quantitative assumptions (primarily for population and overall economic growth) used in the PoleStar system for the *Markets First* and *Policy First* scenarios were reviewed and revised by SEI in light of the narratives.[5]

As noted earlier, in the first draft of the chapter presented in Spring 2001, the quantitative support for the narratives was limited to the *Market First* and *Policy First* scenarios. The data were also inconsistent across regions and scenarios, and not fully consistent with the scenario narratives. Over the next several months, efforts were made to rectify this situation. The set of quantitative data eventually presented in the second draft in October 2001 was developed using all four tools mentioned so far: PoleStar, AIM, IMAGE, and WaterGAP. Moreover, the AIM model of NIES was introduced as another tool for providing quantitative elements for the scenarios, specifically for Asia and the Pacific (see Chapter 6 for more on the AIM model). Data were presented for all four scenarios. In each case, these were based in part on available scenarios having kinship with the GEO-3 scenarios. Whereas the data were considerably more complete and consistent, the comments on this draft, particularly those made at the Scenario Experts Meeting in November 2001, pointed out the need to further improve on the consistency of the data inputs and to link the quantification more clearly to the underlying narratives.

Thus after the Scenario Experts Meeting, a tremendous amount of work needed to be done on the quantitative aspects of the scenarios. In particular, the quantification had to be tailored more specifically to the GEO-3 scenarios, while building on detailed work from already existing scenario studies. To do so, a harmonization exercise was organized to bring the crucial assumptions on

---

[5] At this point, the quantification of the *Security First* and *Sustainability First* scenarios had yet to begin.

Table 2.2: Assumptions for growth rates of per capita Gross Domestic Product (GDP) 2002 - 2032

	Markets First	Policy First	Security First	Sustainability First
	% per year; GDP expressed in purchasing power parity			
North America	1.7 – 2.1	1.0 – 1.7	0.6 – 0.9	0.4 – 1.5
LatinAmerica and the Caribbean	2.0 – 2.4	2.4 – 2.5	1.6 – 1.8	2.7 – 3.1
Europe*	2.0 – 2.5	1.7 – 2.4	0.8 – 1.2	1.4 – 2.1
West Asia*	2.2 – 2.3	2.4 – 2.8	1.4 – 1.8	3.0 – 4.1
Africa*	1.6 – 2.5	2.7 – 3.0	2.1 – 3.6	3.5 – 3.8
Asia and the Pacific*	2.2 – 3.6	2.7 – 3.5	1.4 – 2.2	3.0 – 3.1

*The regional definitions differ between the tools involved; see table 7.1

Table 2.3: Assumed annual average population growth 2002 - 2032

	Markets First	Policy First	Security First	Sustainability First
	% per year			
North America	0.6 – 0.7	0.6 – 0.7	0.9	0.4 – 0.7
Latin America and the Caribbean	1.0 – 1.1	1.0	1.4 – 1.6	0.8 – 1.0
Europe*	-0.1 – 0.2	-0.1 – 0.2	0.2 – 0.4	-0.2 – 0.2
West Asia*	1.7 – 2.2	1.7 – 2.1	2.3 – 2.5	1.7 – 2.0
Africa*	1.9	1.8 – 1.9	2.2	1.7 – 1.9
Asia and the Pacific*	0.7 – 0.8	0.7	1.2 – 1.3	0.6 – 0.7
World	0.9	0.8 – 0.9	1.3 – 1.4	0.7 – 0.9

*The regional definitions differ between the tools involved; see table 7.1

growth in GDP per capita for the four scenarios as closely in line as possible. Tables 2.2 and 2.3 present the eventual range of assumptions for population increase and growth of GDP per capita. The tables present regional aggregates, rather than the subregional numbers that were actually used, in order to allow a good overview that is based on comparable spatial units. The ranges indicate the spread between the assumptions employed by the analytical teams. At the same time material available through the existing integrated models was adapted after tests showed that it was related enough to serve as a basis for the further GEO-3 scenario work[6]. The eventual growth rates of

---

[6] There was no time to invent and test from scratch all the detailed assumptions on sectoral developments that make each of the four story-lines concrete. This included how policies are reflected in physical measures, shifts in technology etc. In integrated models like IMAGE and AIM, this represents a consistent fabric of many interrelated settings. Rewriting this is a major undertaking that should have been commissioned earlier. Therefore the not unusual approach applied was to adapt existing material after testing showed this to be possible.

regional GDP per capita are shown in Table 2.2. And in the same period, the GLOBIO model was introduced as a further tool with possibilities to contribute to the quantification (see Chapter 4 for details on GLOBIO).

The efforts to harmonize the key input assumptions among various analytical tools are elaborated in Section 2.4. As a final step, new calculations were made for the four scenarios, using the now more harmonized data and input assumptions. The final quantitative analyses are presented in the published GEO-3 report and at a more detailed level in the current technical report.

2.4 Further quantification - harmonization efforts

A consistent challenge to the quantification of environmental impacts, as envisaged for GEO-3, was that the available GEO-3 scenarios needed to be interpreted further than the regional write-ups had gone. A host of assumptions on the development of specific sectors, trade and tariffs, technology diffusion, education and effectiveness of measures needed to be detailed and specified in the development trajectories over time in order to analyse environmental impacts with relatively powerful, integrated models such as AIM, IMAGE or WaterGAP. In line with the focus of GEO, this elaboration needed to be regionally differentiated but globally coherent.

Much of this more detailed interpretation could be potentially quickly achieved by adapting large pieces of the recent IPCC Special Report on Emission Scenarios, for which the AIM and RIVM teams had just elaborated regionally detailed scenarios (IPCC, 2000; Morita and others, 2000). Similarly, material from the World Water Vision provided a useful basis. In general, it is not uncommon to analyse the impacts of new scenarios by ‘borrowing’ detailed elaboration from existing scenarios by marginally changing macro-economic assumptions and adding or leaving out specific assumptions and policies.

There are important similarities between GEO-3 and SRES story-lines. One is the correspondence between the GEO-3 narrative for *Security First* and the SRES *A2* narrative as elaborated for IPCC by the RIVM team. The GEO-3 narratives for *Markets First* and *Sustainability First*, however, resemble this team’s elaboration of the SRES *A1b* and *B1-450* scenarios, respectively (IPCC, 2000; Van Vuuren and De Vries, 2001; B1-450 includes climate policies). Finally, the *Policy First* scenario can be associated with another RIVM elaboration of the SRES *A1b* scenario, this time including several policy actions to improve the situation for a number of environmental and social endpoints.

For this reason, the quantitative interpretation of these SRES-narratives had been taken as a starting point for quantification of additional input data and assumptions by the RIVM team for each of the GEO-3 narratives. Population data, as reflected in the GEO-3 scenarios developed with PoleStar by mid-2001, were comparable to the IMAGE/SRES scenarios, but there were clear differences between GDP data for *Markets First* and A1b. Especially in currently low-income regions, the A1b scenario shows a very strong increase in GDP per capita (reflecting among other things the SRES condition that its scenarios should show convergence between rich and poor regions of the world).

The differences between GDP data for *Sustainability First* and IPCC’s *B1-450* are fairly large, since the GEO-3 values for GDP in *Sustainability First* – as provided by the PoleStar team – were remarkably low. However, these differences can be traced back to the fact that the

WorldScan/IMAGE modelling assumes that economic developments and transactions will continue to be reflected in GDP. In contrast, the very low GDP/cap values for North America and Europe recorded from PoleStar reflect the assumption that a growing part of transactions is done informally, possibly via a local service exchange. In fact, what matters most for the GEO-3 scenario exercise is the physical reality behind the numbers. In physical terms, the IMAGE/SRES B1 scenario can be seen as a good representation of a world of *Sustainability First*.

Against this background, the November 2001 Scenario Experts Meeting in London had emphasized the need for more visible harmonization of GDP per capita growth rates between the various teams involved, as these numbers had played a role in the preceding consultations on the story-lines in a number of regions.

In practice, harmonization was implemented as IMAGE, AIM and WaterGAP brought forth new calculations for *Markets First*, *Policy First* and *Sustainability First*. This was done on the basis of pre-existing detailed material, but with key assumptions brought, as far as possible, in line with GDP/cap numbers quoted by the PoleStar team. Conversely, PoleStar calculations for *Security First* were to be redone on the basis of the A2 scenario from the set of SRES mitigation scenarios. The latter was necessary because impacts of the scenarios on hunger were to come from the PoleStar system.

The assumptions for *Security First* had not been quantified in the earlier stages of work on the outlook (at the time when regional consultations were taking place). Thus, strictly speaking, it was not so much harmonization that was needed as agreement on what pre-existing material best fitted the story-line of *Security First*.

Obviously, a key indicator like regional GDP per capita growth is intimately connected with the underlying detailed story about investment climate, demographic developments, openness of economies and the like. Thus, in the preparation of new model runs in response to the advice by the London meeting, the regional GDP per capita growth rates in the pre-existing IMAGE, AIM and WaterGAP material were only changeable to the extent of them being by and large consistent with the ‘world’. This was manifested in the whole fabric of underlying assumptions or plausible amendments to it.

This was the first aspect to clarify. In realizing this aim, the RIVM team ran a test to determine if conditions termed ‘exotic’ in a world of *Markets First* and *Policy First* (e.g. a worldwide increase in trade barriers in *Markets First*) would have to be applied to make the GDP per capita numbers more or less equal to PoleStar numbers. In other words, before re-doing impact analyses, a pre-analysis was run to find out whether the changes in GDP per capita in *Markets First* and *Policy First* in the various regions could be approximately reconstructed in the WorldScan/IMAGE macro-economic framework. This was reflected in the GEO-3 story-lines developed with PoleStar by mid-2001. The IMAGE work for SRES would be the starting point, assuming extra conditions consistent with the GEO-3 story-lines.

Fortunately, the pre-analysis showed that the GDP data for the *Markets First* scenario, as provided by PoleStar in mid 2001, could indeed be reconstructed without assumptions that would be exotic to the scenarios. Specifically, the growth rates could be reconstructed by assuming (within the assumed uncertainty range of the modelling) a 15% slower GDP/cap convergence (see above) for the LAC region. Furthermore, one or more of the following marginal changes would be applied in the input data and assumptions for the IMAGE/SRES *A1b* scenario:

- less removal of trade barriers; or
- no global convergence of risk on investments; or
- a less steep increase in highly educated participants on the labour market (10% off the SRES level); or
- constant rather than increasing labour participation; or
- no global convergence of the demand pattern in consumption–growth, but also no change in the proportion of the demand for agricultural products, or housing, for example.

Since these changes were small, we were confident that the detailed sectoral and regional input data and assumptions for the IMAGE/SRES A1b could be scaled down to GDP data as included in the mid-2001 GEO-3 scenarios without gross inconsistencies. In other words, the slower growth in GDP per capita for *Markets First* could be translated into somewhat slower or later changes in lifestyle, demand and technologies in each sub-region.

Only the low growth rates for the African regions, as postulated in the mid -2001 GEO-3 scenarios remained difficult to imagine without assuming that Africa stays an economic island in a world with otherwise high growth, large international interaction and relatively rapid diffusion of technology. However, the *Markets First* scenario assumes that 'even as it struggles to deal with persistent conflicts and the AIDS pandemic, Africa pushes ahead with economic modernization and greater integration in the global economy' (GEO-3, page 330). The explanation for the initial low growth rates for Africa can be sought in current institutional and governance limitations. Thus we interpreted the 30-year average, mid 2001, assumptions as a combination of relatively slow growth in GDP per capita during the first half of the scenario period (2002-2016), while during the second half (2017-2032), the reverse would apply.

Subsequently, *Policy First* was interpreted to build on the *Markets First* scenario, but the atmosphere of international trust and ambitious pursuit of social and environmental goals would entail:

- ambitious energy and climate policies (see Annex 1),
- a fast phasing-out of trade tariffs (towards almost zero in 2032),
- faster improvement in education in non-OECD countries (translating macro-economically as a 10% larger 'skill upgrading' by 2032), and
- ambitious productivity improvement in agriculture, almost like a second green revolution (see Annex 1).

Security First was taken as identical to the IMAGE/SRES A2 scenario (IPCC, 2000). The basic pattern of this scenario is regional contraction, both cultural and economic, with a correspondingly slow change in demographic patterns and thus large population growth in low-income regions.

Sustainability First was interpreted as being comparable to the IMAGE/SRES B1-450 mitigation scenario (Van Vuuren and De Vries, 2001). This scenario envisions a globalizing world, with values that lead to priority for environmental and social goals. This is made operational by assuming the same environmental and agricultural policies as in the world of *Policy First*, but with more ambitious energy and climate policies. This implies a high-tech interpretation of *Sustainability First* (alternative interpretations can also be argued). Additionally, a strong development towards integrated approaches was assumed (particularly changes in energy production and consumption)

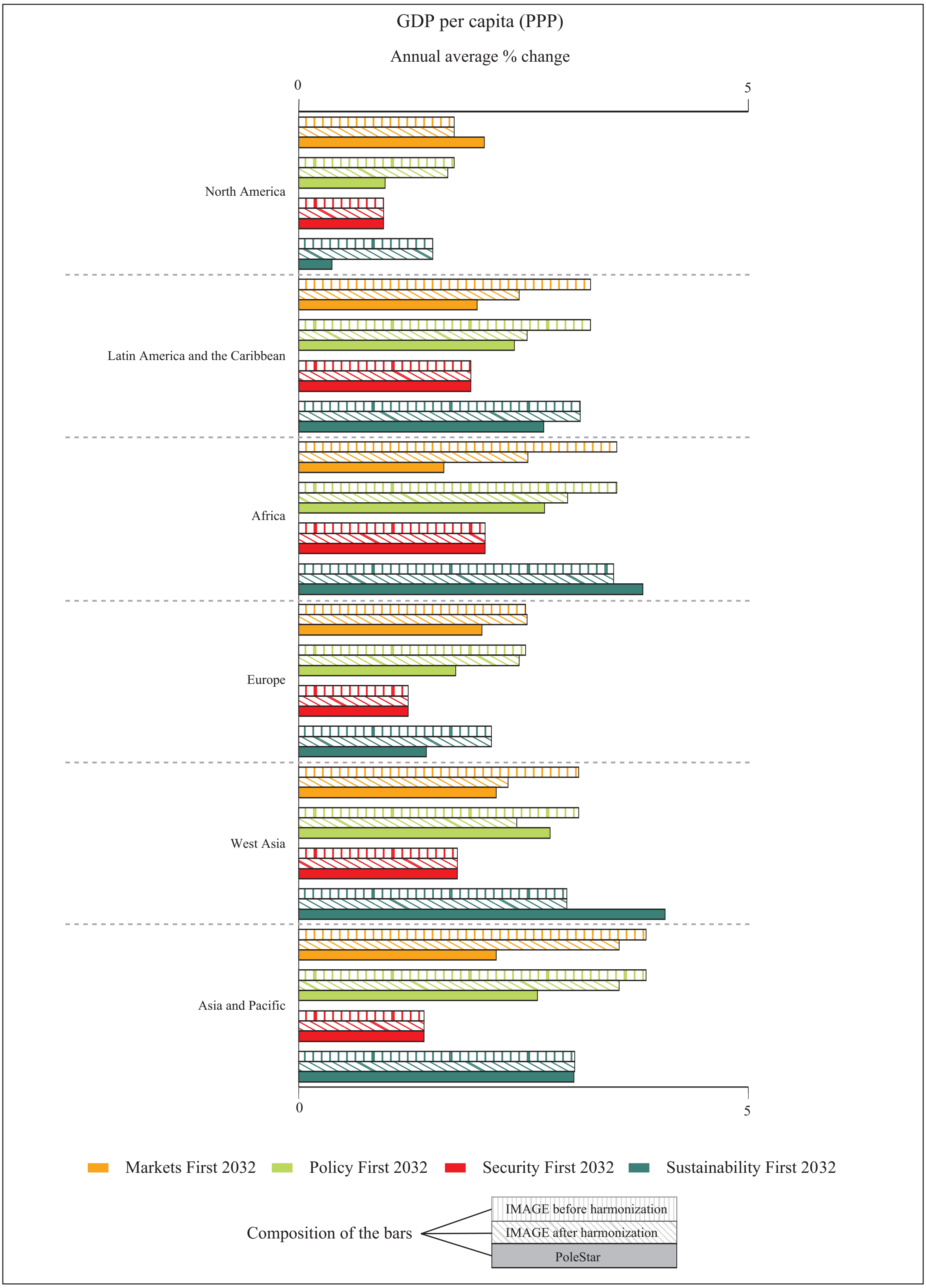


Figure 2.1: PoleStar and IMAGE assumptions for growth rates of per capita Gross Domestic Product (GDP), 2002-2032, before and after harmonization

Note: on harmonization of assumptions regarding *Security First*: see text rather than towards end-of-pipe measures such as large-scale underground storage of carbon dioxide. The GDP per capita growth rates for *Sustainability First* were derived by adjusting the B1-450 rates in line with the derivation of *Markets First* from A1b, as described above.

In summary, for most scenarios and regions the resulting two sets of assumptions have converged (see Figure 2.1). There are still relatively large differences in GDP/cap for *Markets First* in Asia and the Pacific and in Africa, but no differences for North America and Europe. As has been mentioned earlier in this section, the different GDP numbers quoted for *Sustainability First* do not necessarily reflect substantially different assumptions about physical developments.

The conspicuous difference for *Security First* in Africa reflects an unintended difference in interpretation. Although it was agreed to copy the assumptions for this scenario from the SRES A2 scenario, the projections made by the PoleStar team are unaccountably based on a different set of quantitative assumptions. Most importantly, this set of assumptions for *Security First* has been used in the estimate of people living with hunger. As this background influences the resulting impact estimates, the incongruent PoleStar *Security First* number has been included in Figure 2.1.

Making a detailed comparison between the growth assumptions in GEO-3 and other recent scenarios with a similar time horizon, such as the baseline scenario of the OECD Environmental Outlook (OECD, 2001) and IPCC SRES (IPCC, 2000), is not easy. A detailed comparison is hindered by incongruent regional classifications and by the fact that some of the studies expressed growth in market-based exchange rates as opposed to purchasing power parity. But it is in any case clear that the GEO-3 growth assumptions for GDP per capita in developing regions under the *Markets First* and *Policy First* scenarios are high when compared with the OECD's baseline assumptions.

With specific reference to energy and land-related issues, assumptions were added as a quantitative interpretation of the GEO-3 scenarios. Annex 1 lists the specific assumption on energy production. Land-related issues are listed in some detail in Annex 2 and outlined below too, considering their extensive influence on what happens to terrestrial biodiversity, for example, and to the spatial differentiation of developments within the regions.

The GEO-3 scenarios assume ambitious policies towards agricultural efficiency improvements to be pursued in all but the *Security First* scenario. This corresponds with spending on research and development, and fast technology diffusion in the *Markets First* and *Policy First* scenarios, and with pro-nature policies in *Policy First* and *Sustainability First*. Such ambitious improvements in agricultural efficiency slow down the rate of land conversion, which is driven by the increasing demand for agricultural products from a growing population, increasing incomes and changing diets.

The theoretically feasible yield of crops depends on sub-regional climate and soil conditions, and is limited by less than ideal management practices, technology and know-how. The actual yield is assumed to be scenario-dependent, but will increase in time. Actual yields for *Policy First* and *Sustainability First* are 10% larger than for *Markets First* and *Security First,* thanks to larger research expenditures, and more training and education. These crop yields are still achievable under practical conditions, typically assuming an increase in irrigation (see Chapter 5 for irrigation).

The future of livestock production is particularly important for developments in environmental problems. The efficiencies in livestock production are assumed in IMAGE to follow GDP growth, with sub-regions reaching the 1995 efficiency of OECD Europe as soon as their per capita GDP reaches the 1995 income of OECD Europe. Specific sub-regional assumptions on the development in carcass weight, feed efficiency and off-take rate for the various animals can be found on the IMAGE CD main disk (IMAGE team, 2001a,b). A dominant, but not so speculative, assumption is that current worldwide trends toward a lower degree of dependency on grazing systems (Alexandratos, 1995; De Haan and others, 1999; FAO, 1996) are continuing, leading to an increasing use of feed crops.

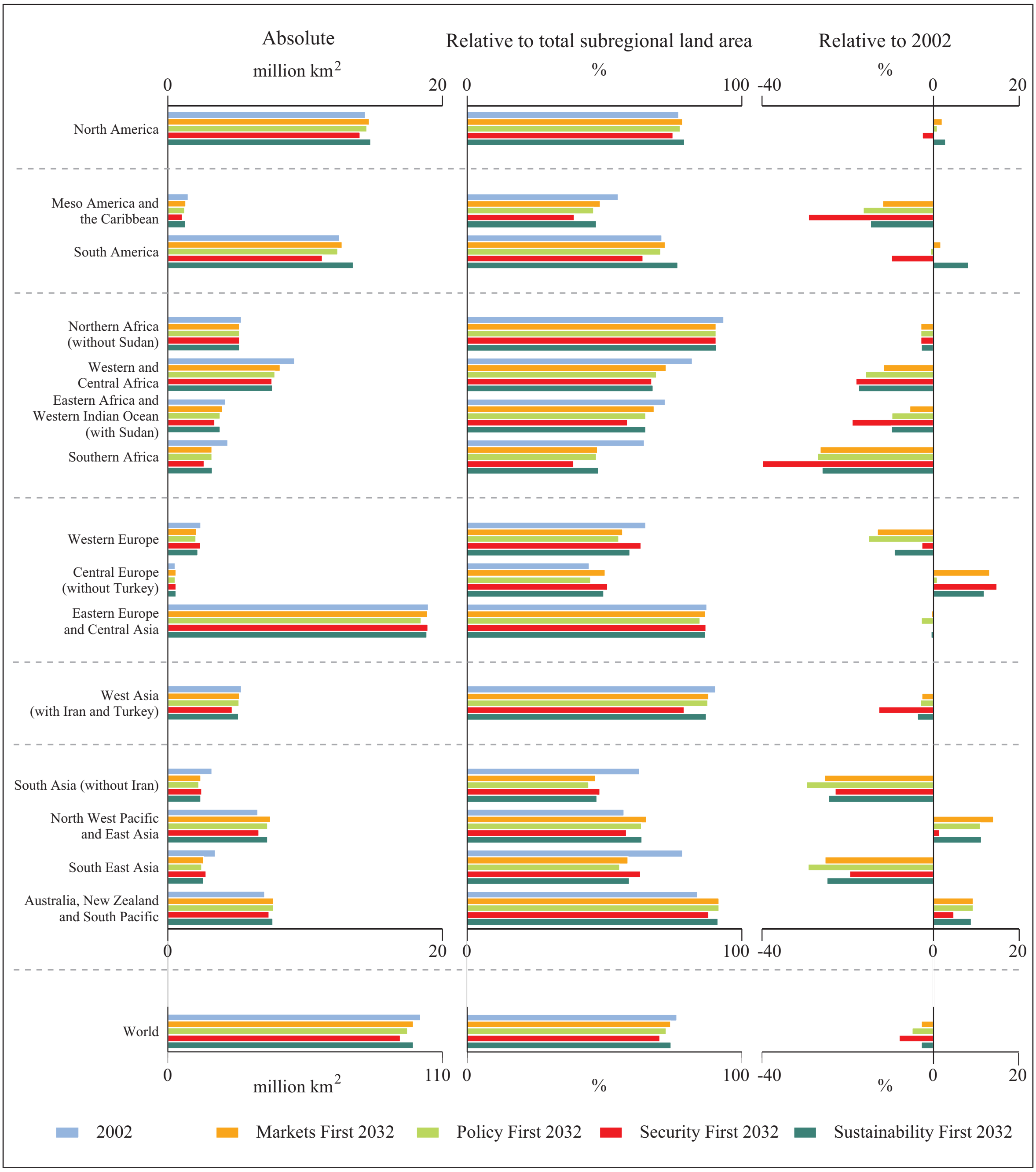


Figure 2.2: Natural land cover area

Source: RIVM

Charts for natural land-cover area can be seen in Figure 2.2. The changes in agricultural land are explained in Annex 2 (see also sections 7.7.2, 7.8.2, and 7.9.2 for land cover, land use and land management assumptions respectively). Note that increases in natural land cover occur mainly through abandonment of agricultural land (grazing areas, in particular) and re-forestation. As explained in sections 7.8.2 and 7.9.2, the biodiversity value of agricultural land taken out of production (e.g. in Australia) will remain modest for a long time. For re-growth of forest, this has even been set in this modelling exercise at 100 years, meaning that natural land cover is considered to have returned only after a 100 years.

The overall picture is one of strong contrast between the scenarios. In particular, the *Security First* world sees the natural land cover rapidly and continuously decrease, driven by a combination of sharp population growth and slow diffusion of efficient technologies. Land use for biofuels also emerges as an important factor in *Policy First*, where the decrease in natural land cover is larger than in *Markets First* because of a higher demand for biofuels due to imposed carbon taxes in the energy system. Sharp decreases can be seen in Meso America and the Caribbean; Western & Central Eastern and Southern Africa; South East Asia and South Asia.

The GDP and population estimates, as well as the land-use projections from this exercise, were subsequently distributed by RIVM to the other analytical teams in January 2002.

2.5 Discussion

The previous sections provided a brief sketch of the general route by which the GEO-3 scenarios were developed, both their narrative and quantitative sides. Two important aspects in this respect are how well the process was able to integrate the narrative and quantitative aspects, and the global and regional components of the scenarios, and make them coherent and consistent.

As has been described above, the development of the narrative and quantitative components of the scenarios followed somewhat parallel paths. It was decided early in the process that the narratives would drive the process, implying that the primary function of the quantitative analyses would be to support and illustrate the narratives. Note that this is almost the reverse of the case for the IPCC SRES scenarios, where the quantitative modelling was the primary focus (IPCC, 2000).

The quantitative efforts focused on reproducing information from already available scenarios akin to the GEO-3 scenarios, so as to illustrate the environmental implications that could be expected in each scenario. This was largely unavoidable, as it had been recognized at the Planning Meeting in July 2000 that time and resources to compile new data were scarce. Although some effort was made to modify these existing scenario data to take some aspects of the narratives into account as the development of the chapter proceeded, concerns were increasingly raised, both internally and externally, about the remaining inconsistencies. It was only after the Scenarios Expert Meeting in November 2001 that a major effort was made to better harmonize the quantitative material and integrate it with the narrative stories. However, the possibilities of doing so fully were limited by the rapidly approaching deadline for the full report, which precluded, among other things, further extensive consultations with the regional teams.

The net result of all of this is that the scenario development process provided less opportunity for integration between the narrative and quantitative elements than desired. It was only late in the process that a major effort was made to ensure coherence and consistency between the qualitative analyses and the narratives. There was also the difficulty in linking the initial quantification, partly based on previous work by the Global Scenario Group and partly on impressions from regional consultations, to impact estimates with deterministic models. It would have been preferred to have iterative phases, with significant regional participation, in which the narratives could have been further refined on the basis of the quantitative work and vice versa. A more successful example of this was accomplished in the development of the WWV scenarios, where several rounds of iteration were realized (Cosgrove and Rijsberman, 2000).

More success was achieved in fulfilling the goal of global and regional linkages, especially as far as the narratives were concerned. The early meetings included a strong representation from the regions. During 2000 a core scenario team was put together in each region. These groups met as a whole at the Planning Meeting in September of that year, where the global scenarios were reviewed and initial discussions were held on their regionalization. These groups also coordinated the Regional Meetings held that autumn, which brought together other participants from the regions to review the global scenarios and to sketch regional details. These meetings lead to the production of much of the regional material that was fed into the first and later drafts of the chapter. The core scenario teams, along with other regional representatives, reviewed the various drafts of the chapter, were asked for specific contributions in preparing the drafts, and participated in the second Production and Scenario Experts meetings. Regional experts provided material for the specific developments presented in the environmental implications section of each of the Chapters 3 to 7. At various points, they were also contacted directly by the groups undertaking the quantitative analyses for the scenarios.

This does not mean that there were no problems with the global and regional linkages. As the scenario approach was new for many of those involved, both at the global and regional level, it took some time to reach common understanding. The blending of regional and global narratives took place only after the first draft of the chapter had been completed. Due to the somewhat late reorganization of the chapter, it was not possible to have further meetings in all regions, which could have contributed more to the integration. Similarly, because of the timing of the preparation of the quantitative aspects, in particular, the impact estimates, it was not possible to have as much feedback from the regions as would have been desired.

Overall, the process of developing the scenarios for GEO-3 can be seen as a qualified success. This was the first major scenario exercise undertaken as part of the GEO process; a tremendous amount of groundwork has been laid for future efforts, including capacity-building in many of the regions. It also represents one of the first efforts to undertake a scenario analysis that was globally comprehensive, but with significant regional participation, and resulting in regionally differentiated scenarios. Certainly, the developers of the scenarios for the Africa Environment Outlook, who closely followed the scenario development for GEO-3, have already benefited from this process (UNEP, 2002).

References

Alexandratos, N., ed., 1995. *World Agriculture: Towards 2010.* Chichester: John Wiley and Sons.

Bakkes, J.A., et al., 2000. *Insights for the third Global Environment Outlook from related global scenario analyses*. Bilthoven: National Institute for Public Health and the Environment (RIVM).

Cosgrove, W.J. and F.R. Rijsberman, 2000. *World Water Vision: Making Water Everybody's Business.* London: Earthscan Publications.

De Haan, C., H. Steinfeld and H. Blackburn, 1999. *Livestock and the environment. Finding a balance*. Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization of the United Nations (FAO), 1996. *Our Land Our Future*. Rome and Nairob: FAO and UNEP.

Gallopín, G.C. and F. Rijsberman, 2000. Three global water scenarios. *International Journal of Water*, 1(1), pp. 16-40.

IMAGE team, 2001a. *The IMAGE 2.2 implementation of the SRES scenarios. A comprehensive analysis of emissions, climate change and impacts in the 21st century*. (RIVM CD-ROM publication 481508018) Bilthoven: National Institute for Public Health and the Environment.

IMAGE team, 2001b. *The IMAGE 2.2 implementation of the SRES scenarios: Climate change scenarios resulting from runs with several GCMs.* (RIVM CD-ROM Publication 481508019). Bilthoven: National Institute for Public Health and the Environment.

IMF, OECD, UN and World Bank, 2000. *A Better World for All: Progress Towards the International Development Goals*. Washington DC and Paris: IMF, OECD, UN, World Bank.

IPCC, 2000. *Special Report on emissions scenarios*. Cambridge: Cambridge University Press.

Morita, T., N. Nakicenovic and J. Robinson, 2000. Overview of Mitigation Scenarios for Global Climate Stabilization based on New IPCC Emission Scenarios (SRES). *Environmental Economics and Policy Studies, 3(2).*

Nakicenovic, N., et al., 2000. *Special Report on emissions scenarios*. Cambridge: Cambridge University Press.

Organisation for Economic Co-operation and Development (OECD), 2001. *OECD Environmental Outlook.* Paris: Organisation for Economic Co-operation and Development.

Raskin, P.D. and Kemp-Benedict, E., 2004. *Global Environment Outlook Scenario Framework - Background Paper for UNEP's Third Global Environment Outlook Report.* UNEP/DEWA Technical Report. Nairobi : United Nations Environment Programme.

Raskin, P., et al., 1998. *Bending the Curve: Toward Global Sustainability*. Stockholm: Stockholm Environment Institute.

Raskin, P., et al., 2002. *Great Transition: The Promise and Lure of the Times Ahead.* Boston: Stockholm Environment Institute-Boston.

United Nations Environment Programme (UNEP), 2000. Draft Report - GEO-3 Expert Group Meeting, 13-14 June 2000, Nairobi.

UNEP, 2002. *Africa Environment Outlook: Past, Present, and Future Perspectives*. Nairobi: United Nations Environment Programme.

Van Vuuren, D.P. and H.J.M. de Vries, 2001. Mitigation scenarios in a world oriented at sustainable development: the role of technology efficiency and timing. Climate Policy, 1, pp. 189-210.

Van Vuuren, D.P., et al., 2002. *Model Structure.* In: J. van der Sluijs et al., *Uncertainty Assessment of the IMAGE/TIMER B1* CO_2 *emissions scenario using the NUSAP method.* (NOP Report no. 410 200 104). Bilthoven: Dutch National Research Programme on Global Air Pollution and Climate Change.

World Business Council for Sustainable Development (WBCSD), 1998. *Global Environmental Scenarios 2000 - 2050.* Geneva: World Business Council for Sustainable Development.

3. Cropland degradation, built environment and hunger

Despite robust economic growth in the Markets First *scenario, hunger, considered as a key poverty indicator, declines only slowly (even in* Markets First*). Clearly, aggregate growth is a necessary, but not sufficient, requirement for poverty reduction.*
Both expansion of the built environment and cropland degradation are likely to be significant determinants of future pressure on land resources. While small in total area, they are at least as important as yield increases for impacting marginal changes in agricultural land area.

3.0 Introduction

This chapter provides background information on the variables provided by the PoleStar analysis for the GEO-3 report. The aim of the chapter is twofold. First, it provides a justification of the analytical methods. Second, it presents and discusses the changes in the variables over the course of the scenarios, the reasons for the patterns seen in the scenarios and their policy relevance. For this GEO-3 scenario exercise three variables, cropland degradation, built environment and hunger, were analyzed with PoleStar. (Some variables analysed with IMAGE, presented in Chapter 7, are also related to land use and land degradation. Furthermore, the GLOBIO analysis of the impacts of expanding infrastructure on biodiversity, presented in Chapter 4, is closely related to changes in the extent of the built environment.)

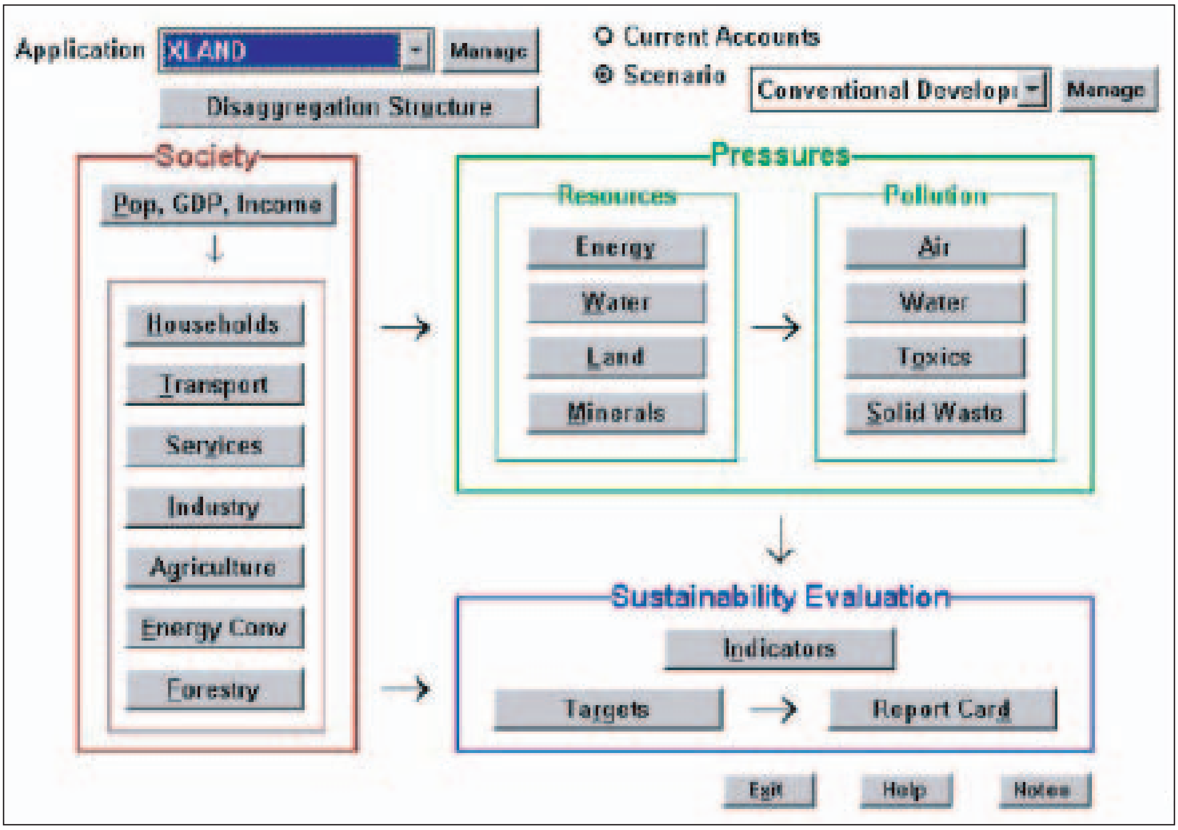
Section 3.1 gives a general description of the model and section 3.2 provides information additional to Chapter 2 on the data inputs and assumptions used to develop quantitative illustrations of the environmental and social consequences of the four GEO-3 scenarios. Subsequent sections describe each of the variables analyzed for GEO-3 with PoleStar (UNEP, 2002); these are severely degraded cropland in section 3.3; extent of built environment in section 3.4 and hunger in section 3.5.

Variables are addressed using the following approaches: meaning of the given variable, available data and information on the scenario analysis and assumptions, and scenario analysis results and interpretation. Section 3.6 presents some discussion and conclusions on the PoleStar analysis.

3.1 Analytical framework

PoleStar is a comprehensive, flexible and easy-to-use accounting framework for organizing economic, resource and environmental information. It is a tool for examining alternative development scenarios on national, regional and global scales. The user customizes data structures, modelling relationships, time horizons and spatial boundaries, all of which can be expanded or altered in the course of an analysis.

PoleStar's approach to examining alternative socio-economic and environmental futures is to trace the relationships between the drivers of change and indicators of their impacts. The nature of the relationship can be based on models, existing studies, historical data or anticipated trends and is likely to vary from study to study. The overall structure of the PoleStar calculations is illustrated by



Application XLAND

○ Current Accounts

● Scenario Conventional Develop

Figure 3.1: PoleStar main menu

the PoleStar Main Menu, shown in Figure 3.1. Because of the complexities, uncertainties and the involvement of human agents in the processes being studied, PoleStar has been designed in an open manner. It is not a rigid model reflecting a particular approach to environment and development interactions. Rather, data structures, time horizons and spatial boundaries can be customized, and the level of detail across and within sectors or areas can be varied as needed. PoleStar can accept information from formal models, existing studies or other sources.

A PoleStar application begins with the Current Accounts, a snapshot of the current state of affairs based on actual data. Scenarios are then developed to explore alternative futures, and environmental and resource pressures are computed and evaluated with reference to user-defined sustainability criteria. Current Accounts and scenarios are developed through a series of modules, indicated by the buttons in Figure 3.1. The *Pop, GDP, Income* module contains the major economic, demographic and social variables that partly drive the scenario. More detailed data and scenario assumptions are introduced in the other modules describing Society (*Households, Transport, Services, Industry, Agriculture and Energy Conversion*). Environmental Pressures are accounted for in the Resource modules (*Energy Resources, Minerals, Land* and *Water Resources*) and in the Pollution modules (*Air, Water, Toxics* and *Solid Waste*). The data in modules may be disaggregated by sub-region, sub-sector (for example, household type, industrial category, transportation mode, crop), and process (for example, farming practice, household equipment, manufacturing process, travel mode and vehicle type). The number and types of regions, sub-sectors and processes can be adjusted in order to match the aims of the analysis and data availability. Fundamental links between modules are predefined in PoleStar's *Basic Structure* – a default set of sub-sectors, processes and relationships – but these can be altered or expanded to meet the needs of an analysis. The PoleStar application used to develop the GEO-3 scenarios has been substantially modified from the Basic Structure.

The Evaluation modules provide an overview of the environmental, resource and developmental performance of a scenario in relation to sustainability targets. The Indicators screen allows the user to specify particular scenario variables as indicators, and compare trends in indicators in different regions or scenarios (see for instance figure 3.11 where the variable 'hunger' has been specified for the GEO-3 scenarios). New sets of indicators can be developed as needed for a given application of PoleStar. The Report Card provides an overview of how user-selected indicators compare to user-defined sustainability targets (for example, critical ecological loads, safe minimum standards). The tool includes a 'bird's-eye' view of scenarios as a series of red and green sustainability indicator lights. By evaluating and modifying scenarios in an iterative manner, scenarios that meet long-term goals may be distinguished from those that do not, providing information for formulating policies and actions for a transition to a desirable, feasible and sustainable future. In Figure 3.11, for instance, the GEO-3 scenario paths for 'hunger' are compared with the goal set for 2015 at the World Food Summit.

3.2 Input data and assumptions

The variables described in this chapter – cropland degradation, built environment and hunger – illustrate several of the options possible with the PoleStar tool. Estimates for severely degraded land rely mainly on sources outside PoleStar, especially UNEP's study of global land degradation (Oldeman and others, 1991), but are constrained by the scenario narratives (see the GEO-3 Scenario development described in Chapter 2). The analysis of change in the area of the built environment uses external information as well, but also a simple mathematical structure to generate scenario assumptions. Finally, hunger estimates rely heavily on a relatively complex mathematical framework that links income distribution with hunger levels, in which key variables are developed in an external analysis based on scenario narratives. For further details the reader is referred to the PoleStar website at http://www.tellus.org/seib/polestar/Publications.html

Scenarios for land degradation, as described in section 3.3, are developed on the basis of past patterns of severe degradation, adapted to conform to scenario narratives. The other variables described in this chapter – built environment and hunger – depend on the population and GDP figures outlined in the previous chapter. Scenarios are elaborated for built environment per capita, with patterns differing according to the scenarios, as described in Section 3.4. The total area of built environment is then given by the product of built environment per capita with population. For hunger, GDP per capita is combined with a measure of income distribution (the Gini coefficient) to estimate hunger incidence per capita. Hunger incidence is then multiplied by population for estimation of the total undernourished population. Scenarios for income distribution are described in Section 3.5.

In general, the *Markets First* scenario is developed on the basis of historical and broadly anticipated patterns, while the other scenarios are constructed as departures from *Markets First* patterns. The *Policy First* scenario attempts to bend a market-based trajectory toward a more sustainable path through policy means. The *Security First* scenario depicts a world in which a market-based approach has failed, and the environmentally and socially negative aspects of the *Markets First* scenario worsen.

Finally, the *Sustainability First* scenario is seen as departing from the *Policy First* scenario. As the limits of a top-down, policy-driven approach are realized, the shift toward sustainability is increasingly accomplished through lifestyle changes. As the *Sustainability First* scenario moves away from the *Policy First* scenario, the net effect represents a significant departure from *Markets First* patterns.

3.3 Severely degraded cropland

3.3.1 Description

The PoleStar variable 'severely degraded cropland' denotes land so degraded that it is of little value for production. In the event that alternative land is available, severely degraded land will probably be abandoned. If abandonment is not an option, yields will be strongly depressed. In either case, an increase in the area of severely degraded land implies increased pressure on land resources and increased vulnerability of the populations affected. Chapter 8 compares agricultural scenarios in IMAGE and PoleStar. Compared to total crop area, additional degraded land is not extensive in many regions; however, it is very extensive in Meso-America, South America, South Asia, North West Pacific and East Asia and Africa (see Figure 3.3). Nevertheless, degraded land and conversion to a built environment collectively turn out to be more than twice the net increase in cropped area as seen in a recent FAO scenario (FAO, 2000a).

3.3.2 Scenario Assumptions

The *Markets First* scenario is based on historical trends in cropland degradation rates, as reported in UNEP's Global Assessment of Soil Degradation (GLASOD) study (Oldeman and others, 1991; GRID/UNEP, 1991) but adjusted in the light of the scenario narrative. The other scenarios depart from the *Markets First* pattern consistent with the scenario narratives.

Four degrees of degradation, 'light', 'moderate', 'strong' and 'extreme', are distinguished in the GLASOD study. According to the GLASOD study guidelines, the last two represent land so degraded it must be pulled from production. These are differentiated one from the other by the effort required to return them to use. Moderately degraded land is considerably reduced in quality, but can still support some level of production. However, the GLASOD classification should not be interpreted too stringently, either as a characterization of the current situation or as a basis for scenario development. The assessment of current patterns has been challenged as being too pessimistic (Alexandratos, 1995), while in scenarios, farmers' responses to land degradation can be expected to vary with the scenario assumptions. Consequently, the GLASOD assessment is used to guide quantitative assumptions on degradation rates, but not to determine them.

Markets First

The PoleStar variable 'severe degradation' corresponds to the total of the GLASOD categories of 'strong' and 'extreme' degradation. In developing the *Markets First* scenario, attention is also paid to rates of 'moderate' degradation, since the extent to which there has been moderate degradation in the past can serve as an indication of likely future pressure of degradation. In most regions, scenario rates are set between the historical levels of moderate degradation and the sum of the rates for strong and extreme degradation due to such agricultural practices as reported in the GLASOD study.

To estimate rates, degraded areas were divided by 45, roughly representing the number of years covered by the GLASOD study. Rates in regions where potential cropland is extremely scarce, such as in West Asia, have been set below historically observed rates, as limited land resources are expected to make protection or partial rehabilitation of degraded land economically attractive. Globally, cropland becomes severely degraded in the *Markets First* scenario at a rate of around 30 – 40 thousand km^2 per year.

Policy First

In keeping with the sustainability goals, land degradation in the *Policy First* scenario is assumed to proceed at a rate under the historical rates. Up to 2015, cropland becomes severely degraded at a rate of about two-thirds of the *Markets First* rate, or 1.8 Mha per year. Between 2015 and 2032, net degradation slows considerably, stabilizing by the end of the period at an average rate of 0.25 Mha per year. This is assumed to represent a balance of slowing degradation on active agricultural land and significantly restoring currently degraded land.

Security First

In OECD regions, where very few households lead an agriculturally sustained subsistence, intensity of degradative activity is similar to that in the *Markets First* scenario. In non-OECD regions, where many individual households rely on their own agricultural production, degradation rates amongst the poor are more rapid as they work low-quality land with insufficient resources, while the most productive agricultural land is expropriated and managed by the elite using agricultural practices similar to those in industrialized regions. Abandonment of cropland is expected to be less prevalent than in the *Markets First* scenario; this is because there are fewer alternatives due to exclusion from more prosperous enclaves and crowding, as larger populations seek to produce their food on less-productive land.

The net effect of expanding the use of marginal land, retention of degraded land and expropriation and development of the most productive land is assumed to be rates of severe degradation similar to those of the *Markets First* scenario in all regions. To quantitatively illustrate the scenarios, *Security First* rates are set equal to the *Markets First* rates, while continued production on severely degraded land is reflected in lower yields. The impact of the yield assumptions is reflected in land-use changes and trade patterns in the larger PoleStar analysis, in which the cropland degradation scenario is embedded; however, this analysis is not presented here.

Sustainability First

Compared to the other scenarios, relatively lower population pressure, more ecologically friendly agricultural practices, greater access to resources through more broadly shared affluence and focused attention on preserving and restoring renewable resources all contribute to a sharp decline in net cropland degradation rates over the course of the scenario. Up to 2015, patterns are assumed to be similar to those of *Policy First*, and rates are only slightly below those of the *Policy First* scenario, at 1.6 Mha per year. However, there is net restoration of degraded land between 2015 and 2032, with net degradation rates averaging just 0.7 Mha per year over the entire scenario period.

3.3.3 Results

The global extent of degraded cropland is shown through a scenario in Figure 3.2. Scenario-specific patterns are discussed below, following a comparison of the *Markets First* scenario to the limited available historical data so as to put the rates in context.

The *Markets First* global degradation rate is higher than the historical rate of 21.5 thousand km^2 per year suggested by the GLASOD study (since past rates of moderate cropland degradation are taken into account when developing scenarios of future severe degradation). However, these rates are apparently lower than some estimates of current rates of degradation. Unfortunately, it is often impossible to make a direct comparison of land degradation estimates among different sources, since they may include different categories, such as degradation from causes other than agricultural practices. For example, Kendall and Pimentel (1994) report the combined effect from degradation and loss to urban expansion. However, an indirect comparison in this case is possible: i.e. Kendall and Pimentel report that cropland lost to urbanization and degradation takes place at a rate of over 100 thousand km^2 per year. If the estimate of 28 thousand km^2 per year due to land degradation in this scenario is to agree with Kendall and Pimentel's estimate, at least 70 thousand km^2 of cropland must be lost in conversion to the built environment. However, in the *Markets First* scenario, the total increase in the built environment is estimated to be less than this – 50 thousand km^2 per year on average (see Section 3.4).

Conversion of other land uses to cropland – primarily forest and rangeland – is a major cause of ecosystem modification. The *Markets First* rate of cropland degradation and loss to built environment can be combined with total cropland requirements to estimate total conversion rates of potentially arable land to cropland. While the PoleStar analysis includes a full agricultural scenario, the focus in this section is on the specific indicators provided for the GEO-3 report.

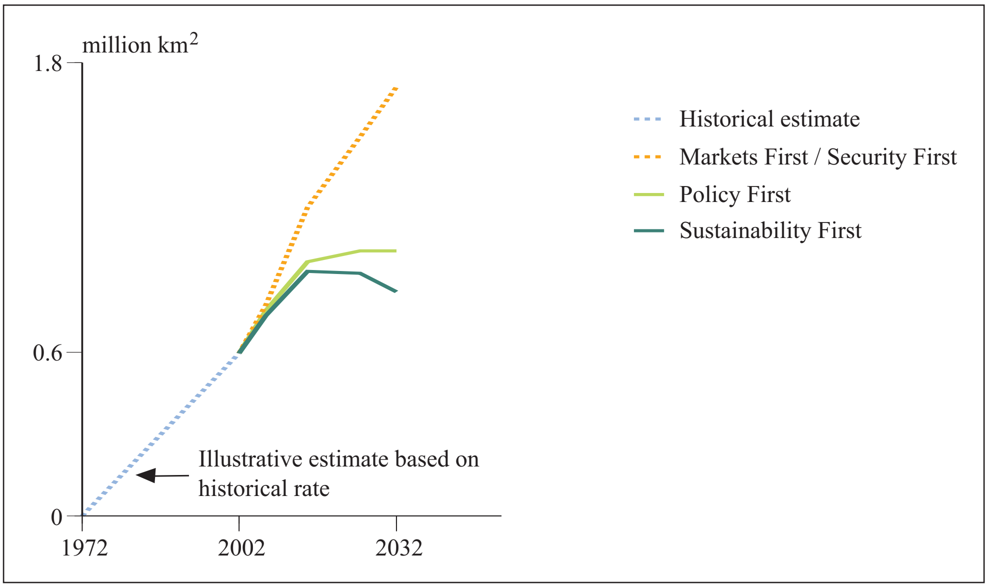


Figure 3.2: Global area of cropland degraded since 1972

Source: SEI Boston

Note: Historical 1972-2002 trend estimations are based on available data

For the present discussion, FAO, which has developed a scenario of agricultural production in developing regions to 2030 (FAO, 2000a), has provided a suitable estimate of the net increase in crop area over the next three decades. The FAO scenario presents an analysis of ‘what is likely to be’ rather than a normative scenario of ‘what ought to be’ (Mahanani, 2001). In this, it differs somewhat from any of the GEO-3 scenarios, which to some degree present *someone’s* normative vision. Nevertheless, it is closest in spirit to the *Markets First* scenario, and can be taken to represent a typical *Markets First* estimate of cropland expansion in the current illustration. In the FAO scenario, cropland in developing regions expands at about an average of 35 thousand km^2 per year between 1996 and 2030. This is not the global increase in cropland, so it is not directly comparable

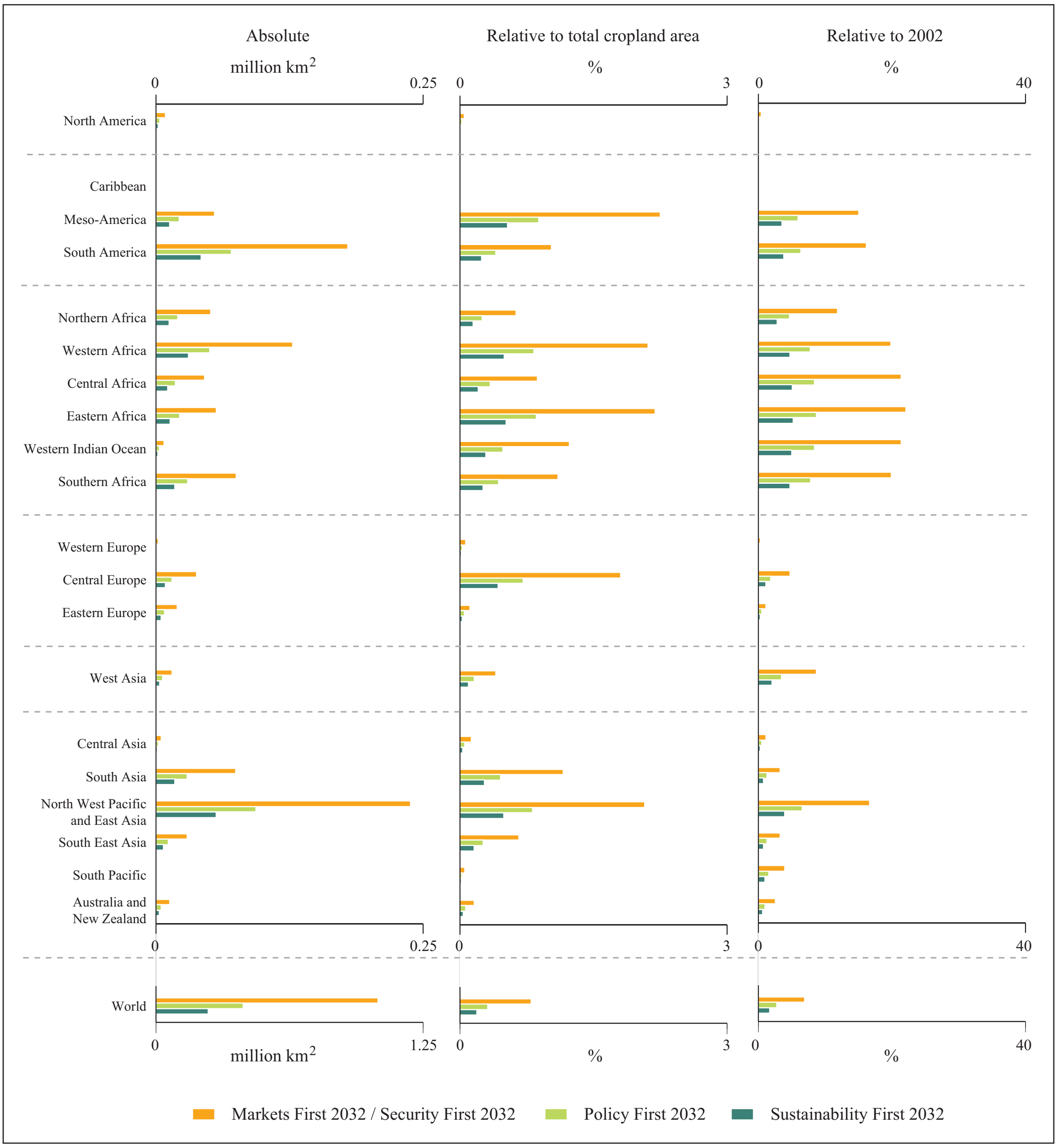


Figure 3.3: Area of cropland degraded by 2032 since 2002

Source: SEI Boston

to the global cropland degradation estimates reported here. However, in the past decades, most cropland expansion has occurred in the developing regions.

Assuming this pattern to continue, the figure of 35 thousand km^2 for the developing world can be taken as a *Markets First* estimate for global annual expansion in the next three decades. With this as a base, different assumptions about land conversion will lead to a range of estimates for total cropland conversion requirements. At the upper limit, if all of the severely degraded land were abandoned, and if all new built environment was converted from cropland, roughly 113 thousand km^2 would have to be converted to cropland each year from other land types. At the lower limit, if none of the severely degraded land is abandoned, and if no new built land comes from cropland, at least 35 thousand km^2 would have to be converted to supply requirements for new cropland and cropland converted to the built environment. This suggests that a broad range of 35-113 thousand km^2 of additional cropland will be converted per year from forest or grazing land. The breadth of the range is indicative of the considerable uncertainties surrounding degradation and conversion rates. Note, however, that the range is compatible with historical rates of around 60 thousand km^2 per year in about 1980, according to the estimates of Houghton and Hackler (1995).

The extent of land degradation at the regional level is shown in Figure 3.3. The differences between scenarios are similar for all regions in line with the assumptions outlined above. The *Markets First* and *Security First* scenarios show the same patterns in illustrating the approximate equivalence for this variable expected from the scenario narratives. The extent of degradation is less in *Policy First* and least in *Sustainability First*. The differences in the absolute figures between regions reflect historical patterns.

Compared to total crop area, additional degraded land is not extensive in many regions, although it is very extensive in Meso-America, South America, North West Pacific, and East Asia and Africa. Nevertheless, degraded land and conversion to the built environment collectively come to more than twice the net increase in cropped area using the FAO scenario for cropland expansion. Removing cropland through degradation, or reducing its yield, can add significantly to the total land area required for conversion to cropland. As countries and research institutions strive to increase the productivity of crops, it is at least as important to work to maintain the fertility of the land on which those crops will be grown and, where possible, to restore already degraded land to a more fertile state.

3.4 Extent of the built environment

3.4.1 Description

In both urban and rural settings, land is cleared and altered for businesses, residences, roads, parking lots, parks, landfills, burial grounds and other uses – the *built environment*. Combined with population growth, the increases in built environment per capita seen in the scenarios imply substantial environmental pressures. While the built environment takes up a very small proportion of the earth's total land area in absolute terms (an estimated 2 per cent of total land area in 1995), it represents a major cause of land conversion or land-cover change, often increasing at the expense of arable land (Meyer and Turner, 1994; FAO, 2000c).

Table 3.1: Built environment per capita – current estimates and scenarios

			2032			
	1995	2002 (est.)	Markets First	Policy First	Security First	Sustainability First
	km^2/100 inhabitants					
North America	12.0	12.2	13.4	10.9	14.1	9.9
Latin America and Caribbean	5.0	5.2	6.4	5.4	6.7	5.5
Africa	6.4	6.5	6.6	6.3	6.9	6.0
Europe	5.0	5.1	5.7	5.3	5.8	5.3
West Asia	6.0	6.1	6.3	5.9	6.5	5.8
Asia and the Pacific	3.0	3.2	4.0	4.0	4.1	4.4
World	4.4	4.6	5.3	5.1	5.5	5.1

Source: SEI Boston
Sources for 1995 data: Günter Fischer, pers. comm.; WRI (1994); own estimates based on other regional values. For North America, estimate based on US data, given by the area of "built-up land" (USDA, 1994) less the area of state parks (USBC, 1992; 1995).

The area of the built environment is not accurately known (Crosson and Anderson, 1992; Meyer and Turner, 1994). Moreover, assessments are plagued by problems of definition. GEO-3 used a combination of different sources and estimates to arrive at regional estimates for built-up land. Historical data on the built environment are very scarce. In many countries and regions, urban population growth lagged behind the growth in urban area in the mid-1980s (Meyer and Turner, 1994). In the USA this trend appears to have accelerated between 1982 and 1997 (USDA, 1994, 2000). Since countries usually converge toward patterns of transportation, urbanization and habitation characteristic of the industrialized countries, built environment per capita is expected to increase.

Current estimates of the area of the built environment per capita, and scenario values, are shown by region in Table 3.1.

3.4.2 Modelling

Currently, Asia and the Pacific, much of which are characterized by relatively low incomes and high population density, has not much built environment per capita. Regions with a higher income and high population density, such as Europe, have built environment per capita that is higher than in the Asian regions, but lower than in North America, where incomes are high and land plentiful. In Africa and Latin America and the Caribbean, where land is plentiful but incomes relatively small, built environment per capita is similar, and greater than that of Western Europe. In West Asia, incomes are relatively high compared to other developing regions, while land is plentiful. Nevertheless, the cost of water delivery constrains the expansion of the built area. Built environment per capita is comparable to the levels in Latin America and the Caribbean, while below those in Africa.

Markets First

In the *Markets First* scenario, growth in the built environment is guided by the assumption that built environment per capita is constrained by the amount of land available, and within these constraints is determined by cultural preferences and income. Support for this view can be found in Table 3.1. Data on changes in the area of the built environment are scarce. For the *Markets First* scenario, built environment in the OECD countries increases at a rate based on historical trends in the United States, consistent with similar economic growth in the OECD. In the USA, developed land per capita between 1982 and 1992 increased at about 0.6 per cent per year on average (USDA, 1994). While this trend appears to be accelerating in the USA, it is unlikely that such a pattern can be replicated in densely populated regions, and is likely to eventually become saturated in the United States as well. Over the 30-year period of the GEO-3 *Markets First* scenario, it is assumed that built environment per capita will increase in all OECD countries at half the historical US rate (0.3 per cent per year) throughout the scenario. Rates in other regions gradually converge towards patterns seen in OECD countries as their incomes rise, but with different convergence targets for different countries consistent with the comments above. So Africa and Latin America & Caribbean converge towards the OECD average, while the other regions converge towards the more compact value for Western Europe and OECD Pacific.[7]

As noted above, water, rather than land, is the constraining factor in West Asia. The assumption of convergence towards Western European values rather than towards the OECD average is based on an assumption that the costs of expanding water delivery systems will limit the growth of the built environment. The convergence pattern for non-OECD Europe, where land is also plentiful, is based on the assumption that these regions will tend more toward Western European patterns than to North American ones. In the case of Europe, alternative assumptions will have little effect on land pressure.

Policy First

In the *Policy First* scenario, policies to protect forest and cropland from encroaching on human settlements are expected to restrain the growth in the built environment in all regions in comparison to the *Markets First* scenario, although this tendency is counteracted to some degree by relatively higher income growth in developing regions. Specifically, all regions are assumed to approach the Western European average. In Western Europe itself, human settlements become slightly more compact throughout the scenario, a pattern also seen in Africa, North America and West Asia. The developing regions approach the Western European pattern as their incomes approach base-year OECD values.

Security First

Assumptions in the *Security First* scenario are similar to those in the *Markets First* scenario, but with different rates of convergence of developing countries toward industrialized country patterns, consistent with the different economic assumptions, and a higher rate of increase in the built environment area in industrialized regions. This reflects the predominance of sprawling, unplanned

---

[7] Global built area in the scenario is not sensitive to the rate assumed in OECD countries. Under the convergence assumptions, if OECD built environment per capita were to grow at the 1982-1992 US rate of 0.6 per cent/year, then the global area of the built environment in 2032 would be 3 per cent larger. If OECD built environment per capita were held at base-year levels, then the global area in 2032 would be 2 per cent smaller.

settlements, as discussed in regional narratives. Combined with comparatively rapid population growth, this leads to a substantial expansion in the built environment in this scenario.

Sustainability First

In the *Sustainability First* scenario, populations and settlement patterns initially follow the *Policy First* trend. However, led by a gradual shift in living patterns in wealthier regions, all regions begin gradually to move toward relatively compact settlements. Specifically, all regions are assumed to begin to converge to a common level of 0.5 km^2 per 1000 persons, equal to the current European average, a value that would only be reached by 2100. This is, of course, a regional average: as in Western Europe today, built environment per person may vary considerably within the regions due to climate, and local preferences and patterns. Combined with relatively low population growth rates, this leads to very modest increases, and in some regions, decreases in the built environment.

3.4.3 Results

Figures 3.4 and 3.5 show changes in built environment at the global and regional level. The patterns seen in the graphs result from a combination of population growth and change in built environment per capita. Ultimately, they depend on the rate at which land area per capita is changed to built environment (the rate of convergence of built environment), which increases with income growth rates and the level to which regions converge. In broad terms, differences between scenarios are similar in all regions to the pattern seen at the global level. The built area is largest in *Security First* due to rapid population growth and sprawl. It is next largest in *Markets First*, while the areas in *Policy First* and *Sustainability First* are similar, and typically low. There are some departures from this general pattern. In many sub-regions, the *Sustainability First* built area exceeds that of the *Policy First* or *Markets First* scenario because of rapid convergence – a sign of relative affluence.

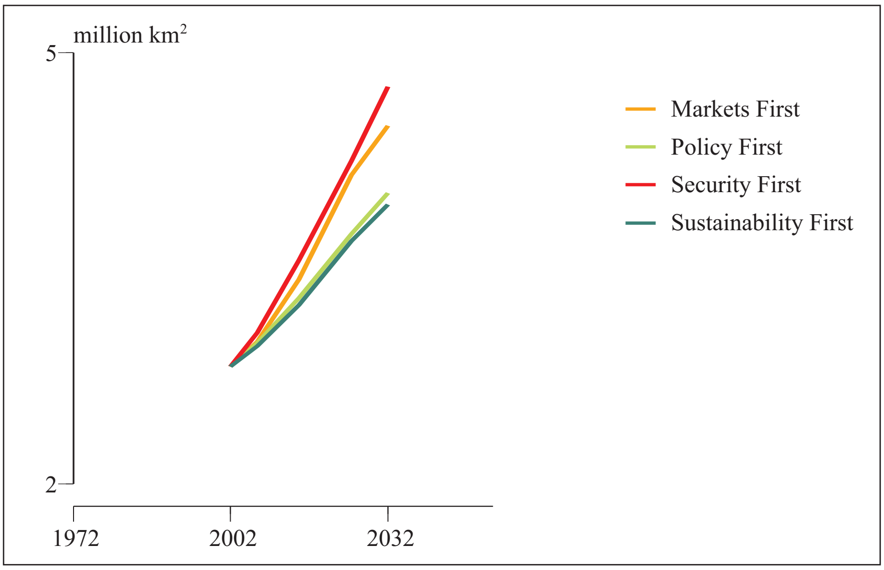


Figure 3.4: Global area of the built environment

Source: SEI Boston

Note: Historical data not available for this variable

This is particularly true in Asia, where settlement patterns are very compact, both in present and future scenarios. It is not true in Africa, where the available land area per capita encourages sprawling in all scenarios except *Sustainability First*; here compact settlements emerge for ecological reasons. In all scenarios the built environment expands in nearly all regions, with two exceptions: 1) Western Europe in *Sustainability First* and *Policy First*, where it contracts as populations stabilize and built environment per capita declines, and 2) in North America in *Sustainability First*, where populations keep growing but where the built environment per capita (starting at a very high level) becomes significantly more compact in the course of the 30-year scenario.

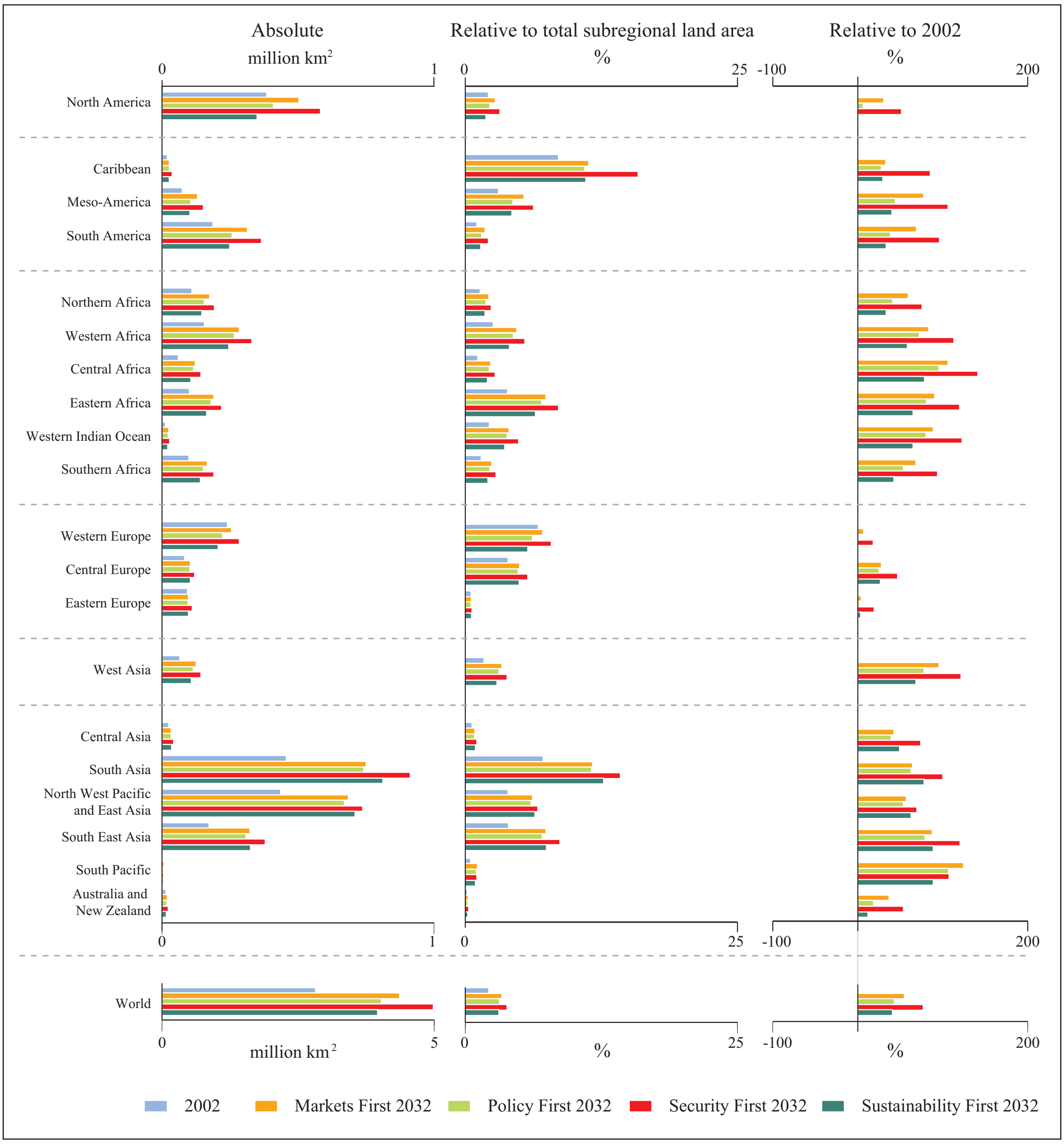


Figure 3.5: Regional-scale built environment areas

Source: SEI Boston

The size of the built environment is intimately associated with the question of transport. How will the transport infrastructure evolve? This is a looming question, which is likely to prove much more serious for developing countries in the short term than the greenhouse gas emissions that will emerge with the increase in motorized transport. Increases in transport will raise problems of infrastructure, congestion, noise, dust and other local pollution (in addition to greenhouse gas emissions). In North America, continuing sprawl – reflected in increasing expansion of the built environment – is tied to reliance on the passenger car as the primary mode of transport. As the built environment often encroaches on good agricultural land, further pressure will be placed on agricultural systems. As with cropland degradation, the absolute area of the built environment is generally small when seen as a fraction of total land area, but the impact on limited availability of productive agricultural land can be severe. Chapter 4 describes the GLOBIO modelling efforts for ecosystems impacted by infrastructure development.

3.5 Hunger

3.5.1 Description

Of the many factors that can affect hunger, we focus on those that are reflected in the distribution of income. This captures many issues indirectly that are reflected in income differences. However, the complexity of the situation should not be underestimated. So can conflict exacerbate problems of access to food, even if superficially it may appear that incomes are sufficient, while targeted food aid may alleviate problems without being reflected in income statistics. Hunger patterns are determined in the scenarios by changes in income, income distribution and population. Broadly similar patterns are seen in all regions, with the highest levels of hunger in *Security First*, the second-highest in *Markets First*, the next-to-lowest levels in *Policy First* and the lowest levels in *Sustainability First*. This pattern follows from the equity and population assumptions in the scenarios.

3.5.2 Modelling

Hunger – chronic undernutrition – is reported in the GEO-3 scenarios as a key poverty variable. The approach to estimating hunger in scenarios is illustrated schematically in Figure 3.6.[8] Given a form for the income distribution, the population suffering from hunger is estimated by calculating the population below a hunger line – a threshold income below which most individuals are unable to obtain the calories required to sustain a normal level of activity. As discussed below, hunger lines are estimated in the base year from income distribution and hunger data, and increase in the scenario as incomes rise. Note that Figure 3.6 represents a snapshot of the situation. At a later point in time,

---

[8] The methodology applied was developed for use at a national level. Both the *Markets First* and *Policy First* scenarios were developed at the national level. However, the 21 GEO-3 sub-regions are sufficiently homogeneous that sub-regional aggregate distributions might be sufficient. To investigate this possibility, the *Markets First* scenario was first developed at a national level, and then at a sub-regional level, aggregated over countries. The results from the two calculations were compared and were found to agree closely, with a correlation coefficient of 98 per cent. As the sub-regional level calculation is more straightforward to implement, and the agreement with the national-level calculations is good, for the GEO-3 scenarios the *Security First* and *Sustainability First* scenarios were developed using regionally aggregated income distributions.

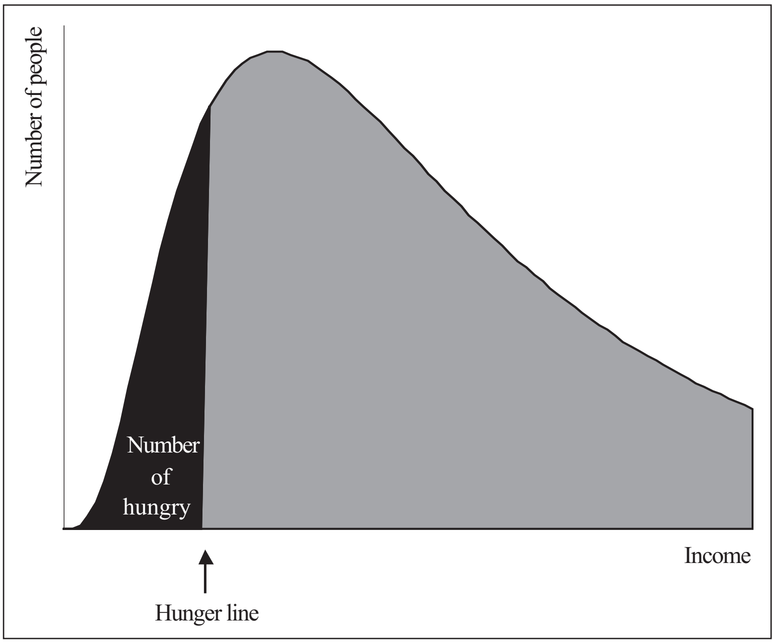


Figure 3.6: Approach to estimating hunger in the scenarios

From: Gallopín and Raskin (2002)

Note: This graph represents a snapshot of the situation in a society.

income levels may have generally increased and the economy become more formal. This means that there are fewer possibilities to obtain food via bartering and the like. Thus, the hunger line will tends to shift upwards, with increasing average income. For a detailed discussion on this, see Gallopín and Raskin (2002) and Kemp-Benedict and others. (2002). This approach to estimating hunger levels is analogous to the use of a poverty line for estimating the incidence of poverty.[9]

To make the procedure operational it is necessary to specify the shape of the income distribution and the value for the hunger line. The approach followed for the GEO-3 scenarios is based on that used for the Global Scenario Group scenarios (Raskin and others, 1998, 2001; Gallopín and Raskin, 2002; Kemp-Benedict and others, 2002). Note that all income figures are in purchasing-power parity (PPP) terms.

Two common variables of income disparity are used in this report: the *Gini coefficient* and the ratio in income of the lowest-earning 20 per cent to that of the highest-earning 20 per cent, called the *low-high ratio* here. These variables can be illustrated with the aid of a *Lorenz curve*, a plot of the fraction of total income held by a given fraction of the population, with the lowest income portion of the population counted first (Figure 3.7). The Lorenz values for the lowest-earning 20 per cent, 40 per cent, 60 per cent and 80 per cent of the population are the income *quintiles* (labelled in the figure). The Gini coefficient is given by the ratio of the areas A and A+B in Figure 3.7. This coefficient can

---

[9] Note that the hunger line is an idealization: in reality some people with income below the line may be sufficiently fed, for instance through subsistence farming, while some above the line will not. Also note that the hunger threshold represents more than the cost of food, since clothing, shelter and fuel must also be obtained even by those just able to meet their basic nutritional needs. Also issues like increased land degradation can have adverse consequences on income ditribution, and, hence, on hunger stressed population estimates.

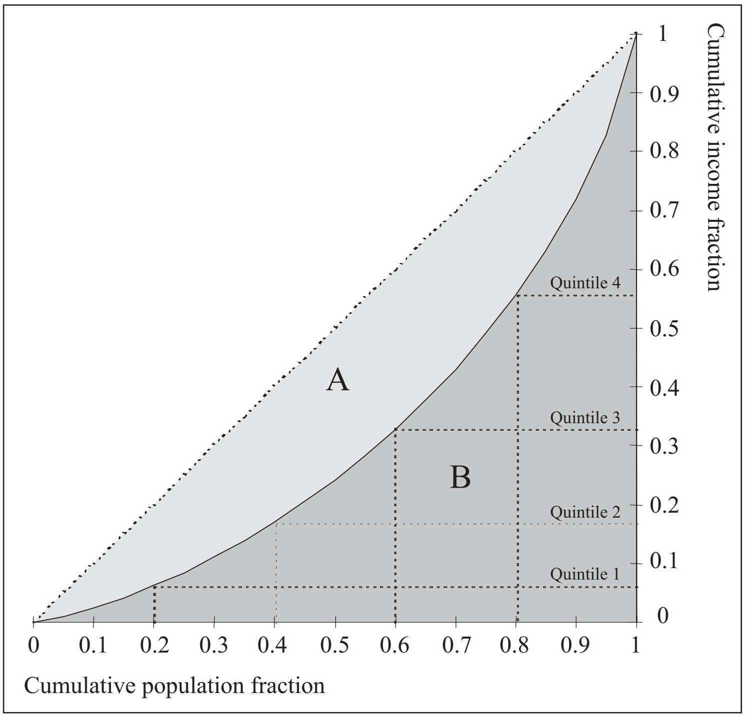


Figure 3.7: The Lorenz curve and quintiles for income
Source: SEI Boston

be assigned values from zero to one, with zero representing complete equality. The low/high ratio is given in terms of the quintiles as (Quintile 1)/(1 - Quintile 4), with a value of one representing complete equality.

A database on income distribution and hunger was compiled for this analysis with national-level data. Current Gini coefficients are not available for most countries, so the most recent values available are used (see Sources listed under Figure 3.8). Statistics on the incidence of chronic undernutrition were collected for developing and transitional countries by the FAO. Data from the FAO's State of Food and Agriculture 1999 are used for developing countries (FAO, 1999). For transitional countries, data used are from the FAO's State of Food Insecurity in the World 2000 (FAO, 2000b). Comparable hunger estimates are not collected for OECD countries. For the base year, hunger in the United States is indicated by the prevalence of 'food insecurity' as defined and measured by the US Department of Agriculture (USDA) (reported in Rose and others, 1995). Hunger levels are estimated for countries with no data on hunger, but with income distribution data, using the analytical framework described in Section 3.5.

The remainder of this section is largely devoted to a description of the methodology used to estimate hunger incidence.

The shape of the income distribution

While many variables might be required, in principle, to characterize a country's income distribution, we argue that they can be satisfactorily represented by a function of one parameter. This conclusion, which substantially simplifies the task of developing income distribution scenarios, relies on the following argument. If one parameter is sufficient to characterize income inequality,

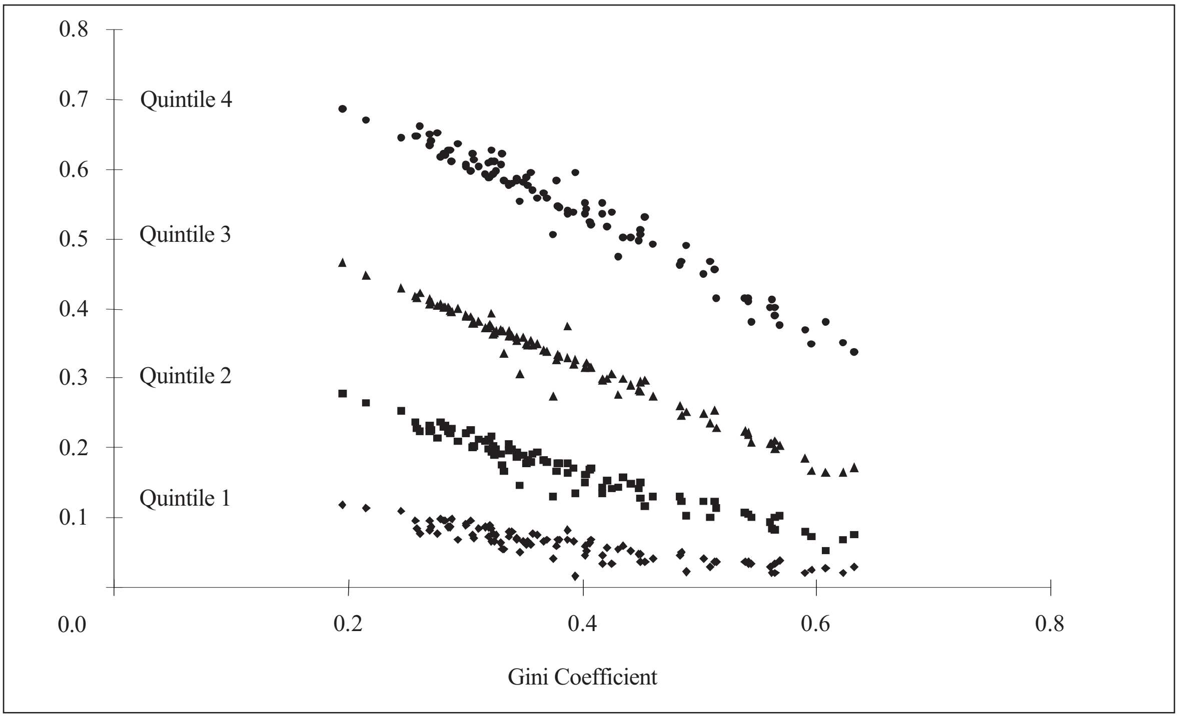


Figure 3.8: Quintiles of income versus Gini coefficients: national data and lognormal

From: Kemp-Benedict and others (2002)

Sources: Deininger and Squire (1996), Tabatabai (1996), UNU/WIDER (1999), USBC (1997) and World Bank (2000)

Note: Data from 1985-1995

then any summary measure of inequality (such as the Gini coefficient, low/high ratio or one of the quintile values) will depend only on that parameter. In this case, we should observe a strong correlation between Gini coefficients and quintiles. A plot of quintiles measured against Gini coefficients for a diverse set of countries shows a strong correlation (Figure 3.8).

A number of different one-parameter income distributions have been suggested as being reasonable representations of real national income distributions. As in the analysis of Kemp-Benedict and others (2002), we use a lognormal distribution function. When income is distributed lognormally, the logarithm of income is normally distributed: i.e. the distribution of the logarithm of income has a classic ‘bell’ shape. When plotted against income, rather than the log of income, the distribution has a broad high-income tail, as in Figure 3.6.

The Lorenz curve L(x, G) for a lognormal income distribution is given by

Equation 3.1: $$L(x,G) = N\left[N^{-1}(x) - \sigma(G)\right]$$

where x is the cumulative population fraction, G the Gini coefficient, $\sigma(G)$ the standard deviation of the logarithm of income, expressed as a function of the Gini coefficient, $N(x)$ the cumulative normal distribution and $N^{-1}(x)$ its inverse.

The standard deviation of log income is given in terms of the Gini coefficient by

Equation 3.2: $\sigma(G) = \sqrt{2}N^{-1}\left(\frac{1+G}{2}\right)$

The low-high ratio can be expressed in terms of the Gini coefficient using Equations 3.1 and 3.2. The low-high ratio R is given by

Equation 3.3: $R = \frac{L(20\%,G)}{1-L(80\%,G)}.$

Equation 3.3 can be used to evaluate the suitability of the lognormal approximation for representing income distributions in the scenarios. We asked whether the low-high ratio estimated using Equation 3.3 is a good predictor of the actual low–high ratio as estimated from measured quintiles. The answer to this question was found in the examination of income distribution data for countries with both Gini coefficients and quintile values. The low-high ratio was estimated using Equation 3.3 and compared to the observed ratio. Results shown in Figure 3.9 reveal both a high degree of correlation and a good fit to the lognormal prediction. If the fit were perfect, the slope would be one and the intercept would be zero. In fact, the estimated value for the slope is 0.978 ± 0.026, where 0.026 is the standard error, and the intercept is 0.003 ± 0.004. Thus, the estimated slope and intercept are each within one standard error of their expected values.

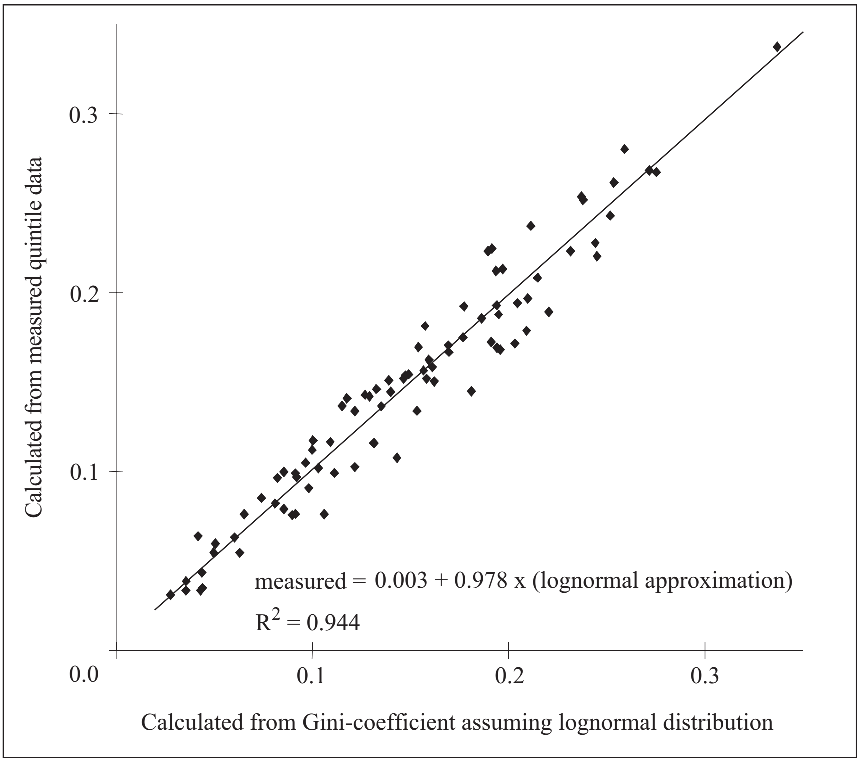


Figure 3.9: Measured versus estimated national low/high ratios in the share of income

From: Kemp-Benedict and others (2002)

Sources: Deininger and Squire (1996), Tabatabai (1996), UNU/WIDER (1999), USBC (1997) and World Bank (2000)

Note: Data from 1985-1995.

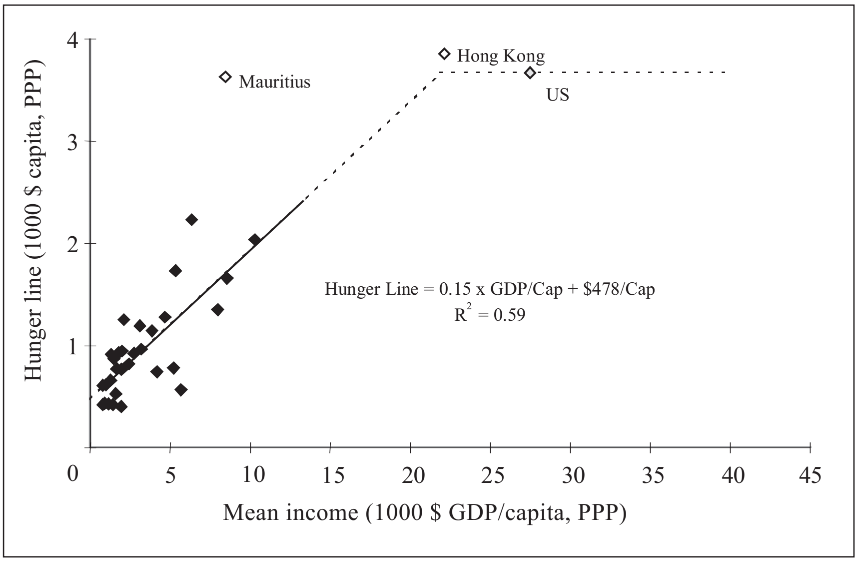


Figure 3.10: Hunger lines versus mean income measured and assumed in the study

From: Kemp-Benedict and others (2002)

Note: Mauritius, Hong Kong and the USA are excluded from the regression. For the developing countries, hunger data from 1990-92 were taken from the FAO (1997), and GDPPPP/capita for 1991 (in constant 1985 dollars) from WRI (1996). The 1985 currency values were converted to 1995 currencies using a deflator derived from historical data (WRI, 1996). The hunger figures from Rose and others (1995) and the 1995 income from the CIAWorld Factbook were used for the USA (CIA, 1997)

Hunger line values

For countries where both hunger and income distribution data are available, it is possible to calculate base-year hunger lines. The estimated values for some developing countries and the USA are plotted against income in Figure 3.10. The hunger lines in the figure tend to increase with income, a pattern that is also seen in national poverty lines. This is related to the fact that more informal economies are developing where informal income generation becomes more difficult. Likely reasons for this pattern are discussed in Gallopín and Raskin (2002) and Kemp-Benedict and others (2002).

In the scenarios, national hunger lines increase from their base-year values toward US$ 3670 – the current inferred value for the United States, as mean income approaches US$ 21880, the income at which the regression line in Figure 3.10 intersects the constant line at US$ 3670. Above an income of US$ 21880, hunger lines remain constant. In constructing the current accounts, the dashed line in Figure 3.10 is used to estimate the incidence of hunger for countries where values are lacking.

Income distribution

To estimate hunger in scenarios, three values are required: average income, a measure of income dispersion, such as the Gini coefficient, and the hunger line. Two of these are already specified: average income levels are specified as a high-level driving variable for the scenarios, while hunger lines are connected analytically to average income through the procedure described above (see Figure 3.10). Consequently, the discussion below focuses on assumptions for income distribution, as expressed by the Gini coefficient (see also discussion under Figure 3.6 on current Gini coefficients (the most recent values available)).

Markets First

In the *Markets First* scenario, the Gini coefficient for the United States increases at half the historic rate, while the other countries converge toward the US pattern, consistent with the central feature of global convergence toward industrial country patterns in the scenario. The *Markets First* scenario is one of convergence toward industrial country patterns, but there are some indications that other industrialized countries may be converging toward US levels of inequality. Inequality has been increasing in the United States for 30 years, and in recent decades inequality has increased in the United Kingdom, Australia and some Western European countries, as social protection programmes have failed to offset rising wage inequality (Ruiz-Huerta and others, 1999). While the causes of the increase in wage inequality are not yet well understood, several contributing factors for the United States have been identified: e.g. technological change, a decline in the strength of unions, a decline in the minimum wage and, to a small degree, globalization (Freeman, 1999).

Policy First

In the *Policy First* scenario, the evolution of income distribution is constrained by two considerations: the scenario target of cutting global hunger in half by 2025 and a plausibility constraint that income distribution patterns remain within historically plausible bounds. Given the income growth assumptions of the scenario, it is possible to meet the scenario target while remaining within plausible bounds on the Gini coefficients. In the scenario, Gini coefficients in all countries converge toward a common pattern set to allow the hunger reduction targets to be met in the scenario.

Security First

Gini coefficients in all regions converge toward a value of 0.60, higher than the current average level in Latin America, where inequality has persistently remained among the highest in the world. Regions do not reach that level during the scenario, but all regions see an increase in inequality consistent with the emerging highly polarized world envisioned in the scenario and described in the regional narratives.

Sustainability First

Gini coefficients initially follow the *Policy First* path, but move away from *Policy First* patterns to converge gradually toward the relatively low value of 0.30, characteristic of Germany today. Regions do not reach that level during the scenario, but nearly all regions have seen a decline in inequality. This is consistent with the shift in values described in the scenario narratives.

3.5.3 Results

Historical and scenario changes in the level of hunger at global level are shown in Figure 3.11. In general, *Markets First* follows a trajectory close to the historical one. The historical decline in hunger slows slightly in the *Markets First* scenario, partly because of persistent hunger in Africa: as the hungry population in Africa comes to dominate in the global distribution, the slow rate of advance in the region begins to impact global patterns. Note that even with sharply narrowing income distributions in the *Sustainability First* scenario, the World Food Summit target of halving hunger by 2015 is not reached – the level of effort required to meet the target rises as we approach the target year of 2015, and the level of inertia seen in the scenario overpowers the drive toward more equal distribution and lower poverty, at least in the short term. Table 3.2 shows regional estimates while sub-regional differences in hunger in the scenarios are shown in Figure 3.12.

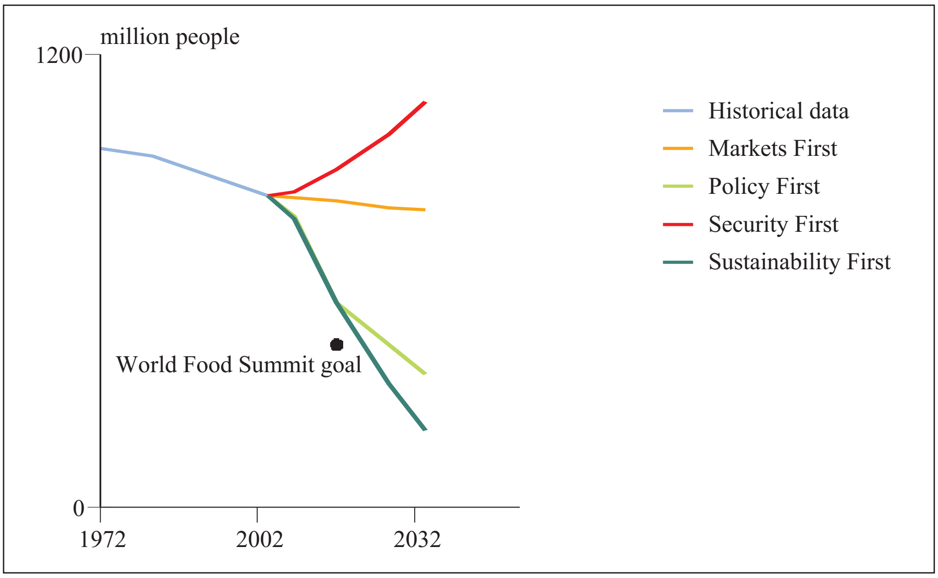


Figure 3.11: Global hunger
Source: SEI Boston

Broadly similar patterns are seen in all regions, with the highest levels of hunger in *Security First*, the second-highest in *Markets First*, the next-to-lowest levels in *Policy First* and the lowest levels in *Sustainability First*. This pattern follows from the equity and population assumptions in the scenarios, as described above. Note that in most regions there is a decline in the percentage of the population that is hungry even in *Security First*. In this scenario, as for the others, there is relatively robust growth in *average* incomes. The scenario features a globally connected and affluent group. Moreover, there is an overall reduction in poverty as income levels and distributions converge, so the standard of living of the poor approaches an intermediate level among all the countries today,

Table 3.2: Hunger incidence – current estimates and scenarios

			2032			
	1995	2002 (est.)	Markets First	Policy First	Security First	Sustainability First
	%					
North America	2	2	1	0	2	0
Latin America and Caribbean	11	11	8	3	12	2
Africa	28	26	17	10	22	6
Europe	2	2	3	1	4	1
West Asia	12	12	10	5	11	3
Asia and the Pacific	16	15	9	4	11	2
World	15	14	10	4	12	3

rather than the level of the poorest countries today. As a consequence, percentage rates for hunger decline slightly in many regions. Nevertheless, as population growth is high, the absolute number rises sharply.

The differences between the scenarios illustrate the potential impact of income distribution on poverty outcomes. The levels of distribution seen in the scenarios are well within historical norms. Perhaps the strongest message forthcoming from this analysis is that ‘broad-based growth’ must not be just a slogan but an actively pursued goal. Even if we set aside the goals of equity and poverty reduction that drive the scenario narratives, persistent hunger will affect the success of other initiatives discussed in GEO-3 and in this report.

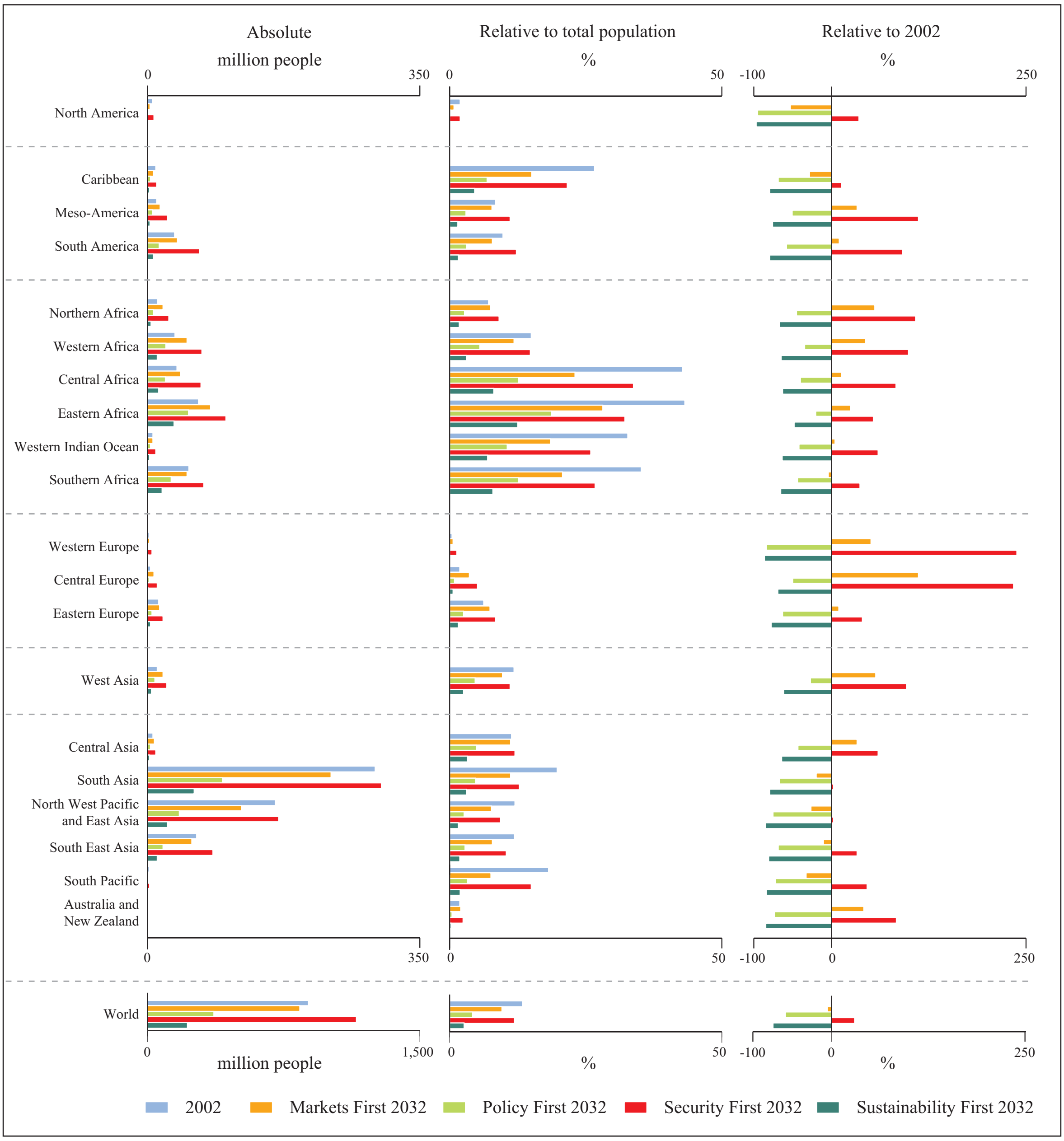


Figure 3.12: Hunger in 2000 and 2032

Source: SEI Boston

Hunger patterns are determined in our scenarios by changes in income, income distribution and population (see also Section 3.5.2 on Modelling). Even though this captures many issues reflected in income differences indirectly, the complexity of the situation should not be underestimated. Conflict, for example, can exacerbate problems of access to food even if superficially it may appear that incomes are sufficient, while targeted food aid may alleviate problems without being reflected in income statistics. Since these aspects were not explicitly addressed, the situation in a world of *Security First* may, in particular, be expected to be worse than our analysis shows.

3.6 Discussion

Two of the three PoleStar variables – land degradation and expansion of the built environment – are connected intimately to other variables developed by other groups and described in this document. Especially notable are two variables from the IMAGE analysis in Chapter 7: the risk of land degradation and the area of mature natural forest. Chapter 8 presents a cross-model comparison, which includes looking at land-related variables analyzed with IMAGE and PoleStar. The third PoleStar variable, hunger, is a key poverty variable. As such, it provides some insight into human vulnerability to environmental and social changes due to socio-economic conditions. It complements other measures of human vulnerability and direct pressures on societies developed for the GEO-3 report, such as water stress forthcoming from the WaterGAP analysis and municipal solid waste generation from NIES.

As with other GEO-3 variables, a key observation is the persistence of negative impacts despite positive changes. Given reasonable rates of change in, for example, land restoration and agricultural practice (or in settlement patterns), expansion of the built environment and loss of productive agricultural land can be expected to persist over coming decades, placing significant constraints on agricultural production. Income and income distribution are each subject to more rapid changes than are agricultural practices and settlement patterns. As a consequence, hunger outcomes in the scenarios vary across a wide range, indicating considerable scope for action. However, persistent hunger over a period of decades emerges in all of the scenarios, and the World Food Summit goal of halving hunger – from 800 million to 400 million – by 2015 seems out of reach, even in the most optimistic scenario.

The research described in this chapter points to the need for improvements in the underlying historical data. Each of the variables – land degradation, expansion of the built environment and hunger – is difficult to analyse due to a lack of quality in the historical data. Where land-use variables are concerned, a global assessment of land degradation is available in the GLASOD study, but changes over time are poorly understood. Also, and perhaps more crucial, rates and patterns of land *restoration* and soil *conservation* are poorly understood. The scenarios presented here offer a plausible range of rates, and indicate what might be achieved with efforts to retain productive cropland. Historical rates of change in the built environment, and the degree to which new built land is converted from forest or agricultural land are also poorly known. The relatively small absolute areas of the built environment, and of degraded cropland, compared to total agricultural area are deceptive. They make large contributions to marginal changes in land cover, but it is at the margins that ecosystems are destroyed; furthermore, the most vulnerable populations live there too.

In turning to the issue of hunger and of poverty in general, this exercise shows that income distribution should be brought into analyses of the interaction between social and environmental systems. In general, to understand human vulnerability to environmental stresses, it is important to understand how populations are distributed –with respect to both income and space. For example, in the analysis presented here, income growth in *Markets First* and *Security First* are comparable. However, because of differences in income distribution, hunger is significantly more prevalent in the *Security First* scenario. Populations in the lower tail of the income distribution are at risk from ecosystem shocks, as are populations in arid and agriculturally poor areas, and peri-urban squatter settlements and coastal zones. These conditions are not unrelated: often the most vulnerable will be found on the edges of both the income and the spatial distributions.

References

Alexandratos, N., ed., 1995. *World Agriculture: Towards 2010.* Chichester: John Wiley and Sons.

Central Intelligence Agency (CIA), 1997. *The World Factbook 1996*. McLean, Virginia: Central Intelligence Agency. Available from: http://www.odci.gov/cia/.

Crosson, P. and J.R. Anderson, 1992. *Resources and Global Food Prospects: Supply and Demand for Cereals to 2030.* (World Bank Technical Paper Number 184). Washington, D.C.: The World Bank.

Deininger, K. and L. Squire, 1996. A New Data Set Measuring Income Inequality. *The World Bank Economic Review,* 10(3), pp. 565-591.

Food and Agriculture Organization of the United Nations (FAO), 1997. *Mapping Undernutrition* (poster). Rome: Food and Agricultural Organization of the United Nations.

FAO, 1999. *State of Food and Agriculture 1999*. Rome: Food and Agriculture Organization of the United Nations.

FAO, 2000a. *Agriculture: Towards 2015/30. Technical Interim Report, April 2000.* Rome: Food and Agriculture Organization of the United Nations.

FAO, 2000b. *The State of Food Insecurity in the World 2000.* Rome: Food and Agriculture Organization of the United Nations.

FAO, 2000c. *Land Resource Potential and Constraints at Regional and Country Levels.* (World Soil Resources Report no. 90). Rome: FAO Land and Water Development Division.

Freeman, Richard B., 1999. *The New Inequality in the United States.* In: A. Fishlow and K. Parker, eds., *Growing Apart: The Causes and Consequences of Global Wage Inequality.* New York: Council on Foreign Relations, 1999.

Gallopín, G. and P. Raskin, 2002. *Global Sustainability: Bending the Curve*. (Routledge/SEI Global Environment and Development Series 3). London: Routledge.

Global Resource Information Database/United Nations Environment Program (GRID/UNEP), 1991. *Global Assessment of Human Induced Soil Degradation (GLASOD): Global Digital Database.* Nairobi: GRID.

Houghton, R.A. and J.L. Hackler, 1995. *Continental Scale Estimates of the Biotic Carbon Flux from Land Cover Change: 1850 to 1980*. Carbon Dioxide Information Analysis Center. NDP-050. Available from http://cdiac.esd.ornl.gov.

Kemp-Benedict, E., C. Heaps and P. Raskin, 2002. *Global Scenario Group Futures: Technical Notes.* (PoleStar Series Report no. 9 (revised)). Boston: Stockholm Environment Institute-Boston.

Kendall, H. and D. Pimentel, 1994. Constraints on the Expansion of the Global Food Supply. *Ambio* 23(3), pp. 198-205.

Mahanani, W.R., 2001. *Achieving Food Security and Environmental Sustainability in Southeast Asia: A Policy Challenge*. (RIVM Report 402001020). Bilthoven: National Institute for Public Health and the Environment.

Meyer, W.B. and B.L. Turner, eds., 1994. *Changes in Land Use and Land Cover: A Global Perspective.* Cambridge: Cambridge University Press.

Oldeman, L., R. Hakkeling and W. Sombroek, 1991. *World Map of the Status of Human-Induced Soil Degradation: An Explanatory Note*. 2nd rev. ed. Nairobi: United Nations Environment Programme.

Raskin, P., et al., 1998. *Bending the Curve: Toward Global Sustainability.* (PoleStar Series Report No. 8). Boston: Stockholm Environment Institute-Boston.

Raskin, P., et al., 2001. *Great Transition: The Promise and Lure of the Times Ahead.* Boston: Stockholm Environment Institute-Boston.

Rose, D., P.P. Basiotis and B.W. Klein, 1995. Improving Federal Efforts to Assess Hunger and Food Insecurity. *Food Review* 18, Jan-Apr.

Ruiz-Huerta, J., R. Martinez and L. Ayala, 1999. *Earnings Inequality, Unemployment and Income Distribution in the OECD.* (Luxembourg Income Study Working Paper No. 214). Syracuse, New York: Maxwell School of Citizenship and Public Affairs, Syracuse University.

Tabatabai, H., 1996. *Statistics on Poverty and Income Distribution: An ILO Compendium of Data.* Geneva: International Labour Office.

United Nations Environment Programme (UNEP), 2002. *Global Environment Outlook 3*. London: Earthscan.

United Nations University/World Institute for Development Economics Research (UNU/WIDER), 1999. *UNDP World Income Inequality Database*. Available from: http://www.wider.unu.edu/wiid/wiid.htm.

United States Department of Agriculture (USDA), 1994. *1992 National Resources Inventory: 1992 NRI Changes in Land Cover/Use Between 1982 and 1992*. Available from: http://www.nhq.nrcs.usda.gov/land/tables/t2211.html.

USDA, 2000. *Summary Report, 1997 National Resources Inventory.* Revised December 2000.

United States Department of Commerce, Bureau of the Census (USBC), 1992. *Statistical Abstract of the United States.* Washington, D.C.: US Government Publishing Office.

USBC, 1995. *Statistical Abstract of the United States.* Washington, D.C.: US Government Publishing Office.

USBC, 1997. *Historical Income and Poverty Tables (Table H-4).* Washington, D.C.: United States Bureau of the Census. Available from http://www.census.gov/.

World Bank, 2000. *World Development Variables 2000*. Washington, D.C.: World Bank.

World Resources Institute (WRI), 1994. *World Resources, 1994-95*. New York: Oxford University Press.

WRI, 1996. *World Resources 1996-97 Database Diskette*. Washington, D.C.: World Resources Institute.

4. Ecosystems impacted by infrastructure expansion

Infrastructure is the central nervous system of the modern world and essential to economic development. At the same time it results in large pressures on biodiversity and ecosystems. GLOBIO estimates for the four GEO-3 scenarios show that even in a Sustainability First *world there will be continued biodiversity loss as a result of infrastructural development and associated land use by humans. Assumedly, the main difference among the three other scenarios is the* rate *at which infrastructure and its impact grows as opposed to the eventual* level *of impact. Differences in trends become most visible 50 years from now.*

4.0 Introduction

4.0.1 Scope and structure of the chapter

GLOBIO is used to identify zones around infrastructure where biodiversity is currently impacted to a certain degree. Specific assumptions on infrastructural growth allow us to estimate the impact of future human expansion on future biodiversity. This chapter provides background information on the GLOBIO analysis carried out for the GEO-3 Outlook chapter.

The overall GLOBIO framework and database are briefly described in sections 4.2 and 4.3, respectively, emphasizing the extensive literature review that provides the basis for GLOBIO. Section 4.4 outlines the assumptions made by GLOBIO for the GEO-3 scenario analysis. GLOBIO comprises both modelling assumptions for any future development and specific interpretations of the GEO-3 scenarios. The chapter goes on to present the impact estimates produced for the GEO-3 Outlook exercise (Section 4.5) and ends with a brief discussion, reflecting on GLOBIO’s use for GEO-3 and sketching the main results.

4.0.2 Description of the issue

The human resource demand continues to take an increasing toll on biodiversity. In less than 150 years humans have directly impacted and altered close to 47% of the global land area. Physical infrastructure, including roads, ports and settlements, is necessary for producing, delivering and accessing goods and services. It accounts for a major share of a country’s national capital. Expansion of infrastructure into previously undeveloped areas open them up for industrialization through oil, gas and mineral exploration, for example, and for logging, farming, official migration and tourism. Infrastructure also stimulates more uncontrolled migration activities that often lead to hunting, poaching, clear-cutting for farming and sometimes for growing illegal crops. Many of these activities, planned or uncontrolled, result in deforestation, land degradation, flooding and land conflicts (Skole and others, 1994; Houghton, 1994; Johnston, 1994; Chomitz and Gray, 1996; Reid and Bowles, 1997; Mäki and others, 2001), as well as loss of biodiversity and ecosystems (see next paragraph).

Expansion of road networks causes fragmentation of landscapes and water systems (Andrews, 1990; Kummer and Turner, 1994; Forman and Alexander, 1998; Lawton and others, 1998; Wilkie and others, 2000; UNEP, 2001; 2002b). Draining of wetlands for infrastructural development also has enormous impacts on biodiversity such as migratory bird species (Johnston, 1994; Findlay and Bourdages, 2000; Wilkie and others, 2000; Mäki and others, 2001; UNEP, 2001). Loss of biodiversity due to infrastructural development has been reported for a broad range of species, including reduced abundance of insects, amphibians, reptiles, birds, and small and larger mammals (UNEP, 2001).

Many studies also emphasize that, in the long run, even more serious effects may be expected on ecosystem functions as a result of altered ratios between numbers of animals, thereby altering species co-actions and modifying animal behavior. Changes can, for instance, be expected in predator-prey relationships, between generalist and specialist species, and in insects and wildlife relationships. Expanded infrastructure will also accelerate the introduction of exotic, potentially invasive, species (Forman and Alexander 1998, Kruess and Tscharntke, 1994; Lawton and others, 1998, Trombulak and Frissell, 2000). Infrastructure thus disrupts the physical environment, induces changes in land use and land cover, alters the chemical environment and impacts on species numbers and co-actions.

4.1 Analytical framework

GLOBIO is a system that translates an analysis of hundreds of peer-reviewed studies on environmental impacts of human expansion on biodiversity and ecosystems into spatially explicit impact zones around infrastructure (see Figure 4.1 for the GLOBIO principles). GLOBIO links the literature overview with current infrastructure patterns (for example, through remote sensing) to designate zones around the infrastructure where biodiversity is currently impacted to a certain degree; in general, the larger the distance to infrastructure, the lower the impact on biodiversity. The impact of future human expansions on future biodiversity can be estimated by assuming certain infrastructure growth factors in the various GEO-3 regions for the four GEO-3 scenarios (see Chapter 2 and UNEP, 2002a).

The source for the review was literature covered by the *Current Contents/Agriculture, Biology and Environmental Sciences* database (www.isiwebofknowledge.com). The database provides access to bibliographic information from articles, editorials, meeting abstracts, commentaries and all other significant items in recently published editions of over 1040 of the world's leading journals and books in agriculture, biology and environmental sciences. Publications on experiments were excluded, with only articles strictly based on empirical investigations published in journals included. The subject had to relate to fragmentation and disturbance effects (decline in abundance of species) associated with roads and/or human transport. Article titles and keywords were searched for terms like 'landscape', 'habitat patch or patch', 'forest fragmentation', 'roads' and 'disturbance' relating to the period from January 1987 to October 2001. The result was a total of 309 relevant articles, cross-checked with recent literature reviews to ensure essential studies are flagged, which, without an extra check, even the best of literature searches can overlook.

The literature study showed avoidance behaviour to be the primary response of most species to human disturbance (Frid and Dill, 2002) as long as an alternative habitat is available (Gill and others, 2001). Species decline is often presented in relation to the size of habitat fragments (islands). Linkages also exist between the degree of habitat fragmentation and road density (Aguilar, 2001). On the basis of this review, it was concluded that avoidance and incremental loss of habitat could be projected as a function of distance to infrastructure (Nellemann and others, 2003b).

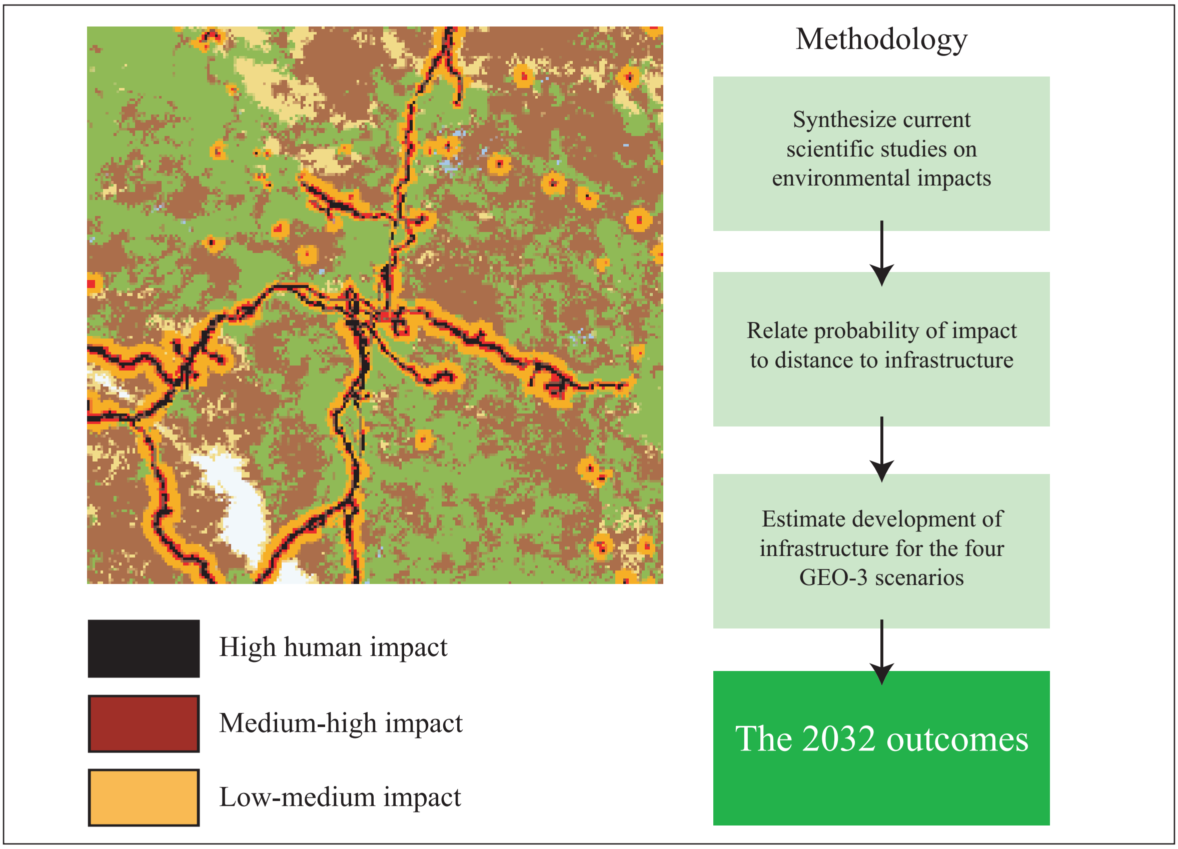


Figure 4.1: The GLOBIO principles

Note: Denoted are zones of probability of reduced biodiversity with distance to infrastructure varying with among other land cover

4.2 Basic data and modelling assumptions

A data set was compiled for GLOBIO on a 1x1 km grid system and included such infrastructure as dual-lane highways, primary or secondary roads, tracks, trails or footpaths, single, multiple and light railroad lines, tramways, utilities, power and pipelines, and settlements. In North America and Europe, traffic along tracks and trails is very limited in contrast to developing countries. Therefore this category was not included for these two GEO regions. Data sources used to compile the data set were:

- the Digital Chart of the World (DCW based on VMAP level 0);
- the USGS Global Land Cover Characterization (GLCC) version 2, using the USGS legend (based on AVHRR data from 1992-1993);
- population density from the Landscan 2000 database and
- various resource data from ArcAtlas.

A measure was defined for GLOBIO to characterize the extent of impact from infrastructure in a given area. The review mentioned in section 4.1 showed almost 95% of all species to be impacted by a decline of 50% or more in abundance within 0-5 km from any infrastructure. This range crops up in the literature again and again, whether dealing with deserts or rainforests, high-altitude plains or steppes, insects, reptiles, plants or large mammals. Figure 4.2 shows the typical distribution of

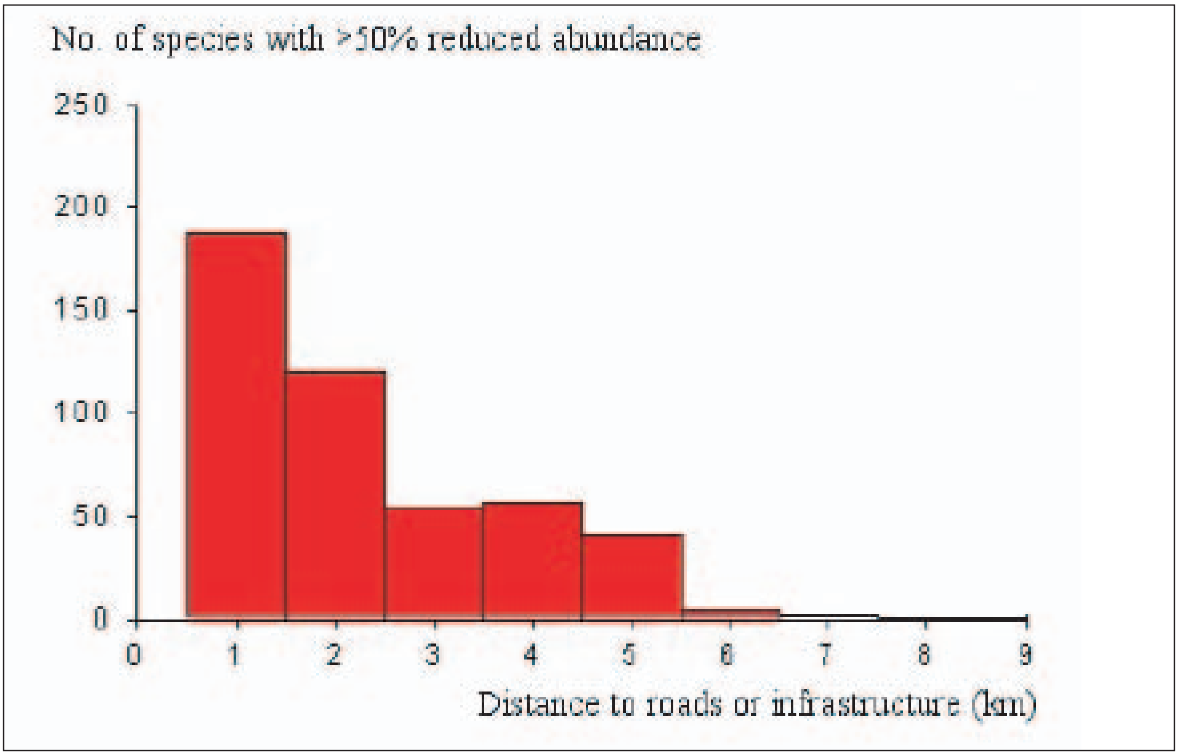


Figure 4.2: Typical distribution of impact from infrastructure on species richness
Source: Nellemann and others, 2003a

impacts from infrastructure on species richness based on studies of more than 400 species, as documented in the 309 selected articles. The measure of impact was formulated as the distance from the infrastructural element within which a 50% decline or more in species abundance was recorded. The actual distance is calculated from the empirical results as the square root of the surface area affected.

On the basis of the responses of species to disturbance arising from infrastructural development, as documented in the literature reviewed, the four following impact zones for GLOBIO were then statistically determined by looking at the distribution of declining species within a certain distance of a particular infrastructure:

- '*high impact*' – upper 50th percentile (i.e. the distance within which more than 50% of all species is found to decline by over 50%);
- '*medium-high impact*' - 25-50th percentile (the distance within which 25 to 50% of all recorded species is found to decline by over 50%);
- '*medium-low*' impact - 1-25th percentile (the distance within which up to 25% of all recorded species is found to decline by over 50%); and
- '*low impact*' - for areas further away.

For modelling impacts, GLOBIO takes into account that the extent of the impact zone surrounding a given infrastructural element will be different for different land covers. For instance, the impact zones will be smaller in forested areas than in open landscapes (Nelleman and others, in press). This has been factored using the values shown in Table 4.1.

Table 4.1: GLOBIO zones for the current situation showing impact on species richness due to disturbance from infrastructure

Vegetation cover (based on a reclassification of GLCCv2)	High impact (upper 50th percentile)	Medium-high impact (25-49th percentile)	Low-medium impact (1-24th percentile)	Low impact
	km			km
Croplands	0.0 - 0.5	0.5 - 1.5	1.5 - 5.0	>5.0
Grasslands	0.0 - 0.5	0.5 - 1.5	1.5 - 5.0	>5.0
Boreal and high altitude forests	0.0 - 0.3	0.3 - 0.9	0.9 - 3.0	>3.0
Deciduous forests	0.0 - 0.3	0.3 - 0.9	0.9 - 3.0	>3.0
Tropical forest	0.0 - 1.0	1.0 - 3.0	3.0 – 10.0	>10.0
Semi-deserts and deserts	0.0 - 0.5	0.5 - 1.5	1.5 - 5.0	>5.0
Wetlands	0.0 - 0.5	0.5 - 1.5	1.5 - 5.0	>5.0
Arctic tundra	0.0 - 1.0	1.0 - 3.0	3.0 – 10.0	>10.0
Ice, snow and barren	0.0 - 0.5	0.5 - 1.5	1.5 - 5.0	>5.0

Note: Distances are given perpendicular to the infrastructure element

Moreover, the extent of impact depends on the type of infrastructure. In the GLOBIO system, infrastructure types with low levels of human traffic are assumed to have substantially less impact (see Nellemann and others, 2001; Vistnes and others, 2001). Table 4.2 shows the impact adjustment factors applied to different types of infrastructure. The percentages in the table were defined by means of various tests using both hindcast-modelling dating from 2002 back to 1940 and using documented changes in road networks in parts of the Northern Hemisphere (USA, Russia and Scandinavia) and parts of Latin America. The analysis was performed per continental land mass, with Europe and Asia analysed separately. Each continent was analysed in a Lambert Azimuthal Equal Area projection centered on the continent with a resolution of 1x1 km.

Table 4.2: Adjustment factors to differentiate the estimated extent of the impact zones by type of infrastructure

Infrastructure	
Highways, primary and secondary roads	100%
Trails, tracks	25% lower
Railroads	100%
Settlements	100%
Utilities	50% lower

Note: For example, 100% for roads means that a road will have the same impact zone as stated in Table 4.1 while 25% for a track means that a track will have only 25% of the impact zones stated in Table 4.1.

4.3 Assumptions for future expansion

As reported in Chapter 2, four scenarios had been developed for the GEO-3 scenario exercise. Functioning as the main link of these scenarios to GLOBIO modelling, the growth of physical infrastructure in a given area is assumed to be proportional to the regional growth in GDP per capita – in purchasing power parity- and is also dependent on human population numbers, location and the exploitation of natural resources. More specifically, the following assumptions were made for all scenarios:

- Infrastructure expands primarily away from existing infrastructure and by adding interconnections, nodes and other forms of aggregation.
- Areas with current relatively high population density will experience relatively high rates of growth in infrastructure.
- Areas with known timber, oil, gas or mineral resources will experience relatively high rates of growth in infrastructure.
- Areas close to coasts will experience relatively high rates of growth in infrastructure.

The latter three assumptions were implemented as multiplication factors (either larger or smaller than one) for determining the infrastructure growth rate at a resolution of 1x1 km. Table 4.3 lists these multiplication factors.

Specific assumptions for the four GEO-3 scenarios hinge on the development of resource extraction and exploitation in the 2002-2032 period placed against the background of historical changes in land

Table 4.3: Multiplication factors for deriving local infrastructural growth for 2002-2032 from growth in GDP/cap (ppp)

Dominant feature of the area	Ratio of growth in local infrastructure to growth of GDP/cap (on ppp basis)
Distance to coast smaller than 50 km	1.25
Croplands	1.0
Grasslands	0.75
Boreal forest	1.25
Broadleaf/tropical forest	1.75
Semi-deserts and deserts	0.5
Arctic tundra	0.75
Ice and snow/barren	0.25
Wetlands	1.0
Mineral deposits, gas & petroleum reserves within a 50 km radius	1.5
Population density 0-10 inhabitants / km^2	0.5
Population density 10-50 inhabitants / km^2	1.0
Population density >50 inhabitants / km^2	1.5

Note: For example, it is assumed that within 50 km from petroleum reserves, local infrastructure grows 50% faster than GDP/cap use and road development for the various continents in the 1850 - 2000 period. In fact, it is assumed for this analysis that the future developments in the exploitation of natural resources will determine whether physical infrastructure will expand at the same rate, or either slower or faster, than during the previous 150 years.

- *Markets First* is a 'let-loose' situation where market forces take complete control of resource development, and multinational corporations play a primary role in rate, location and impacts of development. This corresponds with a large acceleration in resource extraction and exploitation. Therefore an average annual growth of the area impacted by a physical infrastructure of 1.5% is assumed up to 2032. (This is separate from situation-specific adjustments, as presented in Tables 4.1, 4.2 and 4.3.) The 1.5% average annual growth is comparable to the average of 1% per year during the preceding 150 years.
- *Policy First* is a continuation of the gradual development trends experienced during the last century; i.e. an average annual increase of 1% in the growth rate of the area impacted by infrastructure.
- *Security First* brings acceleration in the current regime for exploitation of areas for natural resources extraction. This translates to an annual increase in infrastructure of 1.25 % compared with the current 1% per year.
- *Sustainability First* assumes continued demand for resources; however, strategic regional planning reduces and controls effects of human expansion better than in the current situation thereby minimizing unwanted secondary developments. Networks of protected areas help reduce and direct development into corridors, thereby reducing the extent of areas where biodiversity is reduced. However, due to the spatial development pattern inherited from the past, this scenario really reveals its benefits only after 50 years. Earlier, up to 2032, the annual growth of infrastructure is assumed to be a 0.25 percentage point slower than the historical growth rate of 1%. The expansion starts to 'flatten out' around 2032.

Figure 4.3 illustrates this growth in infrastructure. For full details of the method, including the historical analysis, see http://www.globio.info.

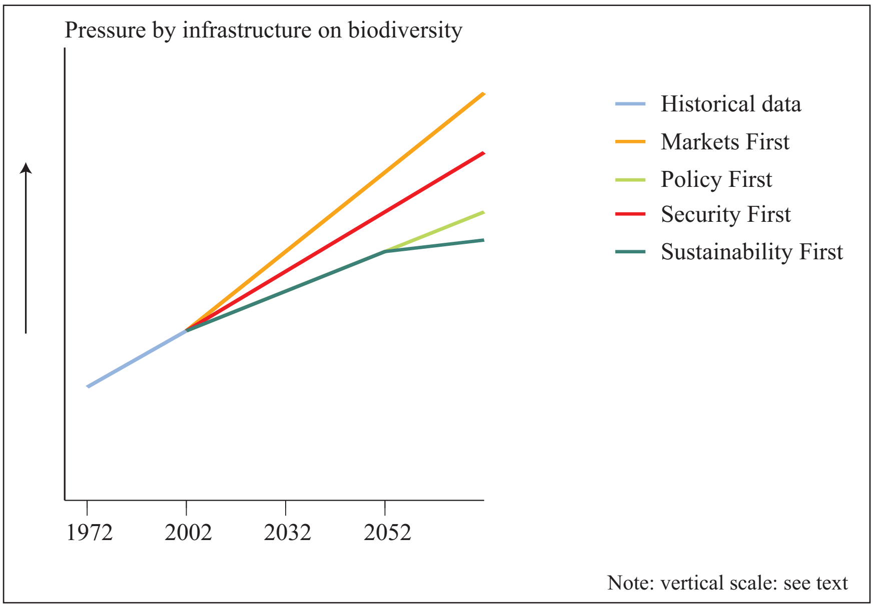


Figure 4.3: Assumed global average growth in physical infrastructure as determined by resource extraction and exploitation

Finally, applying the earlier mentioned impact distances, the approximate future area of risk for biodiversity is estimated at 1x1 km and then aggregated.

4.4 Results

Global results

The GLOBIO analysis quantifies the cumulative effect of assumed differences in trends by 2032. Figure 4.4 shows the global estimates and Map 4.1 the spatial pictures.

In *Markets First,* with its global economic networks, biodiversity will be threatened in nearly 72% of the land area by 2032. The GLOBIO projections suggest particularly large deterioration of biodiversity for South East Asia, the Congo Basin and parts of the Amazon.

In the future, only *Sustainability First* will eventually provide significant protection of ecosystems. But even the *Sustainability First* scenario suggests that we can expect continued loss of biodiversity in nearly 56% of the land area by 2032 (a 9% increase compared to 2002).

By 2032 infrastructure development will assumedly run up against constraints when nearly 75-80% of the global land area is impacted. This is mainly because of mountains at high altitude (UNEP 2003c), and polar and tropical deserts that present marginal interest in development unless significant cost reductions take placein relation to water transport or other developments. In fact, the World's remaining non-impacted land will be mainly desert. However, continuous deterioration– or improvement – may occur on almost 80% of the land area, depending on future policies. In contrast, pressures on biodiversity will continue to increase in other areas beyond 2032 as a result of increases in the built-up areas and further fragmentation, in particular with the *Policy First*, *Markets First* and *Security First* scenarios.

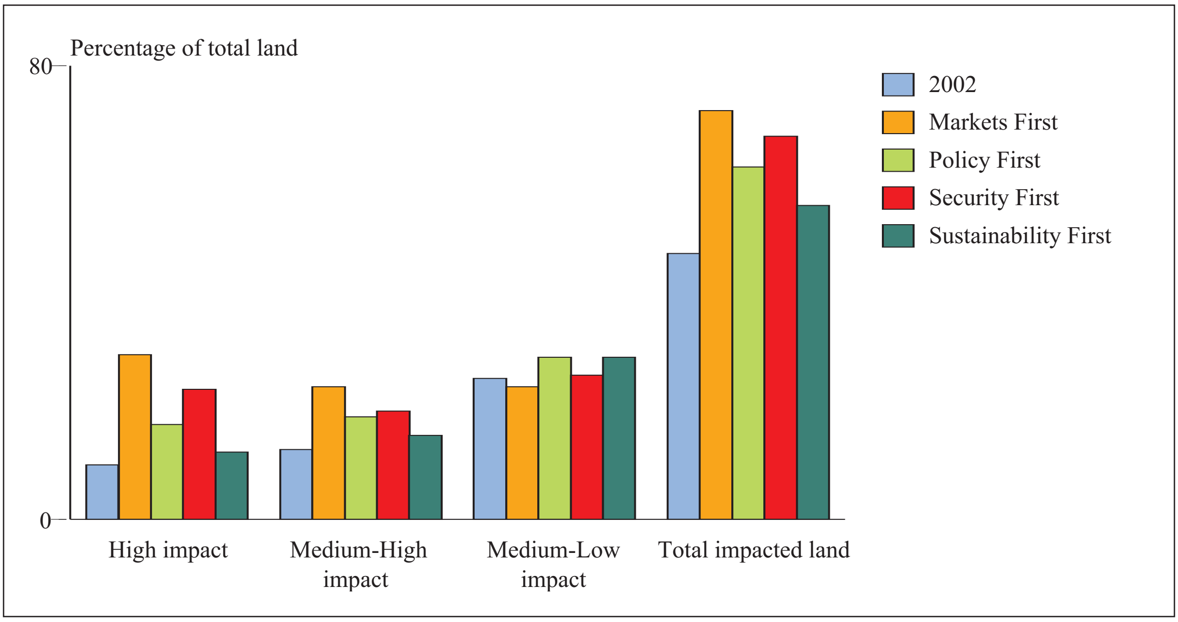
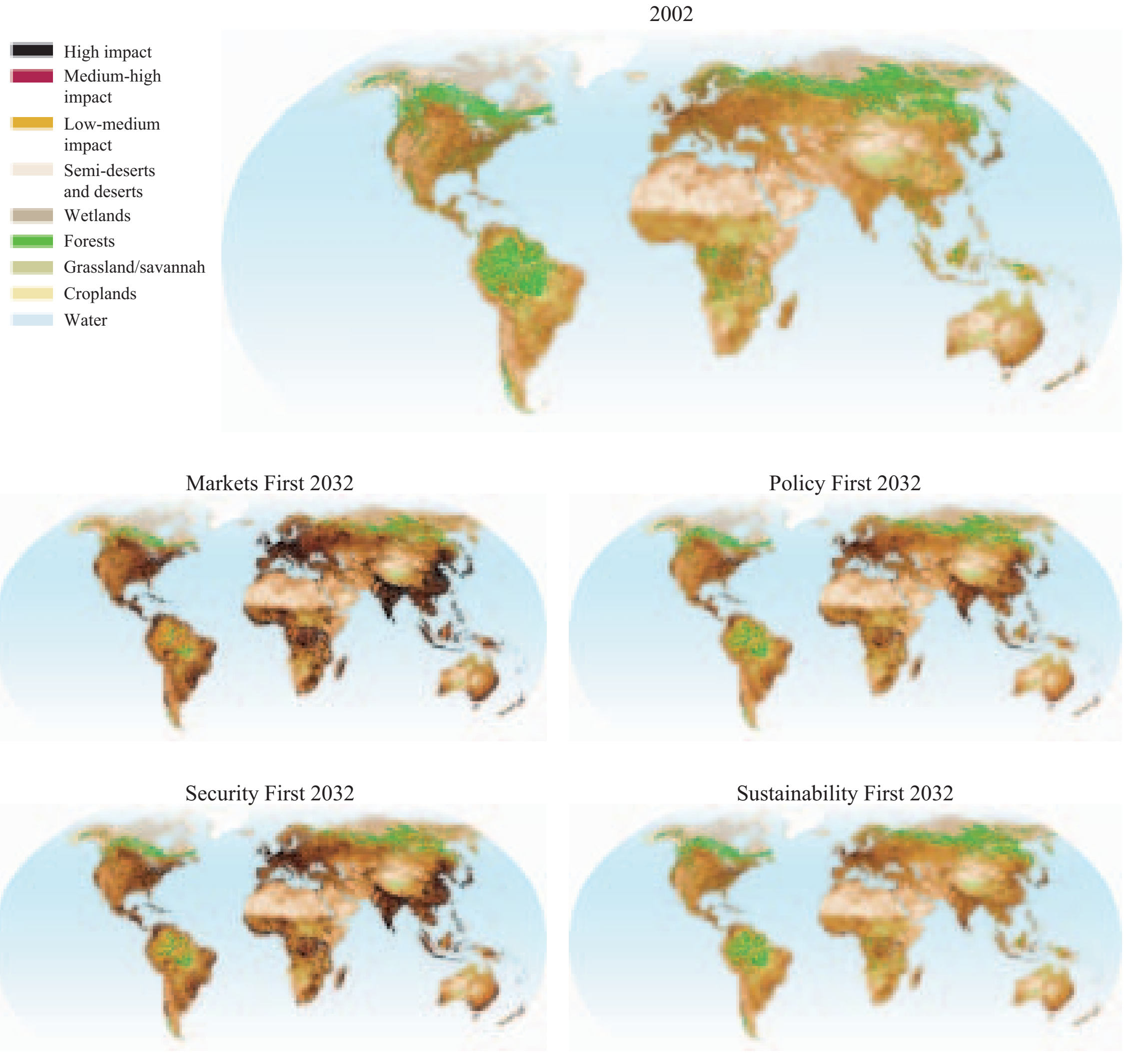


Figure 4.4: Global estimates for 2032 ecosystems impacted by infrastructure

Note: Total land area comes to approximately 131 million km^2


2002

Markets First 2032

Policy First 2032

Security First 2032

Sustainability First 2032

Map 4.1: Ecosystems impacted by infrastructure development

Clearly, halting ecosystem degradation and reversing the 150-year-long trend of declining global biodiversity will only succeed with large efforts to protect the wilderness areas and control and limit road development into undeveloped areas. In most areas, the ecosystem degradation not only includes loss of biodiversity but also increased pressures on freshwater ecosystems, and natural products such as pharmaceuticals and food resources, all of these related to social security and potential conflicts.

Regional implications

In order to appreciate the changing impact on biodiversity in the regions of the world, the infrastructure impact has to be seen in the context of related developments such as changes in agriculture in these regions.

North America

Biodiversity is under increasing pressure in North America. In Canada, large land areas have been set aside for indigenous people, with a likely positive outlook for many of the ecosystems involved

(UNEP, 2001). However, in most scenarios, very extensive mining, hydropower, oil and gas development projects, along with forest road construction result in rapidly diminishing wilderness areas. In the *Security First* and the *Markets First* scenarios, exploration processes will increase substantially, as in Alaska, Yukon and Quebec. The *Policy First* scenario will continue most of the current development, which so far highly exceeds conservation and restoration efforts. Only *Sustainability First* can alter this process.

Latin America

Latin America contains some of the largest global reservoirs of biodiversity. Conversion of tropical rainforest to farmland and ranches constitutes one of the greatest threats to biodiversity. Under *Policy First,* current increased industrial exploration of oil, gas and minerals accelerating road construction will continue, leading to more uncontrolled immigration and logging, and conversion of land to plantations and farmland (with heavy losses of biodiversity) be it more at lower speed. *Sustainability First* may change this path in 20-30 years, although some continued losses are expected as a result of continued requirements for farmland and industrial development. Under *Markets First* and *Security First* the mining, logging and oil sectors will continue to heavily increase production as new areas will be required for development to at least maintain the current production levels over time. Serious negative impacts on ecosystems and biodiversity due to infrastructural expansion will be the result.

Europe

Most of Europe has been directly converted to farmland and production forestry, the most extreme conversion being in Western Europe. The remaining low-disturbance areas are mainly confined to mountainous areas and protected zones in places like Scotland and Scandinavia. But tourism and recreational development is putting increasingly greater strain on these little-disturbed ecosystems. Restoration of former wetlands has begun, but still on a much smaller scale than the continued development of infrastructure, plantations and other human activities. Under *Markets First* and *Security First*, increased pressures towards developing resources and infrastructure will reduce remaining biodiversity, including loss of reindeer and wolf populations, and many insects and plants that cannot adapt to chemical-intensive modern agriculture. *Sustainability First* will be required to restore lost habitat, such as wetlands and traditional agro-ecosystems.

West Asia

In West Asia, comprising large desert regions and important wetland areas, further development of dams and infrastructure will increasingly negatively impact on migratory bird and fish populations, and on the Marsh Arab society. Under *Policy First*, *Markets First* and *Security First*, increasing demand for irrigation water, agricultural land and hydropower will become detrimental to large parts of the remaining biodiversity in this region in a very short time span. Under *Sustainability First,* rapidly applied mitigation and restoration measures will help protect some of the remaining biodiversity, although even then, losses will be expected due to the time lag of cumulative impacts.

Asia and the Pacific

South East Asia is one of the sub-regions in the world with the strongest pressures on biodiversity. In most of South East Asia *Markets First* and *Security First* scenarios, infrastructural expansion will result in near complete deforestation or conversion to plantations by 2032. Loss of the complex forest ecosystems means losses of many different flora and fauna species, e.g. the world’s only remaining Orang-utan populations. Forest loss exacerbates the effects of landslides, flooding and the quality and quantity of freshwater supply, traditional energy sources and traditional medicine. Even with *Sustainability First*, the situation will be critical for much of the remaining biodiversity in this region. In Australia, New Zealand and the South Pacific, most of the productive lands have already been developed, but Australia and New Zealand still contain large wilderness areas. However, also here, industrial development and ranching, with the subsequent infrastructural expansion, will greatly change landscapes and their biodiversity in the years to come.

Africa

Africa also holds large biodiversity reservoirs. With *Markets First* and *Security First*, pressures for mineral and logging exploration will increase in the Congo Basin, resulting in increased deforestation and illegal bush-meat hunting, with severe impacts on biodiversity. Expansion of infrastructure will increase land pressures and disrupt traditional grazing cycles in parts of the Sahel and across other semi-arid regions. This, in turn, may well increase land conflicts, land degradation and desertification. In *Sustainability First*, changes for the better will only come about effectively in 10-15 years due to the severity of the water and land productivity pressures, and those due to associated infrastructural expansion, facing many parts of this continent.

Polar regions

The Arctic contains the largest undisturbed, but very sensitive, wilderness remaining in the world. In the *Markets First* scenario, the Arctic will, however, develop rapidly as it holds some of the largest reservoirs of oil, gas and minerals. The resultant negative impacts of infrastructural expansion will be large on migratory species of both birds and reindeer/caribou, for example, and also on indigenous people. *Security First* will also accelerate the demand for the resources in the North, including fisheries and petroleum. Even with *Policy First*, the protection of areas will not be able to keep up with development rates of petroleum, minerals and hydropower. In addition, more tourism will be made possible in the Arctic by expanding the infrastructural network of roads and airports. Under *Sustainability First*, however, there may still be time to turn the prospects for the sub-region in the right direction. The Antarctic is not yet open for development, but pressures from tourism and exploration may over time open up this sub-region. Especially in a *Markets First* situation, infrastructure will clearly expand, bringing with it negative impacts on ecosystems and biodiversity.

4.5 Discussion

4.5.1 The use of GLOBIO for scenario exercises

Infrastructure as the central nervous system of the modern world is essential to economic development. At the same time it exerts large pressures on biodiversity and ecosystems (UNEP, 2002b). Infrastructure relates closely to local, regional and national industrial and human development activities. It is an essential parameter in many societal issues, and most people can easily associate with the benefits and costs related to infrastructure. Furthermore, it is very visual and indisputable. All of the above arguments are used to explain why in GLOBIO expansion in infrastructure is used as an umbrella pressure to analyse potential future impacts of society on biodiversity and ecosystems.

One strength of GLOBIO is its relative simplicity. In addition, GLOBIO results project a broad review of scientific, peer-reviewed studies on impacts of infrastructural expansions on ecosystems.

The zone-extent estimates can thus be updated when new studies are published. However, such updates are expected to change the impact zones only slightly, as the number of studies already considered is very large.

GLOBIO is primarily intended to help bridge the gaps between the aspects of global environmental change that relate to infrastructural expansions and the impacts on biodiversity and ecosystems (UNEP, 2002b). In general, the GLOBIO historical database shows a clear correlation between infrastructural expansions and losses over time in biodiversity and pristine areas. GLOBIO can also project the degree of disturbance. Simple historical trends are followed for the different scenarios but with growth rates varying according to the scenarios. Due to its relative simplicity, GLOBIO can conceivably be presented along with results from integrated models, such as IMAGE or AIM, for more holistic presentations. Application of GLOBIO to GEO-3 represents a first-time attempt in doing this.

Infrastructure projections as presented here also include a significant element of probability. First of all, the reversibility of established infrastructure is very low. Only a fraction, if any, of established infrastructure ever disappears. Secondly, the historical patterns described are not the result of short-term economic ‘booms’ or political trends, but of a 150-year incremental pattern of development. As resource demands continue to grow as a result of increasing consumption and growing populations, the demand for infrastructure development in the future will increase as well, a development that is very likely to continue in all scenarios. Indeed, perhaps the most significant part of the scenarios is that even a minor slowing-down or acceleration in current trends will still lead to major increases in pressures on biodiversity unless specific action is taken to control piecemeal development. This is particularly true as wilderness areas are increasingly lost and infrastructure networks merge and link.

4.5.2 Results from the GLOBIO analysis for the GEO-3 Outlook

Assumedly, the main difference among the scenarios is the time at which maximum impact from infrastructure will be reached and not the eventual level of impact. Obviously, differences in trends will become more and more visible over time, typically 50 years from now and beyond. Noteworthy in this respect is the very short time span, at least seen from the perspective of biodiversity.

By and large, in global terms, only *Sustainability First* will come close to limiting the expansion of impact on species richness from infrastructure. This relates mostly to the growth of high-impact zones. But even in a world of *Sustainability First* there will be continued biodiversity loss from infrastructural development.

The most striking finding in the GLOBIO analysis for the GEO-3 Outlook is that tropical rain forests will continue to disappear at alarming rates if no measures are taken to reduce infrastructural expansion for exploitation, particularly in South East Asia. On the other hand, it is also clear that even 50 years from now there will still be some wilderness left – be it largely heavily fragmented or confined to tropical deserts and the Arctic.

References

Aguilar, M.C.F., et al., 2001. *On the impact of roads in Neotropical landscapes with regard to land use and effects on vertebrate populations*. (ECOSUR-report).

Andrews, A., 1990. Fragmentation of habitat by roads and utility corridors: A review. *Australian Zoologist* 26, 130-141.

Chomitz, K. and D. Gray, 1996. Roads, Lands, Markets and Deforestation: a spatial model of land use in Belize. *The World Bank Economic Review*, 10, 487-512.

Findlay, C.S. and J. Bourdages, 2000. *Response time of wetland biodiversity to road construction on adjacent lands.*

Forman, R. T. T. and L.E. Alexander, 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, 29, 207-231.

Frid, A. and L.M. Dill, 2002. Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology*, 6(11), 1-16.

Gill, J. A., K. Norris and W.J. Sutherland, 2001. Why behavioural responses may not reflect the population consequences of human disturbance. *Biological Conservation*, 97, 265-268.

Houghton, R.A., 1994. The worldwide extent of land-use change. *BioScience,* 44, 305-313.

Johnston, C. A., 1994. Cumulative impacts to wetlands. *Wetlands,* 14, 49-55.

Kruess, A. and T. Tscharntke, 1994. Habitat fragmentation, species loss, and biological-control. *Science,* 264, 1581-1584.

Kummer, D.M., and B.L. Turner, 1994. The human causes of deforestation in Southeast-Asia. *BioScience*, 44, 323-328.

Lawton, J.H., et al., 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. *Nature*, 391(6662), 72-76

Mäki, S., R. Kalliola and K. Vuorinen, 2001. Road construction in the Peruvian Amazon: process, causes and consequences. *Environmental Conservation*, 28, 199-214.

Nellemann, C., et al., 2001. Winter distribution of wild reindeer in relation to powerlines, roads and resorts. *Biological Conservation* 101: 351-360.

Nellemann, C., et al., 2003a. Progressive impacts of piecemeal infrastructure development on wild reindeer. *Biological Conservation* 113/2: 307-317.

Nellemann, C., et al., 2003b. *Environment and Security: 2050 scenarios.* In: R. Rasmussen (Ed.): *Social and environmental impacts in the North: methods in evaluation of socio-economic and environmental consequences of mining and energy production in the Arctic and Sub-Arctic.* (NATO Science series). Dordrecht: Kluwer Academic Publishers.

Reid, J. W. and I.A. Bowles, 1997. Reducing the impacts of roads on tropical forests. *Environment,* 39, 10-35.

Skole, D.L., et al., 1994. Physical and human dimensions of deforestation in Amazonia. *BioScience,* 44, 314-322.

Trombulak, S.C. and C.A. Frissell, 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*, 14, 18-30.

United Nations Environment Programme (UNEP), 2001. *GLOBIO – Global methodology for mapping human impacts on the biosphere.* Nellemann, C., and others (eds.). (UNEP/DEWA/TR.01-3). Available from: www.globio.info.

UNEP, 2002a. *Global Environment Outlook 3.* London: Earthscan Publications.

UNEP 2002b. *The great apes – the road ahead. A GLOBIO-perspective of the impacts of infrastructural development on the great apes.* Cambridge: UNEP-World Conservation Monitoring Centre. Available from: www.globio.info.

UNEP 2002c. *Mountain watch – environmental change and sustainable development in mountains*. Cambridge: UNEP-World Conservation Monitoring Centre. Available from: www.globio.info.

Vistnes, I. et al., 2001. Wild reindeer: Impacts of progressive infrastructure development on distribution and range use. *Polar Biology,* 21, 531-537.

Wilkie, D. et al., 2000. Roads, development, and conservation in the Congo Basin. *Conservation Biology*, 14, 1614-1622.

5. Water Stress

Water resources face severe stress in many regions of the world today. In all four GEO-3 scenarios analysed, continuing population growth, economic development and climate change further increase the number of people living in areas with severe water stress, particularly in developing countries. Nevertheless, the reform-oriented scenarios do offer possible paths to more sustainable water use.

5.0 Introduction

The Water–Global Assessment and Prognosis (WaterGAP) model combines geographically explicit computations of water availability and water withdrawals on a river-basin scale worldwide. This chapter discusses the variables ‘Water Stress’ and ’Population living in areas with severe water stress’. Water Stress is a variable indicating the average degree of pressure placed on water resources by anthropogenic water withdrawals in a river basin, thus providing a measure of quantity rather than quality. The aim of this chapter is twofold: 1) to provide a scientific explanation of the modelling methods, and 2) to present and discuss the results and the policy relevance of these methods.

Section 5.1 presents a general description of the model. Supplementary to the information presented in Chapter 2, section 5.2 explains the data inputs and assumptions used by WaterGAP to model the environmental consequences of the four GEO-3 scenarios. Section 5.3 describes the analysis results and Section 5.4 comprises discussion and conclusions on the WaterGAP variables.

5.1 Analytical framework

5.1.1 WaterGAP

The WaterGAP model, a global model estimating water availability and water use, was developed at the Centre for Environmental Systems Research at the University of Kassel in Germany in co-operation with the National Institute for Public Health and the Environment of the Netherlands (RIVM). The aim of the model is to provide a basis: (i) to compare and assess current water resources and water use in different parts of the world, and (ii) to provide an integrated long-term perspective of the impacts of global change on the water sector. WaterGAP belongs to the group of environmental models that can be classified as ‘integrated’, because they seek to couple and thus compile knowledge from different scientific disciplines within a single integrated framework. An overview of the model is presented below; for more detailed descriptions of the model please refer to Alcamo and others (2000), Alcamo and others (2002) and Lehner and others (2001).

WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use Model (Figure 5.1). The Global Hydrology Model simulates the characteristic macro-scale behaviour of the terrestrial water cycle to estimate water resources, while the Global Water Use Model computes water use for the household, industrial, irrigation and livestock sectors. All calculations made apply to the entire land surface of the globe (except the Antarctic) and are performed for cells on a 0.5° by 0.5° spatial resolution,. At the moment this is the highest feasible resolution for global hydrological models since climate input data is usually not available at higher levels of detail.

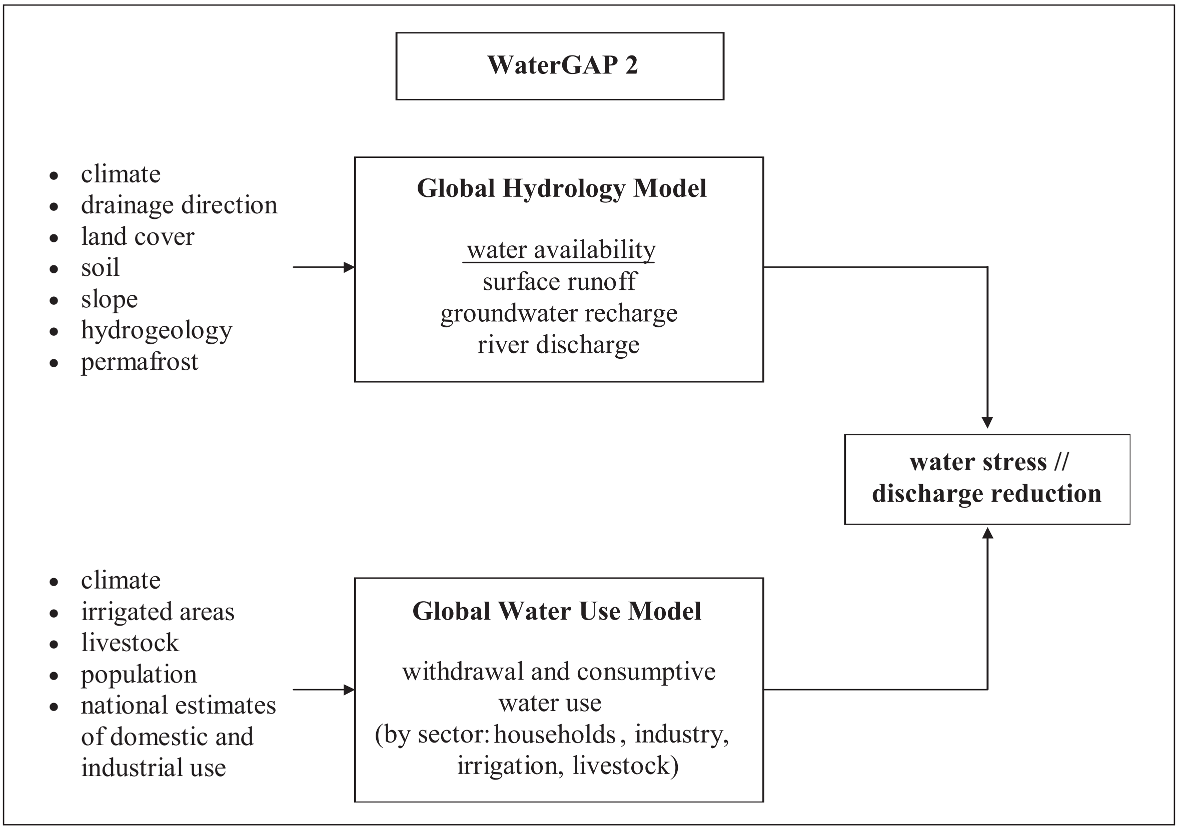
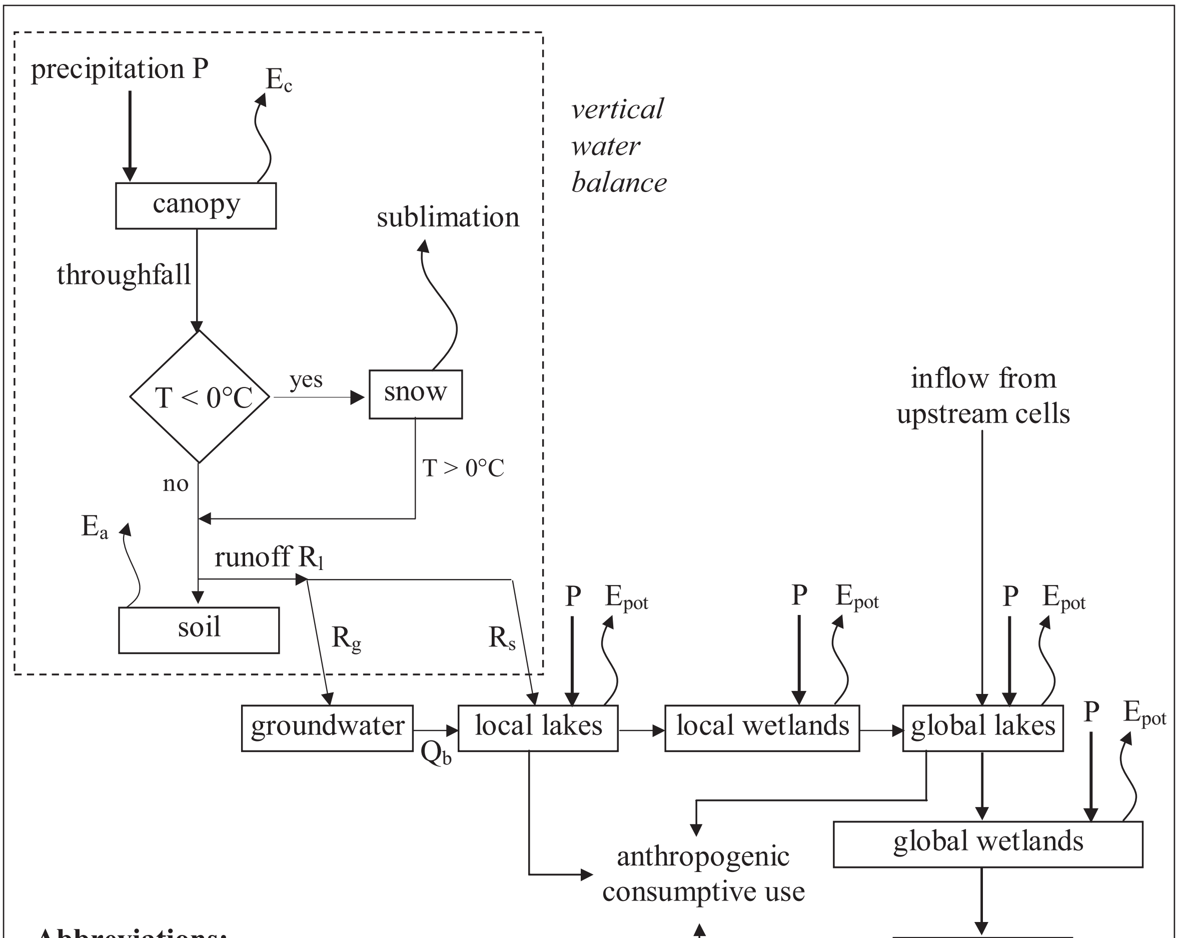


Figure 5.1: Schematic representation of WaterGAP 2, a global model for water availability and water use

5.1.2 WaterGAP – Global Hydrology Model

The WaterGAP–Global Hydrology Model calculates a daily vertical water balance for both land area and open water bodies in each 0.5°-cell (Figure 5.2). The vertical water balance for the land fraction in a cell includes a canopy water balance and a soil-water balance; balances are calculated as a function of land cover, soil-water capacity, and monthly climate variables (i.e. temperature, radiation, and precipitation). The canopy water balance determines which part of the precipitation is intercepted by the canopy and directly evaporates, and which part reaches the soil as throughfall. The soil–water balance subdivides the throughfall into evapotranspiration and total runoff. A different vertical water balance is applied to open water bodies (lakes, reservoirs, and wetlands - based on a global one-minute wetlands, lakes and reservoirs map by Lehner and Döll (2001)), where the runoff is computed as the difference between precipitation and open water evaporation. The sum of runoff produced within a cell plus the upstream discharge into a cell is transported through a series of storages representing groundwater, lakes, reservoirs, wetlands and the river itself. Finally, the river discharge is routed to the next downstream cell according to a global drainage direction map (Döll and Lehner, 2002). This allows us to perform calculations for more than 10 000 ‘first-order’ rivers (i.e. rivers that drain into the ocean or into inner-continental sinks). These cover the earth’s entire land surface, except for the ice caps, and include more than 3 500 river basins larger than 2 500 km^2.

Calibrating the calculated total discharge to measured values (from GRDC 2000) is performed for 724 drainage basins worldwide, covering half the global land area, except the Antarctic. The historical long-term modelled average annual discharge is within 1 per cent of measured discharge. For drainage basins without measured discharge data, runoff factors are regionalized by applying a multiple regression approach. Döll and others (2002) provide a detailed description of the attuning and validation of the WaterGAP Global Hydrology Model.



Abbreviations:
P: precipitation,
E_c: evapotranspiration from canopy,
E_a: actual evapotranspiration from soil,
R_l: runoff from land,
R_g: groundwater recharge,
R_s: surface runoff,
Q_b: baseflow,
E_{pot}: potential evapotranspiration

Figure 5.2: Schematic representation of the WaterGAP 2 Global Hydrological Model

Source: Döll and others, 2002

Note: The vertical water balance of the land and open water fractions of each 0.5° by 0.5° cell is linked to a lateral transport scheme, which first routes the runoff through a storage series within the cell.

5.1.3 WaterGAP – Global Water Use Model

The WaterGAP–Global Water Use Model computes water withdrawals and consumptive water use for the main water-use sectors: households, industry, irrigation and livestock. Water withdrawal is known as the total amount of water that is taken from the terrestrial part of the water cycle. Consumption is understood as the part of the withdrawal that does not return to the terrestrial water cycle. In other words, it is the proportion of water withdrawal that is lost by evapotranspiration during the various processes of 'use'. Water use in the household and industrial sectors is computed annually, while for the irrigation sector, the sub-model operates on a daily basis.

Each sector's water use is computed as a function of 'water-use intensity' and 'driving force'. Variables representing 'water-use intensity' are per capita water withdrawals (households), water withdrawals per unit of produced electricity (industry), gross irrigation water requirement per unit of irrigated area (irrigation) and per-animal drinking-water use (livestock).

Over time, societies are subjected to 'structural changes' and 'technological changes', which can lead to changes in the water-use intensity. Structural changes reflect the idea that changes in water-use intensity are connected, for example, to the development of economies and lifestyles (households), the shifting of thermal to non-thermal power plants (industry), or to changes in climate or the types of crops grown (irrigation). Technological changes complement structural changes and usually lead to improvements in the efficiency of water use, and thus tend to decrease water-use intensities.

For household and industrial sectors, historical structural changes correlate with income, and trends are based on data provided by Shiklomanov (1997, 2000) for 26 different world regions. To be able to compute scenarios of country-specific future water use in these two sectors, assumptions on regional, structural and technological changes applied to country estimates for recent (i.e. 1995) sectoral water use are assumed to be close to current levels (Shiklomanov, 2000; WRI, 2000). These country-specific values are finally distributed to grid cells according to the spatial distribution of population, and information on urbanization and access to safe drinking water.

Computations for the irrigation sector rely on an irrigation sub-model, which calculates irrigation water requirements by cell, reflecting an optimal supply of water to irrigated crops (Döll and Siebert, 2001). To compute net irrigation requirements (i.e. water consumption), the cropping patterns (rice and non-rice crops) and optimal growing seasons for each cell with irrigated land are first modelled as a function of long-term average climate, soil conditions and cropping intensities. After this, the net irrigation water intensities are computed for each day of the growing season as the difference between the crop-specific potential evapotranspiration and the plant-available precipitation. Taking into account region-specific irrigation efficiencies (i.e. withdrawal to consumption ratio), the gross irrigation water requirement (i.e. water withdrawals) per unit of irrigated area are calculated. Since irrigation efficiency is subject to technological change, water withdrawals can be reduced through this change (while in the model irrigation water consumption is assumed to remain unaffected by technological change).

Once the water-use intensities have been determined for each sector, total water use is obtained by multiplying water-use intensities by the respective 'driving forces'. The corresponding driving forces for each sector are country-level scenarios for population (households), electricity production (industry), irrigated area (irrigation) and number of livestock (livestock).

5.2 Input data and assumptions

The WaterGAP model requires several scenario-specific driving forces on climate change and key socio-economic developments to compute the future situation for water resources. In this section we will describe how the main quantitative assumptions driving the scenarios have been derived. Most driving force assumptions were provided either by the IMAGE 2.2 model (Chapters 2 and 7) or borrowed from the extensively elaborated World Water Scenarios, developed in the context of the World Water Vision exercise (see Chapter 2 and Cosgrove and Rijsberman, 2000).

5.2.1 Climate driving forces

Computation of the current long-term average water resources and the average water use for irrigation under normal climate conditions builds on a 30-year time series of monthly climate data for the 1961 to 1990 period. Available water resources and water withdrawals for irrigation over the last few decades are calculated for each year of the time series, providing the basis for the estimation of long-term average conditions. To compute current conditions, WaterGAP uses observed data of precipitation, temperature, number of wet days per month, cloudiness and average daily sunshine hours on a 0.5° by 0.5° spatial grid covering the globe, available from the Climate Research Unit at the University of East Anglia (New and others, 2000). Pseudo-daily precipitation values are generated stochastically on the basis of number of wet days in a month and the total monthly precipitation.

Climate conditions under different scenarios are simulated by changing monthly temperature and precipitation, while the other climate variables are kept constant. Future 30-year temperature time series are obtained by adding the difference between the future long-term average and the present-day long-term average, according to climate output from the IMAGE 2.2 model, to the historical time series. The historical monthly precipitation time series is scaled by multiplying the precipitation by the respective ratio between future and present-day precipitation, as calculated by the IMAGE 2.2 model.

5.2.2 Socio-economic driving forces

The main driving forces for water use by sector are country-level scenarios for population (households), electricity production (industry), irrigated area (irrigation), and number of livestock (livestock). Additionally, country-level scenarios for income play an important role in the determination of structural changes in the water-use intensity and efficiency for the household and industrial sectors. Water-use intensity in the irrigation sector depends on the types of crops grown and the climatic conditions (see 5.2). Furthermore, in all sectors, water-use intensity may be reduced by technological changes.

Population data (distinguishing between urban and rural population) for the scenarios are based on IMAGE 2.2 estimates for the world-regions. The country-level population estimates from the UN98 population prognosis at a medium birth rate for each country within a given region are scaled using the population development obtained by IMAGE 2.2 for the regions. In *Markets First*, *Policy First* and *Sustainability First* the global population increases to above 8.1 billion by the 2030s. In *Security*

First, the increase is assumed to be even more marked, with global population growing to more than 9.2 billion by the 2030s (as described in Chapter 2, this volume).

Electricity production (in TWh) is based on IMAGE 2.2 results for the world regions. The values for the world regions are scaled to country values, assuming that all countries within a region follow the same trend as the region itself. Total electricity production is assumed to increase in nearly all regions under all scenarios. The highest increase in electricity production is expected in *Markets First*, increasing by a factor of 3, and the lowest in *Sustainability First*, increasing by less than a factor of 2.

Income data (GDP) is based on estimates from IMAGE 2.2 for the world-regions, as described in Section 2.4. The values for the world-regions are scaled to country values, assuming that all countries within a region follow the same trend as the region itself. Average income growth in all regions is relatively low and very unevenly distributed in *Security First*. Under the other scenarios, income growth is higher at the global level (leading to a doubling in income by the 2030s), although its distribution in the world-regions varies substantially across scenarios. In *Policy First*, assumptions of a more equitable world cause average incomes to grow slightly slower in the richer regions and rise more rapidly in the poorer regions than in *Markets First*, while *Sustainability First* sees the greatest convergence in income of all the scenarios. However, large differences in income between the countries characterize all scenarios.

The expansion of irrigated area is seen to be one of the most critical determinants of water stress – and two contrasting views prevail on whether the trend in irrigated agriculture expansion will continue or bend. The assumptions for the GEO-3 scenarios here borrow from the World Water Vision Scenarios (Cosgrove and Rijsberman, 2000), which discuss the role of irrigation in some detail. True to the assumptions of the market-oriented ‘Technology, Economy and the Private Sector’ scenario of the World Water Vision, irrigated areas are assumed to expand across the globe by some 23 per cent in *Markets First*. The ‘Business-as-Usual’ scenario of the World Water Vision features a more or less constant extent of irrigated areas worldwide, with no new initiatives to expand irrigated areas. The *Security First* scenario adheres to this conservative assumption, as neither market forces nor political initiatives are assumed to press for a major expansion of irrigated areas. The assumptions in *Policy First* and *Sustainability First* are based on the reform-oriented ‘Values and Lifestyles’ scenario of the World Water Vision to reflect attempts to arrive at a more sustainable combination of agriculture and water management. This scenario leads to a much smaller increase in irrigated areas worldwide (less than 5 per cent), with concurrent major redistribution of irrigated land according to the water availability. In all scenarios, future expansion of irrigated land is assumed to follow the current distribution of irrigated area (Döll and Siebert, 2000).

The number of livestock is assumed to develop following a baseline scenario described in Alcamo and others (1998). These assumptions result in an average increase of more than 1 per cent per year in developing regions, a decrease of up to 0.3 per cent per year in industrialized regions for all scenarios analysed here.

Structural changes are driven, for example, by the development of economies and lifestyles (households), changes in the proportion of water use from power plants and manufacturers (industry), or changes in climate or the types of crops grown (irrigation). The assumptions pertaining to structural changes are similar to those for the World Water Vision Scenarios. For the household sector, historical data show a trend in which average water-use intensity of households in a country first sharply increases with income but eventually stabilizes at higher income levels. At the same time, water-use intensity in the industrial sector decreases with income to level off at a higher national income. These general developments are believed to continue for both households and industry in *Markets First* and *Security First*. In *Policy First* and *Sustainability First*, changes in lifestyles and values result in a reduction of water-use intensity by half compared to historical trends; additionally, it is assumed that each individual will have access to a minimum of 14.6 m^3 per year (40 liter per day). Although no changes in the types of crops grown are assumed, changing climate conditions in the irrigation sector alter water-use intensity.

Technological changes complement structural changes and usually lead to improvements in the efficiency of water use, and thus to a decrease in water-use intensities. The assumptions for technological changes also borrow from the World Water Scenarios. Historical data indicates that water-use intensity has decreased at about 2 per cent per year in both the household and industrial sectors. In *Markets First* the rapid technological advances of recent years continues but slows down over time to a value of 1 per cent per year. At the same time, irrigation efficiency continues to reduce withdrawals in irrigation at 0.6 per cent per year. A similar pattern is assumed in *Security First*, however, improvement in irrigation efficiency is somewhat slower at 0.3 per cent per year. Rapid advances in technology continue at historical rates for the household and industrial sectors (2 per cent per year) in *Policy First* and *Sustainability First*, while changes in irrigation efficiency are as high as 0.9 per cent per year.

5.3 Water Stress

5.3.1 Description

Water Stress is defined here by the long-term average of the annual withdrawal-to-availability ratio (wta). This ratio describes how much of the average annual renewable water resources of a river basin are withdrawn for human purposes (in the household, industrial, agricultural and livestock sectors). In principle, the higher this ratio is, the more intensively the waters in a river basin are used; this reduces either water quantity or water quality, or both, for downstream users. According to this variable, water stress increases when either water withdrawals increase and/or water availability decreases. On the basis of experience and expert judgement, it is assumed that if the long-term average wta-ratio in a river basin exceeds 0.4 (or 40 per cent), the river basin experiences severe water stress (see, for example, Raskin and others (1997); Cosgrove and Rijsberman (2000)).

An important aspect of this variable is that it is based on water withdrawals without consideration of the fact that part of these withdrawals might be returned and re-used downstream without loss of quality. In addition, the variable Water Stress describes the long-term annual average only and thus does not consider important inter-annual or seasonal variations. Furthermore, Water Stress does not take into explicit account available water infrastructure, water management capacity, or water quality. Still, Water Stress as approximated by the withdrawal-to-availability ratio gives an initial indication of where pressure on water resources is high in relation to the capacity of the water system.

The variable ‘number of people living in areas with severe water stress’ shows an important dimension of water scarcity by visualizing the population in a region or sub-region living in river basins affected by severe water stress. Not all the people in a river basin will be affected by severe water stress to the same degree though. Nevertheless, this variable does give an indication of how many people in a particular region are vulnerable to water-related stress. For instance, in many parts of the world, the largest fraction of water abstraction, by far, is used by agriculture (FAO/Aquastat). In such regions the main problem with ‘water stress’ is how agricultural practices can be adjusted to a situation where there is less water. And in countries with high enough incomes, drinking-water needs can be met through desalinization, for instance.

5.3.2 Modelling

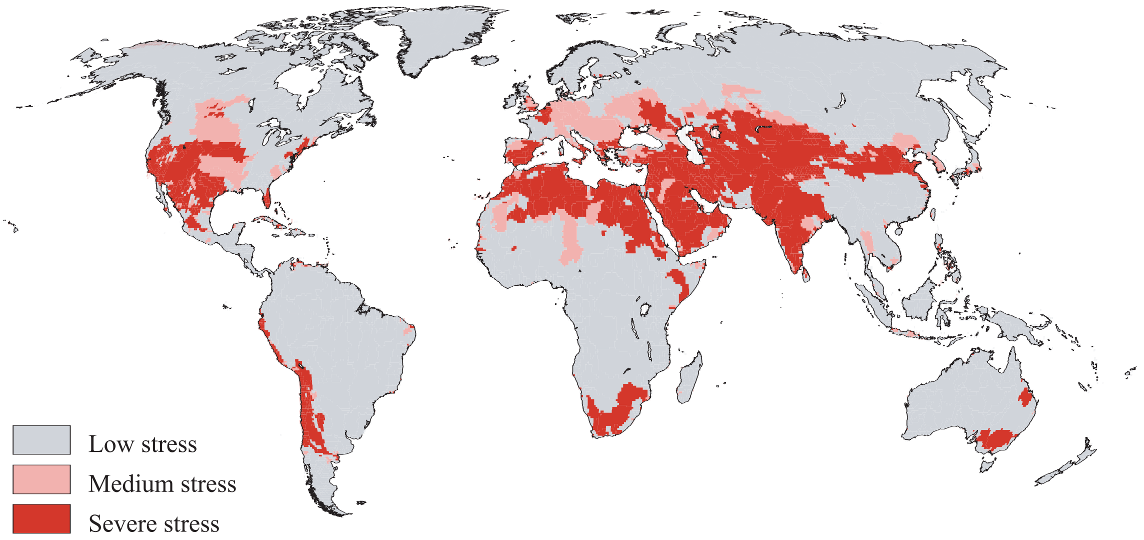
The Water Stress variable brings together information on the situation of water resources (i.e. water availability) and water use (i.e. water withdrawals) per river basin. Both variables are computed by the WaterGAP model, as described in section 5.1.

Water availability is computed by the WaterGAP Global Hydrology Model. In this context we define ‘water availability’ as the total river discharge, which is the combined surface runoff and groundwater recharge. Long-term average annual water availability for the ‘current’ situation is calculated on the basis of monthly climate input data from the climate normal period (1961 to 1990 time series). Computations of future long-term water availability under the scenarios make use of climate change scenario data as described in section 5.2.1 above.

Total water withdrawals comprise the sum of the water withdrawals for the four main water-use sectors, i.e. households, industry, irrigation and livestock, as computed by the WaterGAP Global Water Use Model. Due to data availability, ‘current’ water withdrawals per watershed for the household and industrial sectors reflect the 1995 country-specific water-use data taken from Shiklomanov (2000) and WRI (2000). Annual water use in these sectors is computed for the scenarios based on the main driving-forces population, electricity production and structural changes based on income. Current water withdrawals for irrigation are calculated for average climate conditions (i.e. 1961 to 1990 time series, section 5.2.1) using the 1995 distribution of irrigated areas. Water uses for irrigation under the four scenarios are modelled incorporating assumptions of climate change and irrigated area expansion as described above.

5.3.3 Results

The description of the current Water Stress situation provides an important basis for analysing the implications of differ, ent scenario assumptions. Therefore, before examining the pressure on water resources under various scenarios, we will consider Figure 5.3, which displays the present-day average water-stress situation as computed by the WaterGAP model. Roughly a quarter of the terrestrial surface is, today, estimated to belong to the severe water stress category. Not surprisingly, most desert areas fall into this category. Due to high anthropogenic water withdrawals, however, some of the large river basins in China, most of the river basins on the Indian sub-continent, much of Central Asia, most of Southern Africa, parts of the eastern coast of Australia, the Pacific coast of Latin America, parts of Western Europe, and the south-western part of the USA are also included in the severe water stress category.



Low stress indicates a withdrawel-to-availability ratio of less than 0.2
Medium stress indicates a withdrawal-to-availability ratio between 0.2 and 0.4
Severe stress indicates a withdrawal-to-availability ratio of 0.4 or more

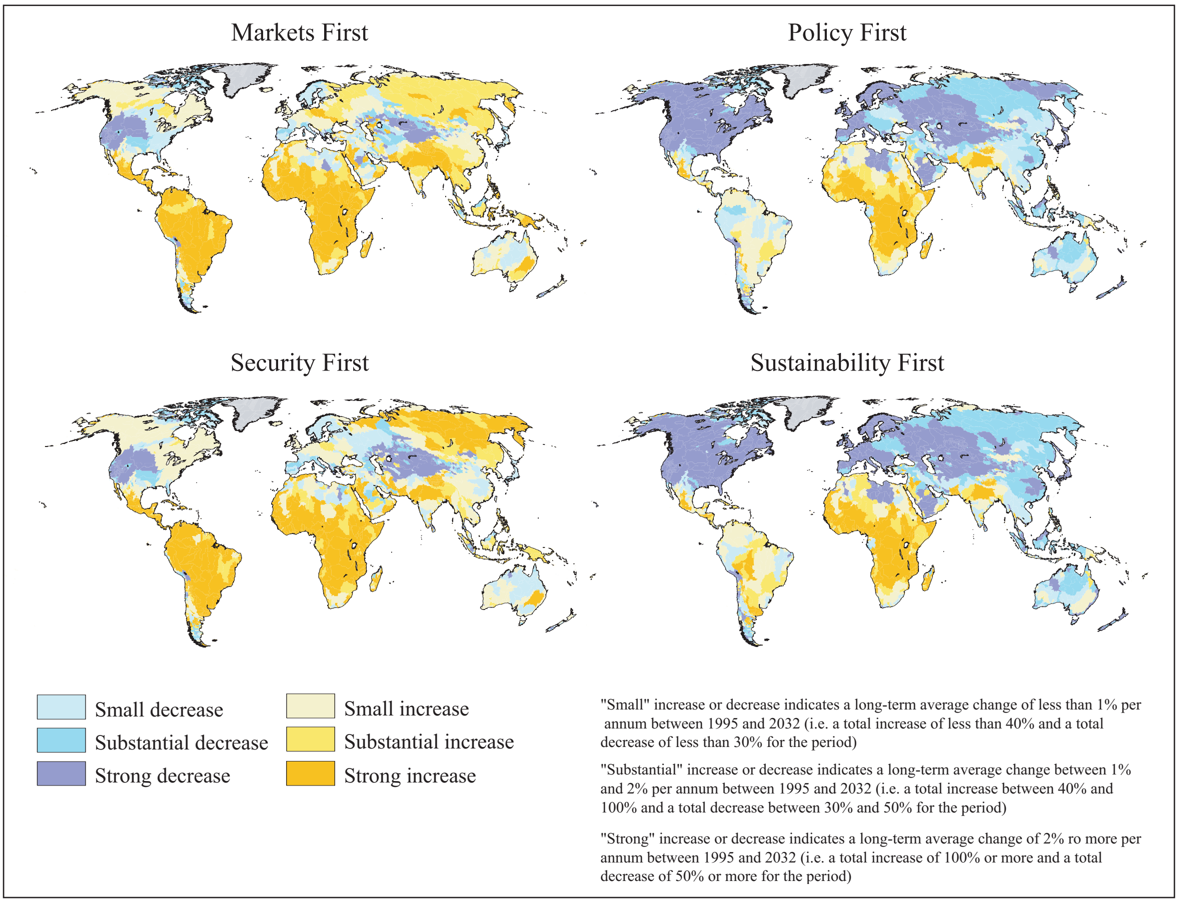
Figure 5.3: Current average water stress for river basins
Source: CESR
Note: Water stress is depicted by the average annual withdrawal-to-availability ratio, based on water withdrawals representative for 1995 and long-term average water availability for 1961-1990.

The Water Stress situation is bound to change with changing water withdrawals (due to socio-economic and/or climatic changes) and/or changing water availability (due to climatic changes). Currently, a total of approximately 3 500 km^3 water is withdrawn to meet water demands from households, industry, irrigation and livestock. WRI (2000) summarizes the global annual water withdrawal as follows: 71 per cent by agriculture (mainly irrigation); 20 per cent by industry; and 9 per cent by households. Large increases in water withdrawals worldwide are expected in *Markets First* (up to some 4 800 km^3 in the 2030s); this increase is particularly high in developing countries, because continuing economic growth in low-income countries is assumed to lead to a larger water demand across all sectors due to structural changes. However, total water withdrawals remain stable or may even decrease in some industrialized countries (for example, in the USA and Western Europe), resulting from further technological improvements.

Water withdrawals are also estimated to decrease in Central Asia, with declining water needs for irrigation (due to the combined effects of improved irrigation efficiency and increasing water availability with changing climate conditions). In *Security First*, future water withdrawals generally follow a similar pattern to that of *Markets First*, but the increases are somewhat lower in most regions due to slower economic growth assumptions (leading to some 4 200 km^3 worldwide in the 2030s). In *Policy First* and *Sustainability First*, total water withdrawals are computed to decrease with structural changes in most parts of the world (leading to less than 2 800 km^3 worldwide under both scenarios in the 2030s). Yet, under these two reform-oriented scenarios too, assumptions on population growth and economic growth result in substantial increases in water withdrawals in most of Africa and parts of Asia.

Simultaneously, climate change leads to a change in water availability for all scenarios. Due to the relatively long delay in response of the climate system to changes in emissions, the geographical patterns and magnitudes of change are similar in all scenarios. Water availability is assumed to increase in some regions of the world, including Central Asia, the western parts of the USA, the sub-polar regions and Eastern Africa. Conversely, water availability is computed to decrease substantially in the Mediterranean region, in many Meso-American river basins, across Southern Africa and Senegal, in most of Australia, in some river basins in West Asia and on the Indian sub-continent.

The combination of the trends in water withdrawals and water availability leads to significant changes in Water Stress (Figure 5.4) between the 'current' situation (i.e. 1995) and the 2030s. Under all scenarios, water stress decreases in the Mississippi River basin, in the Northern part of Western Europe and in Central Asia. Large increases in water stress are expected for most developing countries in *Markets First* and *Security First*. Increases in water withdrawals also lead to an increase in water stress in most of Africa, Latin America and South Asia, in both *Policy First* and *Sustainability First*, while for most other regions of the world water stress is reduced under these



"Small" increase or decrease indicates a long-term average change of less than 1% per annum between 1995 and 2032 (i.e. a total increase of less than 40% and a total decrease of less than 30% for the period)

"Substantial" increase or decrease indicates a long-term average change between 1% and 2% per annum between 1995 and 2032 (i.e. a total increase between 40% and 100% and a total decrease between 30% and 50% for the period)

"Strong" increase or decrease indicates a long-term average change of 2% ro more per annum between 1995 and 2032 (i.e. a total increase of 100% or more and a total decrease of 50% or more for the period)

Figure 5.4: Changes in water stress for river basins up to the 2030s relative to the current situation (i.e. 1995)

Source: CESR

Note: Changes in water stress are likely to be critical in regions with current high levels of water stress (as shown in Figure 5.3) and further increases in water stress.

scenarios. In Australia water stress decreases slightly under a *Policy First* and *Sustainability First* scenarios, the reason being that due to policy measures to reduce water withdrawal the decreased water availability problems can be absorbed. Under the *Markets First* and *Security First* scenarios the decreases in water availability can not be overcome, which is why the stress increases in Australia.

Currently, some 2 400 million people worldwide (more than 40 per cent of the total population) are estimated to live in river basins under severe water stress. Under all four scenarios, the total number of people in areas with severe water stress is expected to increase. The highest total number of people living in areas with severe water stress is computed in *Security First* (some 4 700 million), i.e. more than half of the expected world population in the 2030s under this scenario. Under *Markets First* the number of people living in river basins with severe stress is slightly lower than under the *Security First* scenario (some 4 600 million), but this still comprises more than half of the total expected population in the 2030s under this scenario. Despite the reductions in water stress in many regions of the world in both *Policy First* and *Sustainability First*, the number of people living in areas with severe stress still increases to 3 500 million and 3 600 million worldwide, respectively (amounting to more than 40 per cent of the expected total population). Figure 5.5 provides an overview by sub-region under the four scenarios in 2032 of the population living in river basins with severe water stress.

All scenarios show that the populous Asia and Pacific region remains one of the world regions with the largest number of people living under severe water stress. At present, more than 1 600 million, i.e. every second person in the region, live in a river basin under severe water stress. This makes water stress one of the most pressing environmental problems in Asia and the Pacific region and, according to any of the scenarios, will remain so for the foreseeable future. Particularly high numbers of people living in areas under severe water stress are computed for the sub-regions of South Asia (some 1 000 million) and East Asia (some 500 million). Increase in water withdrawals is estimated to be the highest in *Markets First* for all sectors, especially due to the assumed further expansion of irrigated areas. This leads to more river basins being taken up in the severe water-stress category, particularly in South Asia and Southeast Asia. Although the overall growth in withdrawals is somewhat moderated by slower economic growth and almost no expansion of irrigated areas in *Security First*, water demand still rises in the industrial and household sectors. In *Policy First* and *Sustainability First,* water withdrawals remain at current levels or even decrease in most of Asia, mainly due to effective water-related policies, modifications in lifestyle and technology transfer, resulting in structural and technological changes. However, this only leads to a slight decrease in areas under severe water stress, while the total number of people living in river basins with severe stress continues to increase.

In relative terms, the West Asia region has the highest fraction of total population living in river basins with severe stress (approximately 9 out of 10 people). In *Markets First* and *Security First*, competition between users increases with increasing water withdrawals, and is even higher under the *Security First* scenario. Although improvements in irrigation efficiency and minor shifts in irrigated areas should lead to a decrease of water withdrawals for irrigation, this will not revert the water-stress situation. In total, slight increases in water withdrawals are expected for both scenarios, leading to a further increase in the number of people living in river basins with severe water stress in the region. In *Policy First* and *Sustainability First*, water savings in the irrigation sector, together with structural changes in the way water is used in the industrial sector, lead to a reduction in total

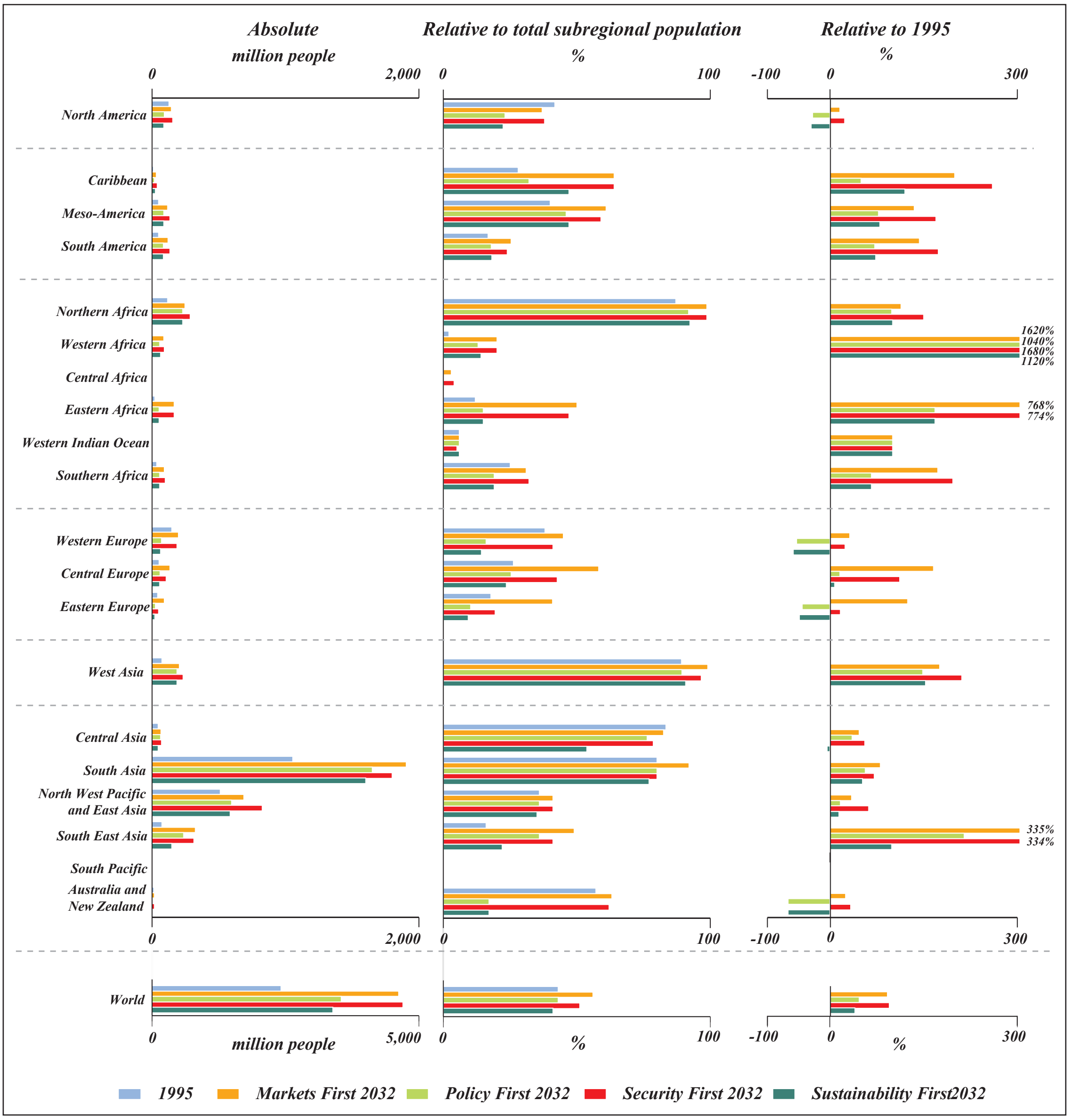


Figure 5.5: Population living in areas under water stress in 2032

Source: CESR

water withdrawals. Still, in absolute terms, more people are assumed to be living in severe water-stress river basins due to population growth. This makes international co-operation on water policies to mitigate the impacts of water stress an imperative.

In Africa nearly a quarter of the total population currently lives in river basins with severe water stress. More than half of these 170 million people live in Northern Africa. In *Markets First*, total water withdrawals are expected to nearly double, with particularly high increases in the sub-Saharan regions. Similar increases are expected in *Security First*, although generally slower growth in the economy decelerates the increase in demand. In both scenarios, the population living in areas under severe water stress increases to around 40 per cent. Increases in water withdrawals in the sub-

Saharan regions are also expected in *Policy First* and *Sustainability First*, although these increases are considerably less than in the other two scenarios. This is due to a combination of technology transfer, additional policies that encourage water savings in all sectors and a restructuring of the irrigation sector. Nevertheless, as the population continues to grow, the number of people living in areas with severe water stress will still double, even for these more reform-oriented scenarios.

Similarly, in the Latin America and the Caribbean region nearly a quarter of the total population currently lives in river basins with severe water stress. Most of these 110 million people live in severe water-stress river basins in Mexico, Argentina and along the Pacific coastline of South America. With increasing water withdrawals in *Markets First* and *Security First*, the area under severe water stress increases in Meso-America and the Caribbean sub-regions but remains constant in most of South America. The number of people living in severe water stress river basins increases by a factor of two to three with the growth in population. The number of people living in areas with severe water stress also increases in *Policy First* and *Sustainability First*, despite water withdrawals and areas with severe water stress remaining roughly at current levels.

In North America, large parts of the southwest of the United States are subject to high levels of water stress; overall some 40 per cent of the total population live in river basins categorized as being under severe water stress. Water withdrawals are projected to decrease under all scenarios in all sectors; however, this effect is especially significant under the *Policy First* and *Sustainability First* scenarios due to the strong action of further technological and structural change. As a result, some river basins drop out of the severe water-stress category. Under these two scenarios, the number of people living in areas with severe water stress decreases. Under *Markets First* and *Security First*, the total number of people living in river basins with severe water stress increases with population growth, despite a decline in percentage of population affected.

High levels of Water Stress in Europe are generally related to high levels of withdrawals for industry or irrigation. About 10 per cent of the European river basin area is found in the severe water-stress category and about 30 per cent of the total population lives in river basins under severe water stress. In *Markets First*, economic growth leads to a strong increase in water demand, especially in Central and Eastern Europe. With these increases comes an expansion of areas with severe water stress and, consequently, the number of people living in areas with severe water stress is expected to increase. A similar situation occurs in *Security First*. The situation is very different in *Policy First* and *Sustainability First*. Structural changes lead to significant decreases in water withdrawals for all sectors across Europe. Further water-saving policies are even expected to revert the situation in many of the river basins that currently experience severe water stress. Assuming these advances, the number of people living in severe water-stress river basins drops significantly.

5.4 Discussion

The current Water Stress situation, along with the broad implications of developments under different scenarios up to the 2030s, have been outlined on the basis of results obtained from the WaterGAP model.

When studying these results, it should be kept in mind that all model-based assessments have unavoidable uncertainties linked to underlying model assumptions and available input data. For example, historical water-use data by sector (needed to derive structural change assumptions to project water use) is scarce and often incomplete, particularly for developing countries. In the absence of higher resolution data, it is assumed that regional trends in structural changes apply to all countries within the region, while, in fact, the trends may vary considerably from country to country. In general, it can be said that conclusions on future trends in water withdrawals for industrialized countries have a lower uncertainty than for developing countries (Alcamo and others 2000). Another example of uncertainty of the model output is that the hydrology model is attuned to matching measured long-term runoff for some 700 drainage basins, which only cover about half the globe's terrestrial surface outside Antarctica. For the remaining river basins, model parameters are derived from attuned river basins, making estimates of water availability more uncertain (Döll and others 2002). An additional uncertainty is related to the Water Stress variable. While it has become a widely used indicator for primarily quantity-related pressure on water resources, there is some uncertainty in setting the thresholds used to mark severe water stress.

Furthermore, it should be stressed that top-down global assessments of water resources are not designed to replace detailed vulnerability studies of particular river basins. Yet, they may complement bottom-up river-basin analyses by offering consistent approaches to a wide range of river basins by providing an overview of the different regions, including areas where more detailed studies are limited or absent. They may also allow assessment of the developments within a particular region in relation to the global context. Top-down global assessments also help to view developments in individual river basins within their respective regional context, and in doing so, allow identification of regional patterns. These characteristics of top-down model-based assessment approaches make them valuable frameworks for comprehensive analyses of global environmental change scenarios.

Furthermore, care should be taken not to make unwarranted inferences when moving from the water-stress indicator to the indicator on 'number of people living in an areas with severe water stress'. The reader should realize that the latter indicator does not automatically mean that future access of all households to adequate water is likely to be imperilled. After all, the stress will often be felt mainly in the agricultural sector. In higher-income parts of the world, this sector is relatively small and in many developing regions efforts are underway to move away from dependency on agriculture. In general, certainly in the *Policy First* and *Sustainability First* worlds, many households will be able to re-allocate enough water away from agriculture to ensure that household needs are met. Besides, in high-income countries drinking- water needs can, for instance, be met by desalinization, which is increasingly becoming less expensive. And in countries where the water-stress indicator is high, agriculture can be changed to focus on high-value crops and exports from non-agricultural sectors so as to be able to import agricultural products that are water-intensive. For such a strategy to work, the political situation needs to be such that a country can afford to be dependent on food coming from abroad.

The WaterGAP-based analysis of the GEO-3 scenarios shows that in the longer term climate change is bound to substantially impact water resources. Meanwhile, changes in water withdrawals due to population development, economic activity and expansion of irrigation continue to dominate the development of water stress in many regions of the world. In *Markets First* and *Security First* these effects lead to a further intensification of the pressure on water resources in many of the currently severely stressed river basins, and even to an expansion of the areas under severe water stress. The expansion of these areas, combined with the continuing population growth in today's severe water-stress areas, will cause an increase in the number of people living in areas with severe water stress in both absolute and relative terms. While these increases are seen in all regions of the world, they are particularly high in developing countries.

The two reform-oriented scenarios, *Policy First* and *Sustainability First*, feature strong assumptions on structural and technological changes. These changes lead to decreases in water withdrawals and water stress in most industrialized countries, and even result in a decrease in the number of people living in areas with severe water stress in Northern America, Europe and Australia. Yet, across most of the developing world, the number of people living in areas under severe water stress is likely to increase substantially in absolute terms. This trend is mainly due to continuing population growth in today's severely water-stressed areas, as in most regions the actual area under severe water stress remains more or less constant or may even decrease as a result of the reduction of water withdrawals. In this respect, the modelling results indicate that the reason for concern about the global water situation remains under all scenarios. Nevertheless, the two reform-oriented scenarios show a path to more sustainable water use based on improvements in water use efficiency and marked changes in the irrigation sector.

In total, the GEO-3 scenarios confirm that many regions of the world will be facing a big challenge in the prevention or mitigation of future severe water stress. This challenge calls for substantial structural changes to accompany further improvements in water-use efficiency. Scenario narratives presented elsewhere (Cosgrove and Rijsberman, 2000) outline conceivable pathways to arrive at the difficult but necessary changes in this regard.

References

Alcamo, J., R. Leemans and E. Kreileman, 1998. *Global Change Scenarios of the 21st Century – Results from the IMAGE 2.1 Model.* Oxford: Elsevier Science.

Alcamo, J., T. Henrichs, and T. Rösch, 2000. *World Water in 2025 – Global modeling and scenario analysis for the World Water Commission on Water for the 21st Century*. (Kassel World Water Series 2). Kassel: Center for Environmental Systems Research, University of Kassel. Available from: http://www.usf.uni-kassel.de.

Alcamo, J., et al., 2002. WaterGAP: Development and Application of a Global Model for Water Withdrawals and Water Availability. (submitted to *Hydrological Sciences Journal*)

Cosgrove, W. and F. Rijsberman, 2000. *World Water Vision: Making water everybody's business.* London: Earthscan.

Döll, P., F. Kaspar and B. Lehner, 2002. A global hydrological model for deriving water availability indicators – model tuning and validation. (accepted by *Journal of Hydrology*).

Döll, P., and B. Lehner, 2002. Validation of a new global 30-min drainage direction map. *Journal of Hydrology*, 258, pp. 214-231.

Döll, P., and S. Siebert, 2000. A digital global map of irrigated areas. *ICID Journal*, 49(2), pp. 55-66.

Döll, P., and S. Siebert, 2001. Global modeling of irrigation water requirements (10.1029/2001WR000355). *Water Resources Research*, 38(4), 8.1-8.10.

FAO/Aquastat. Available from: http://www.fao.org/ag/agl/aglw/aquastat/main/index.stm.

Global Runoff Data Centre (GRDC), 2000. *Observed river discharges.* Koblenz: Global Runoff Data Centre.

Lehner, B., and P. Döll, 2001. *WELAREM1 - A global 1-minute wetlands, lakes and reservoirs map.* Available from: http://www.usf.uni-kassel.de.

Lehner, B., et al., 2001. *EuroWasser – Model-based assessment of European water resources and hydrology in the face of global change.* (Kassel World Water Series 5). Kassel: Center for Environmental Systems Research, University of Kassel. www.usf.uni-kassel.de.

New, M., M. Hulme and P. Jones, 2000. Representing twientieth-century space-time variability, Part I : Development of a 1961-90 mean monthly terrestiral climatology. *Journal of Climate* 12(3), pp. 829-856.

Raskin, P., et al, 1997. *Water Futures: Assessment of long-range patterns and problems. Comprehensive assessment of the freshwater resources of the world.* Stockholm: Stockholm Environment Institute.

Shiklomanov, I., 1997. *Assessment of Water Resources and Water Availability of the World.* Stockholm: Stockholm Environment Institute.

Shiklomanov, I., 2000. Appraisal and Assessment of World Water Resources. *Water International,* 25(1), pp. 11-32. (supplemented by CD-ROM: Shiklomanov, I., *World freshwater resources.* Available from: International Hydrological Programme, UNESCO, Paris).

United Nations Environment Programme (UNEP), 2002. *Global Environment Outlook 3.* London: Earthscan.

World Resources Institute (WRI), 2000. *World Resources 2000-2001: People and Ecosystems.* Oxford: Elsevier Science.

6. Municipal waste and emissions in Asia and the Pacific

The Asia-Pacific region is rapidly taking centre stage with respect to energy demand, with very high growth rates in China and South Asia, and Japan. Consequently, future emissions from this region are going to play a very important part in the rising global concentrations of greenhouse gases and other types of environmental stress.

6.0 Introduction

In the GEO-3 scenario exercise the Asian-Pacific Integrated Model (AIM) is used to provide projections of energy-related carbon dioxide, and sulphur and nitrogen oxide emissions, along with municipal solid waste generation, in the Asia-Pacific region. Energy-related emissions of carbon dioxide, sulphur dioxide and nitrogen oxide represent clear negative consequences of increased energy use in our modern lives. Another negative consequence of the modern consumption pattern is growth of solid-waste generation. There are complex interactions between the social, economic and physical systems at various levels. The choices that individuals make about their consumption goods, and the changes in behaviour of individuals caused by such economic impulses as price deviations, lead to changes in the behaviour of producers in terms of choice of products and input materials. This ultimately affects changes in the utilization of resource bases in the physical environment. These systems also have feedback effects. For example, depletion of one type of resource may lead to changes in inputs of production process and thus affect the cost structure of firms. Producers send a price signal to the ultimate consumer, which could bring a change in the consumption basket. Such interwoven systems make it necessary to employ appropriate analytical tools such as integrated models to enable us to comprehensively understand the impacts of changes of key driving forces in a variety of scenarios.

Section 6.1 provides us with a general description of the model and section 6.2 with information, additional to Chapter 2, on data inputs and assumptions used by AIM to model environmental consequences of the four GEO-3 scenarios. The next sections describe the successive variables provided by AIM for GEO-3 (UNEP, 2002) – energy-related carbon dioxide emissions in Section 6.3, energy-related sulphur dioxide emissions in section 6.4, energy-related nitrogen dioxide emissions in section 6.5, and municipal solid waste in section 6.6. Each section briefly describes the meaning of the given variable and its modelling. However, the core of section 6.3 to 6.6 presents the results of the scenario analysis. Some overall discussion and conclusions on the AIM variables are included in section 6.7.

6.1 Analytical framework

The Asian-Pacific Integrated Model (AIM) is a large-scale computer simulation model developed by the National Institute for Environmental Studies in collaboration with Kyoto University and several research institutes in the Asia-Pacific region. The AIM model assesses policy options for reducing greenhouse gas emissions and avoiding impacts of climate change, particularly in the Asia-Pacific region. It can also be used for analysis at the global level. The period of analysis can be medium-

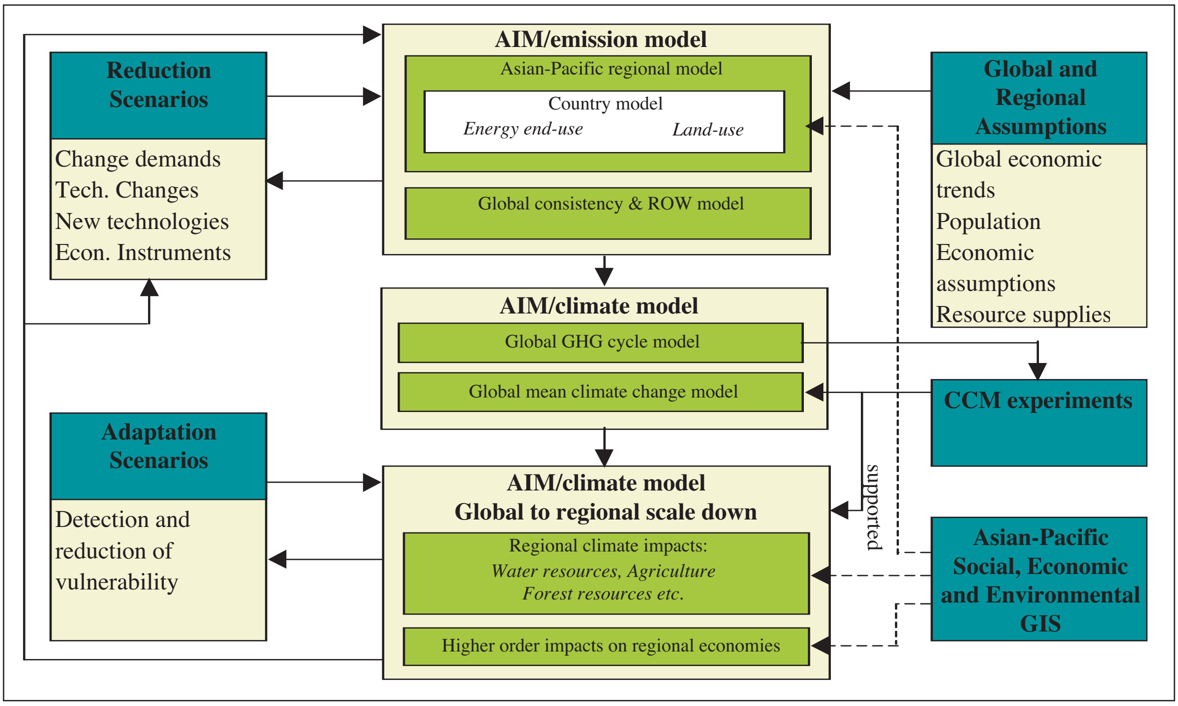


Figure 6.1: The AIM Framework

term (up to 30 years) to long-term (up to 100 years). The original AIM is an integrated 'top-down and bottom-up' model, comprising an emissions model, a climate model and an impact model (Matsuoka and others, 1995). The framework of this model is shown in Figure 6.1. The emission model consists of a module on energy efficiency improvement, a module on energy service and a technology selection module for regional models. For the global emission model, AIM uses a general equilibrium model with higher sectoral aggregation, while regional models, applied only to Asia, use a detailed representation of energy service and technology. The climate model is developed to link emission and impact models. The impact model contains a spatial water-balance model, an ecological model and a health impact model. It is used to estimate the increased risks of droughts, floods, vegetation changes and malaria.

A variety of – interrelated and interconnected – new models have been added to the group in the course of development (shown in coloured boxes in Figure 6.2). These are AIM/Local, AIM/Country, AIM/Trend, AIM/Impact (Country version), AIM/Ecosystems, AIM/Material and a computable general equilibrium model – AIM/CGE. Some of the recent results of these models are reflected in the Asia-Pacific Environmental Innovation Strategy Project (Fujino and others, 2001) currently in progress. Of the various models in the AIM family, the AIM/Trend model (Fujino and others, 2002; Fujino, 2001) has been the most relevant to the preparation of the GEO-3 Outlook chapter.

The AIM/Trend model is an econometric model to project the economic, energy and environmental situation for a mid-term future. It calculates the relationships between each parameter through regression methods using time-series data from 1971 to 1998 and extrapolates these relationships for future projection, making simulations of energy supply and demand, Greenhouse Gas emissions, Municipal Solid Waste, and water supply and demand, on the basis of data on population, Gross

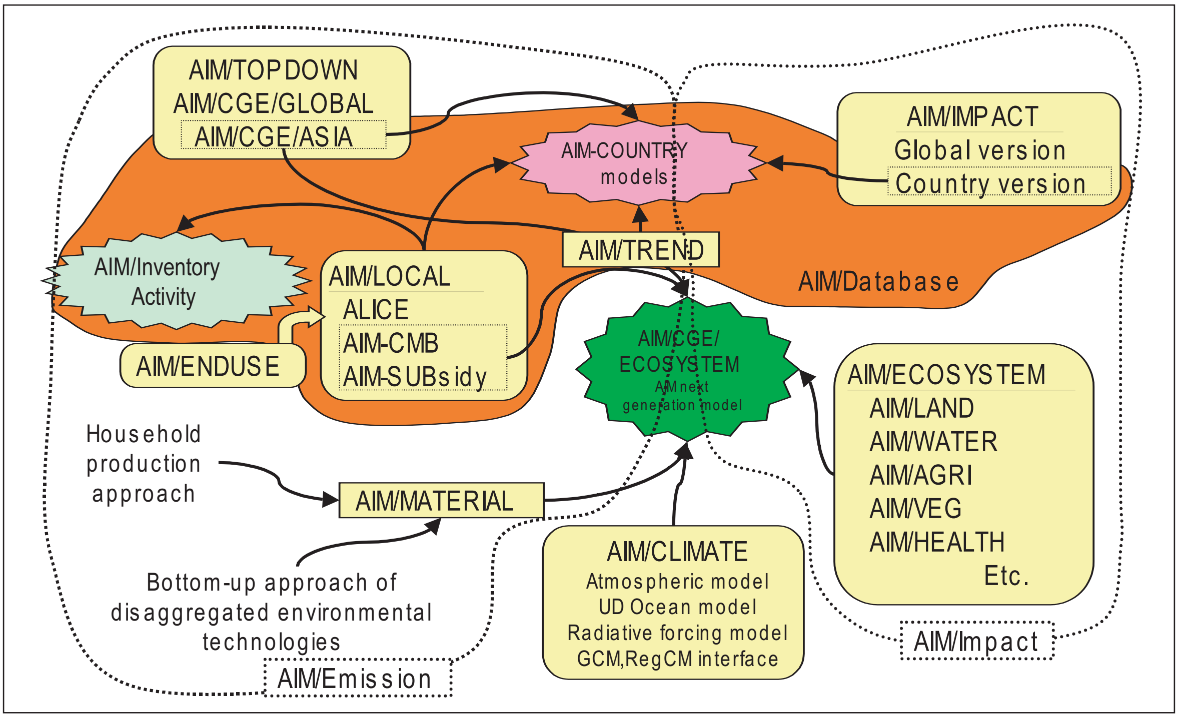


Figure 6.2: The AIM family of models

Note: New models are shown in colour.

Domestic Product (GDP) and sectorial contributions to GDP (Figure 6.3). The simple structure of this model makes it a unique communication tool for researchers and policy-makers at country level. It can thus be used to consolidate country results in (sub-)regional contexts.

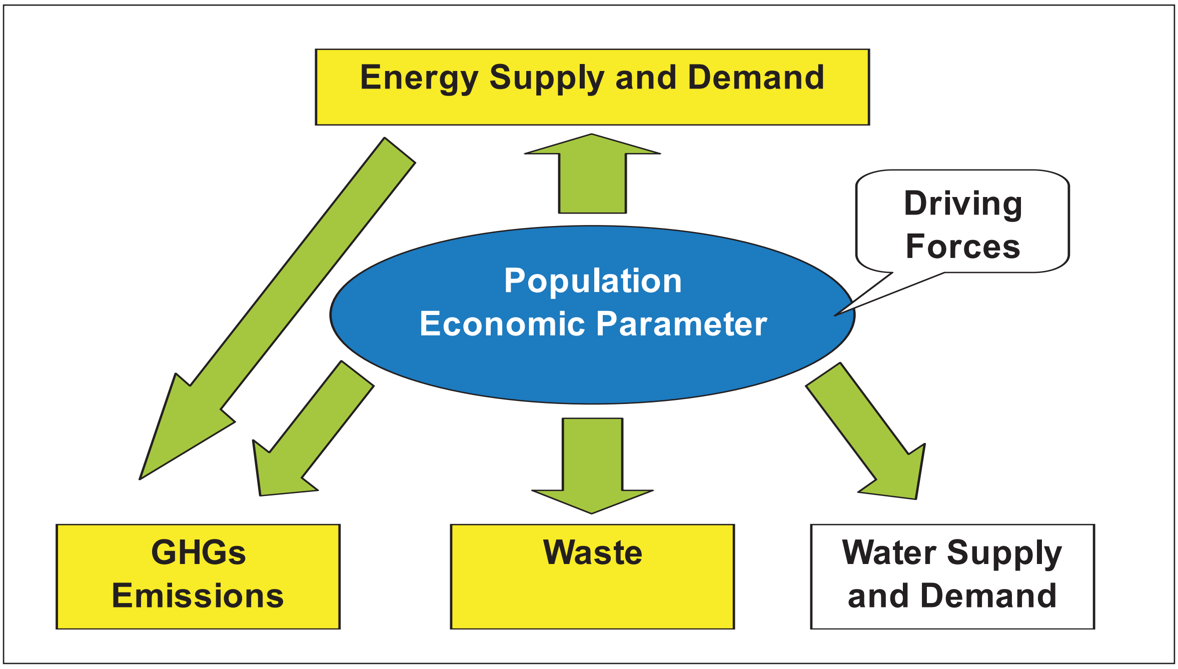


Figure 6.3: The AIM/Trend model structure

6.2 Input data and assumptions

Input and assumptions with regard to population and GDP are already described in Chapter 2. Additional inputs and assumptions are used for the models. These inputs represent energy data, emission factors and shares of value-added by various demand sectors. Assumptions on the coefficients of autonomous energy efficiency improvement (AEEI) and generation efficiency of various technologies are also needed.

The chief data sources for energy were international publications of the IEA (1999) and UN (1995), while emission factors were taken from IPCC (1997). For the assumption of AEEI and generation efficiency, documented information was used wherever available. For countries where data were absolutely insufficient, proxy assumptions, based on data from other countries, were made.

There are very few databases on solid waste. For the developed countries, long-term historical data are available from OECD publications, e.g. OECD environmental data compendium reports on municipal and industrial waste (OECD, 1999). However, just as for the developing countries, there are no long-term historical data. Although some solid waste data are available (e.g. SSB, 1996; 1999) for China and CSO (2000) for India), the offer of historical data is rarely suffcient for the analysis. As a result, we used the 1990 cross-sectional data on solid waste and economic activity for 65 countries in regression analysis for estimating parameters in solid waste generation, even though other estimations for GEO-3 are based on country-by-country data. The data for solid waste generation for the 65 countries were taken from a US EPA report (Adler, 1994).

6.3 Energy-related carbon dioxide emissions

6.3.1 Description

Energy-related carbon dioxide emissions are total carbon dioxide emissions from all energy uses: e.g. industrial, road transport, other transport, agriculture and households.

6.3.2 Modelling

The AIM/Trend model divides final energy demand into five sectors: IND (industry), TPR (transport on road), TPO (transport others), AGR (agriculture), and OTH (other such as households). IVA (industry value added), CAR (car holders), GDP, AVA (agriculture value added), and PFC (private final consumption) are used as the driving forces for each final energy sector. Calculated are the future trajectory projections of driving forces' regression between GDP per capita, and IVA share of GDP, number of cars per capita, AVA share of GDP and the PFC share of GDP. Elasticity between driving force and final energy demand for each sector is calculated by regression analysis of historical data. If the reliability of regression is low, a default value (=1) is set. Final energy demand is calculated using driving force, elasticity and the AEEI for each final energy sector. The AEEI is set for each GEO-3 scenario. Each share of fossil energy in the final energy demand sector, and electricity use in each sector, is calculated by regression analysis with historical data. Share of heat in each final energy sector is set in each GEO-3 scenario. Energy supply is in the form of electricity and heat generated by power plants, heat plants and Combined Heat and Power (CHP) plants.

Power plants generate electricity and heat plants generate heat, whereas CHP plants can generate both electricity and heat. All plants operate using fossil fuels (coal, oil, gas) and combustible renewable waste. Power plants, however, can also generate electricity through nuclear power, hydroelectricity, geothermal power and new technologies such as solar photovoltaic (PV) and wind power. Efficiency of each energy plant is assumed to increase or be fixed, depending on the GEO-3 scenario. Each fossil-fired power plant share is calculated by regression with historical data. Non-fossil-fired power plant supply is assumed by each GEO-3 scenario. For instance, in line with the quantification and harmonisation of the scenarios, as explained in Chapter 2 (see sections 2.3 and 2.4 and Annex I of Chapter 2), the share of non-fossil fired power plant supply remains moderate in *Markets First* and *Security First* scenarios but becomes important in *Policy First* and significant in *Sustainability First*. Both the transformation efficiency from primary energy to final energy and the transformation efficiency of electricity and heat are assumed to remain constant in accordance with the latest historical data. Emissions of greenhouse-related gases (carbon dioxide, sulphur dioxide, nitrogen oxides, methane, dinitrogen oxide, carbon monoxide) are calculated using energy supply and emission factors. Kuznets curves are assumed, with sulphur dioxide and nitrogen oxides explained in their respective modelling sections. The calculation flow in the model is depicted in Figure 6.4.

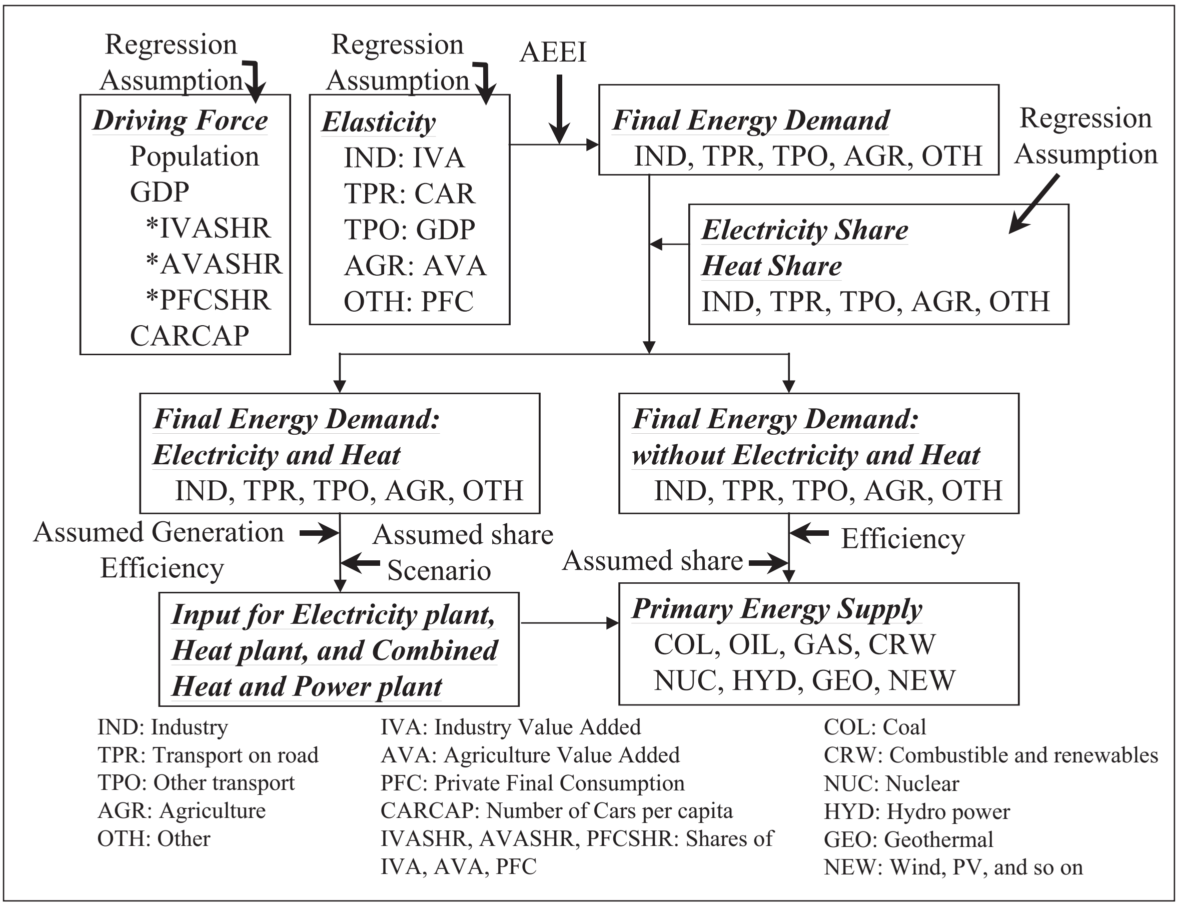


Figure 6.4: Calculation flow in the AIM/Trend model

6.3.3 Results

Figure 6.5 shows the energy-related carbon dioxide emissions in the Asia-Pacific region in the four scenarios. Emissions of carbon dioxide increase more rapidly under *Markets First* circumstances because of high economic growth. In *Policy First*, advanced technologies are introduced to reduce carbon dioxide emissions. Because a *Sustainability First* society shifts from conventional to sustainable lifestyles, carbon dioxide emissions are somewhat mitigated. On the other hand, a *Security First* society holds on to technologies with low-energy efficiency. Carbon dioxide emissions increase most rapidly in this scenario everywhere except in Central Asia, where low economic activities mitigate carbon dioxide emissions vis-à-vis *Markets First*.

Figure 6.6 shows the change in energy-related carbon dioxide emissions by 2032 relative to 2002 in sub-regions of the Asia Pacific. China, in the sub-region, 'North West Pacific and East Asia', India in South Asia and Kazakhstan in Central Asia experience a maximum change in carbon dioxide emissions over the 30-year period, while the South Pacific sub-region (including Australia and New Zealand (ANZ)) experiences the least change in all the scenarios. An interesting observation is that the ANZ and South Pacific sub-region and Japan show a decline in carbon dioxide emissions in the *Policy First* scenario, because this scenario is more severe than *Sustainability First* scenario. In all but Central Asia, carbon dioxide emissions are higher in the *Security First* scenario than in the *Markets First* scenario for the reason mentioned above.

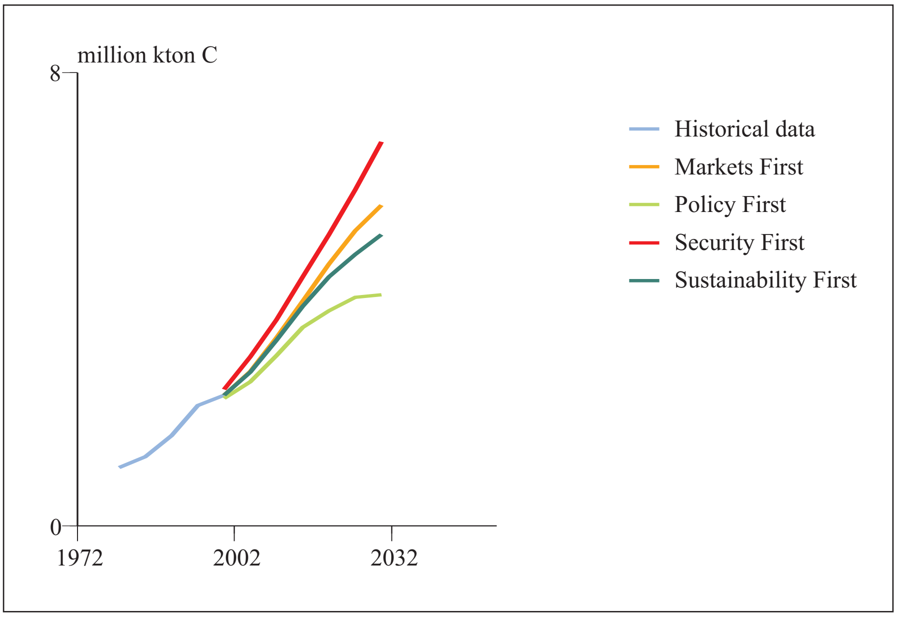


Figure 6.5: Energy-related carbon dioxide emissions in Asia and the Pacific as a whole
Source: NIES

Stack order absolute from left to right:

South Asia
India, Iran, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan, Maldives, Afganistan

South East Asia
Indonesia, Thailand, Malaysia, Singapore, Philippines, Vietnam, Myanmar, Brunei, Cambodia, Laos

North West Pacific and East Asia
China, Japan, Rep. Korea, Taiwan Province of China, Dem. Korea, Mongolia

Central Asia
Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, Kyrgyzstan

Australia, New Zeeland and South Pacific
Australia, New Zeeland, Papua New Guinea, Fiji, French Polynesia, Palau, Solomon Islands, Samoa, Nauru, Tonga, Vanuatu, Kiribati

Figure 6.6: Energy-related carbon dioxide emissions in the five sub-regions of Asia and the Pacific

Source: NIES

Note the fine lines within the sub-regional, horizontal, bars. The segments of the bars are values for individual countries. The stacking orders are mentioned in the chart.

6.4 Energy-related sulphur dioxide emissions

6.4.1 Description

Energy-related sulphur dioxide emissions are total sulphur dioxide emissions from all energy uses.

6.4.2 Modelling

The AIM-Trend model is applied to calculate sulphur dioxide emissions, as described in section 6.3.2. As with the carbon dioxide emission factor, emission factors for sulphur dioxide and nitrogen oxides are set for each country. Kuznets curves, which postulate an inverse U relationship between income level and pollution, are assumed to deal with the changes in emission reduction rate according to economic growth. In modelling this, thresholds are set as a function of GDP per capita and at these thresholds the emission reduction rate changes (higher thresholds – or higher GDP per capita – will show lower emission reduction rates).

6.4.3 Results

Sulphur dioxide emissions will increase most rapidly in the *Security First* scenario, because little money is invested to reduce sulphur dioxide emission in a low economic growth world (Figure 6.7). In the other scenarios, the increase of sulphur dioxide emissions will be slow, as measures are taken to avoid severe air pollution. This is especially so in *Policy First* and *Sustainability First,* where sulphur dioxide emissions will be controlled more strictly. For *Markets First* it was assumed that no specific government action is taken. With rising income levels, however, the need for a better environment is recognized by all sectors of the society. In *Markets First*, therefore, voluntary initiatives by business/industry and structural shifts in society will in the long run also show an

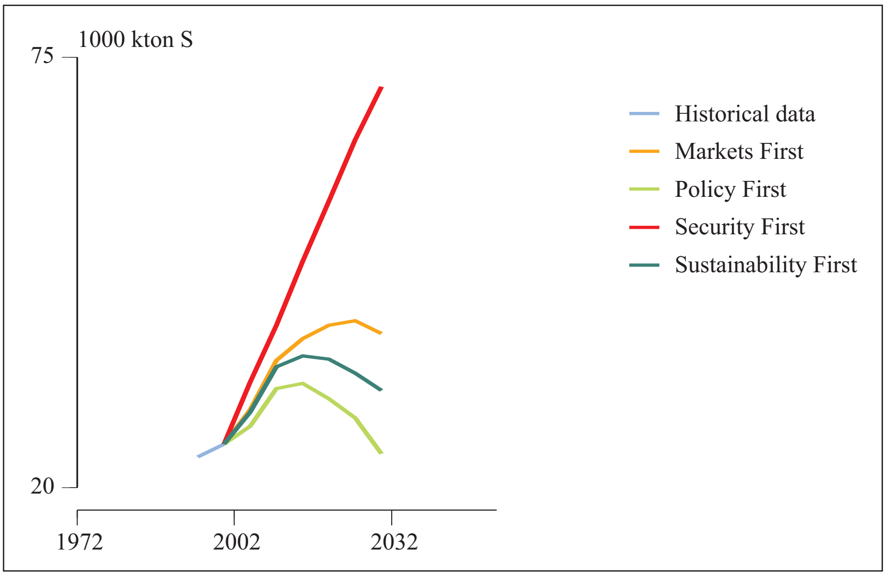


Figure 6.7: Energy-related sulphur dioxide emissions in Asia and the Pacific as a whole

Source: NIES

Stack order absolute from left to right:

South Asia:
India, Iran, Pakistan, Bangladesh, Sri Lanka, Nepal, Maldives, Bhutan, Afghanistan

South East Asia:
Thailand, Indonesia, Philippines, Malaysia, Singapore, Vietnam, Myanmar, Brunei, Cambodia, Laos

North West Pacific and East Asia:
China, Rep. Korea, Taiwan Province of China, Japan, Dem. Korea, Mongolia

Central Asia:
Uzbekistan, Kazakhstan, Turkmenistan, Tajikistan, Kyrgyzstan

Australia, New Zeeland and South Pacific:
Australia, New Zealand, Papua New Guinea, Fiji, French Polynesia, Palau, Solomon Islands, Samoa, Nauru, Tonga, Vanuatu, Kiribati

Figure 6.8: Energy-related sulphur dioxide emissions in the five sub-regions of Asia and the Pacific

Source: NIES

Note the fine lines within the sub-regional, horizontal, bars. The segments of the bars are values for individual countries. The stacking orders are mentioned in the chart.
"

improved situation. Due to this Kuznets effect, a downward trend is observed in *Policy First* and *Sustainability First* scenarios from around 2015, while this trend is observed in *Markets First* only

Sub-regional results for changes in sulphur dioxide emissions by 2032 (Figure 6.8) provide interesting observations. In the ANZ and South Pacific, sulphur dioxide emissions are reduced by 40 to 50 per cent between 2002 and 2032 in all scenarios. In modelling the scenarios, it is assumed that all the industrialized countries would reduce their sulphur dioxide emissions regardless of the scenario. Australia dominates emissions in the ANZ and South Pacific, and therefore the whole area appears to be decreasing its sulphur dioxide emissions. In the North West Pacific and East Asia sub-region, China's emissions decrease at a slower rate than those of Japan. As a result, the sub-region as a whole increases its emissions in most scenarios. Emissions also decrease in some countries in the South East Asia, and North West Pacific and East Asia, sub-regions under *Policy First* and *Sustainability First* scenarios. In all other regions emissions increase most rapidly in *Security First* because of relatively low investment in emission reduction, especially in India and China, where the emissions more than double over the 30-year scenario period.

6.5 Energy-related nitrogen oxide emissions

6.5.1 Description

Energy-related nitrogen dioxide emissions represent total emissions of nitrogen oxides from all energy uses: e.g. industrial, road transport, other transport, agriculture and households.

6.5.2 Modelling

The modelling applied to nitrogen oxide emissions also uses the AIM-Trend model, as described in section 6.3.2. Kuznets curves are assumed for emissions of nitrogen oxides too; i.e. the emissions per unit of activity decrease according to economic growth.

6.5.3 Results

Similar to other greenhouse gas emissions, emissions of nitrogen oxides also increase most rapidly in the *Security First* scenario. Because of lower economic growth, there is less attention paid to technological advancement, resulting in continued use of lower efficiency equipment. Emissions increase more rapidly in the *Markets First* scenario than in the *Sustainability First* scenario. In the *Policy First* scenario, a downward trend sets in after around 2025 in the Asia Pacific region (Figure 6.9) because of the Kuznets effect.

Within the region, Australia, New Zealand and Japan show a reduction in emissions of nitrogen oxides in all scenarios, although it is very small in Japan (Figure 6.10). Following the same trend as that of sulphur dioxide emissions, emissions of nitrogen oxides also increase rapidly in the *Security First* scenario in all sub-regions except ANZ and the South Pacific. In the *Policy First* scenario, some countries in South East Asia also show a marginal decline in their emissions, although the net emissions for the region show an increase. Even in *Sustainability First* scenario, South Asia and Central Asia at least double their emissions between 2002 and 2032.

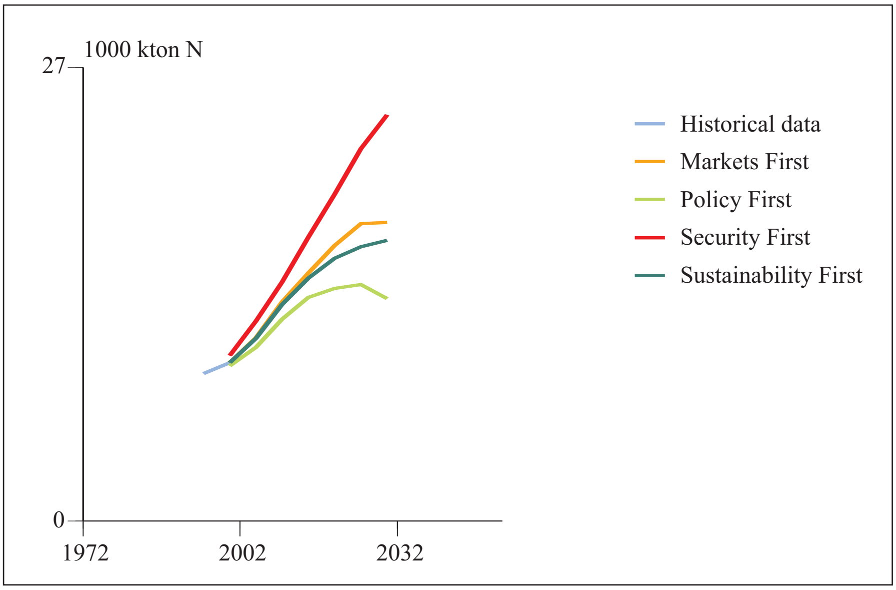
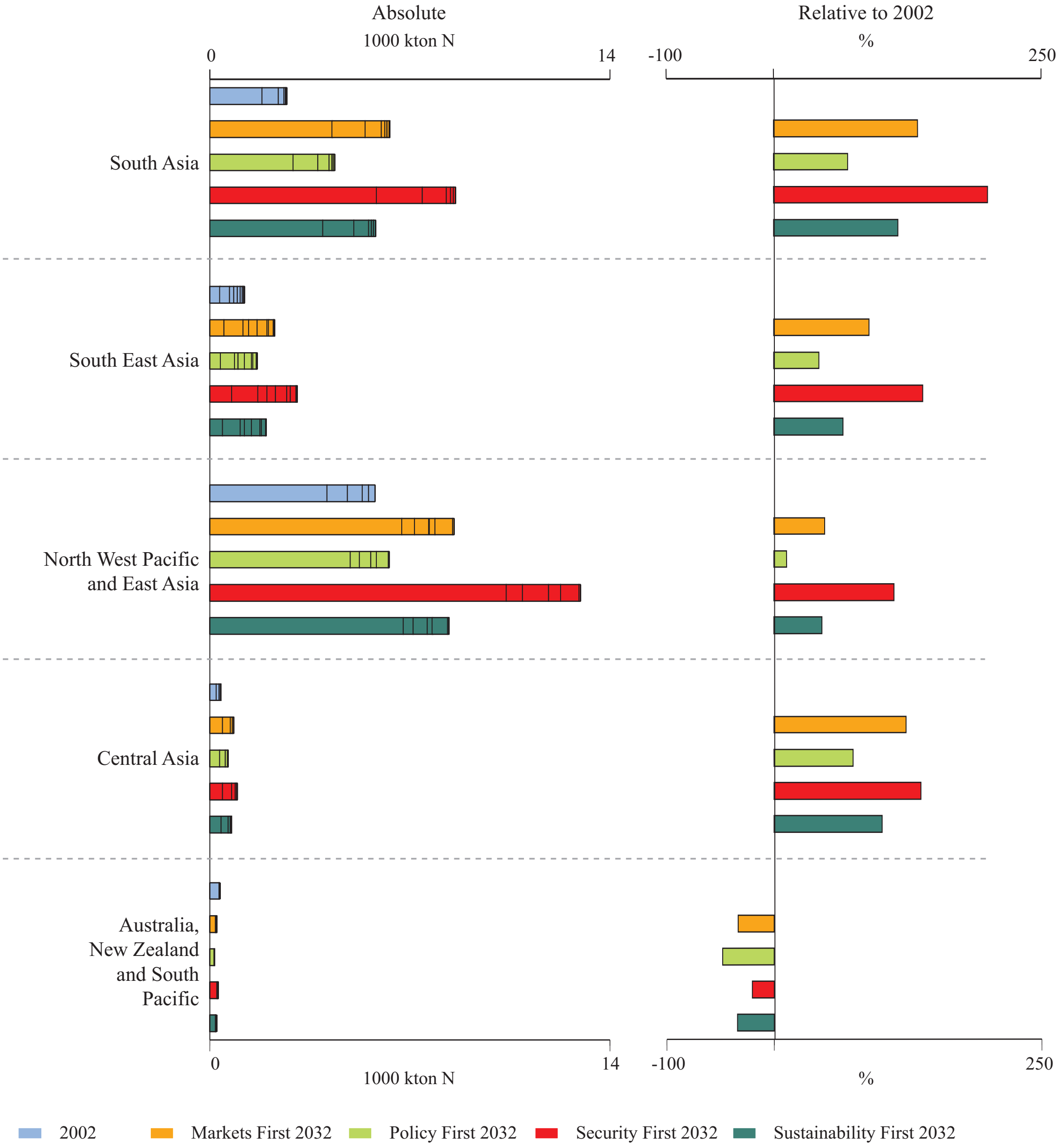


Figure 6.9: Energy-related nitrogen oxide emissions in Asia and the Pacific as a whole

Source: NIES



Stack order absolute from left to right:

South Asia:
India, Iran, Pakistan, Bangladesh, Sri Lanka, Nepal, Maldives, Bhutan, Afganistan

South East Asia:
Thailand, Indonesia, Malaysia, Philippines, Vietnam, Singapore, Myanmar, Brunei, Cambodia, Laos

North West Pacific and East Asia:
China, Japan, Rep. Korea, Taiwan Province of China, Dem. Korea, Mongolia

Central Asia:
Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, Tajikistan

Australia, New Zeeland and South Pacific:
Australia, New Zealand, Papua New Guinea, Fiji, French Polynesia, Vanuatu, Solomon Islands, Samoa, Tonga, Palau, Kiribati, Nauru

Figure 6.10: Energy-related nitrogen oxide emissions the five sub-regions of Asia and the Pacific

Source: NIES

Note the fine lines within the sub-regional, horizontal, bars. The segments of the bars are values for individual countries. The stacking orders are mentioned in the chart.

6.6 Municipal solid waste

6.6.1 Description

Municipal solid waste generation is an index of solid waste generation from household and commercial sources. Total solid waste generation in the Asia-Pacific region in the year 1995 was allocated an index value of 1. Index values for 2032 under each scenario relate to the index for the base year.

6.6.2 Modelling

Data on solid waste generation, GDP and population show solid waste generation per capita to be positively correlated to GDP per capita (Figure 6.11). From the historical analysis in Japan, the waste generation per capita eventually levels off to the GDP per capita as shown in Figure 6.12. As a result, the relationship between waste generation per capita and GDP per capita is adopted as shown in Figure 6.11 and a regression curve is estimated. The implicit assumption is that if other Asian countries follow a similar pattern to Japan, such a trend will be observed. Finally, the total municipal waste generation is calculated from the estimated waste generation per capita and population assumption. To construct various scenarios, this simple model assumes different pathways of economic growth, taking into account various narratives of the scenarios. In such a simple methodology, elaborate structural changes, distribution of goods, the urban and rural situation, and the like are not modelled.

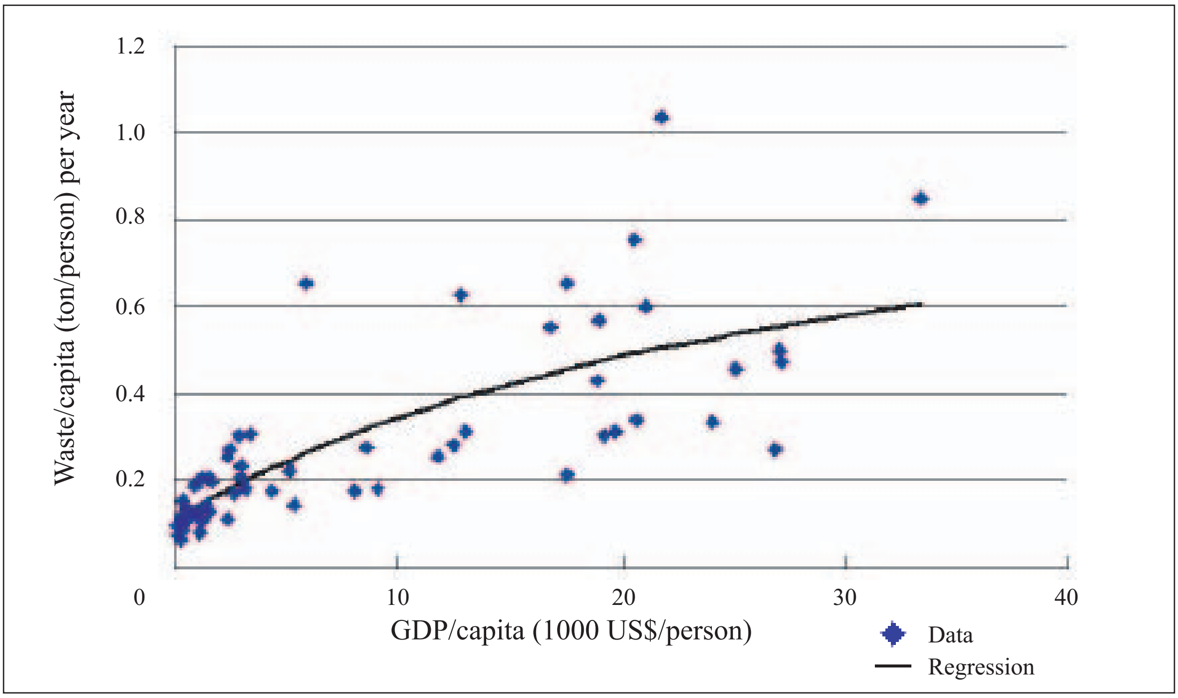


Figure 6.11: GDP per capita, waste generation per capita and estimated regression curve

Source: NIES

Note: The points in the figure represent countries (65 countries from around the world; so not limited to Asia and the Pacific).

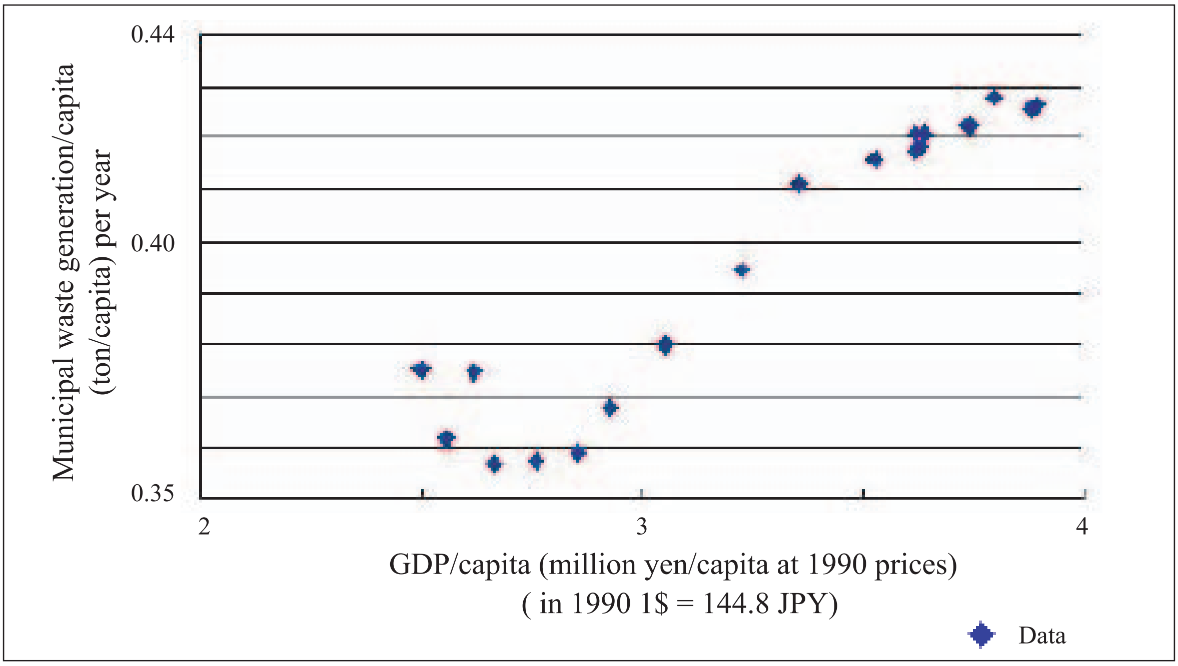


Figure 6.12: Relationship between GDP per capita and municipal waste generation per capita in Japan, 1980-1998
Source: NIES

6.6.3 Results

Because of the scarcity of data on solid waste, results are represented by index numbers normalized to 1 in 1995.

Figure 6.13 shows the solid waste trajectories in the whole Asia-Pacific region by scenario. Solid waste is generated the most rapidly in the *Markets First* scenario because it has the highest economic growth rate. In the *Policy First* case, the solid waste generation will be restricted in the same way as the carbon dioxide emissions. This restriction on solid waste could take place for two reasons. First, there is a policy push for recycling, which reduces the material requirements and hence waste generation. Secondly, there is a need to reduce solid waste, because overall capacity to treat waste is limited in many Asian-Pacific countries. In a *Security First* world, low economic growth rate will result in low municipal waste generation; successful implementation of municipal-waste generation reduction policies and efficient recycling will be introduced in the *Sustainability First* scenario. As a result, the generation of municipal solid waste will increase even more slowly.

Figure 6.14 presents changes in municipal waste generation per country in 2032 relative to 1995. In the *Markets First* scenario, the increase in the South East Asia sub-region is almost 200 per cent. The increase is especially large in India because of the large economic growth and population.

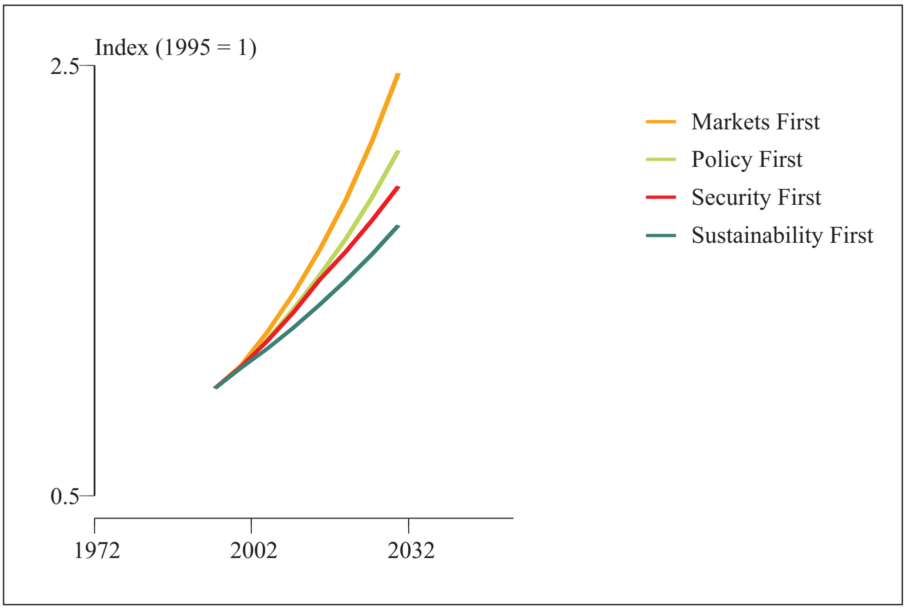
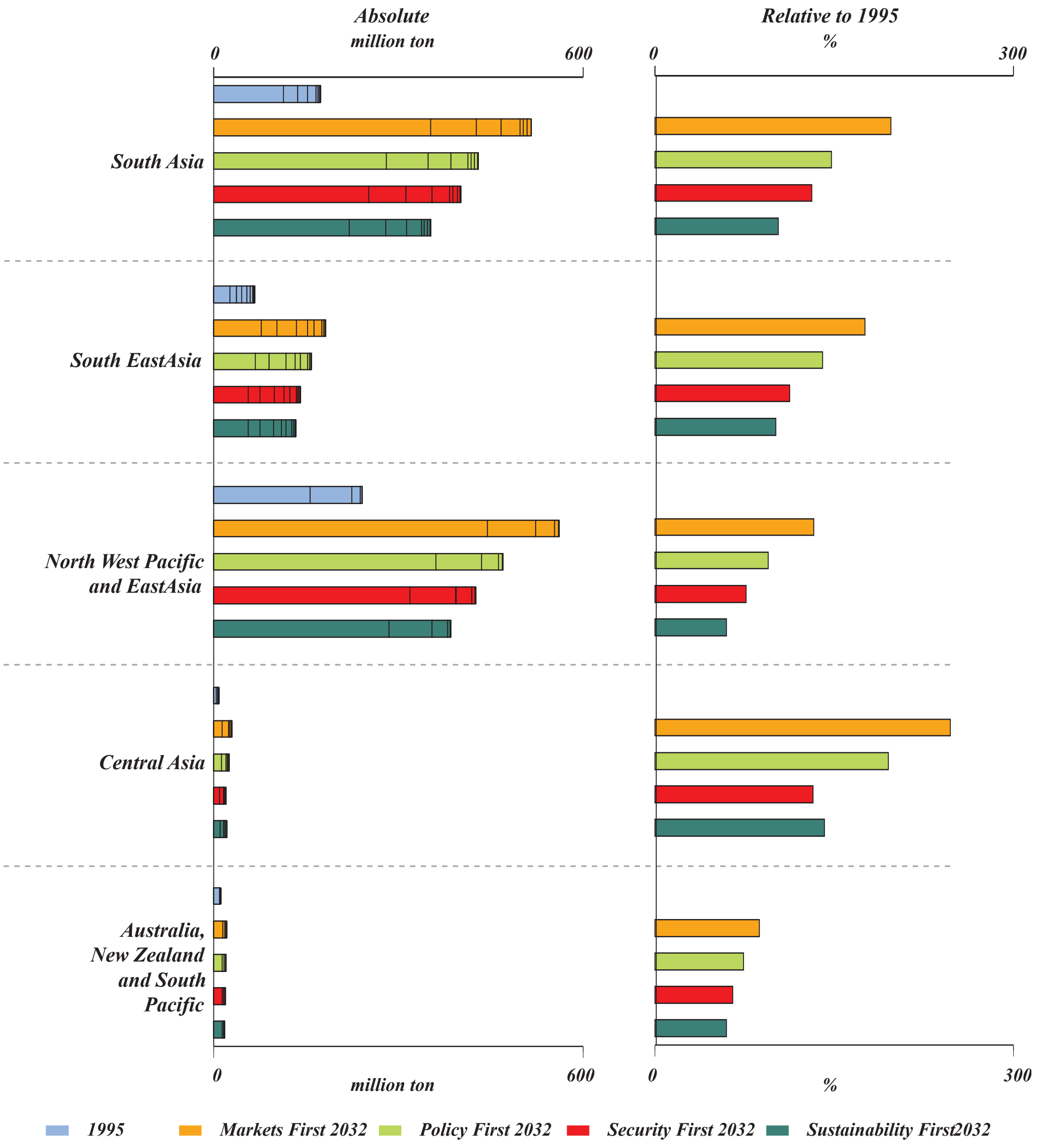


Figure 6.13: Municipal solid waste generation in Asia and the Pacific as a whole
Source: NIES

A similar situation exists in China, in the North West Pacific and East Asia sub-regions. Among the other sub-regions, Central Asia experiences the most change in its municipal waste generation, i.e. an increase of 3.5 times. Countries in this sub-region, such as Kazakhstan and Uzbekistan, have economies in transition and therefore the changes in consumption behaviour brought about by opening up these markets could be one of the reasons for such a trend. In the *Policy First* scenario, changes in waste generation are smaller than in the *Markets First* scenario. The South East Asia, South Asia and North West Pacific and East Asia sub-regions show a significantly lower increase in their waste production in a world of *Policy First*, as compared to *Markets First*. These three regions also show a significantly smaller change in their waste generation in the *Sustainability First* scenario; the increase in the North West Pacific and East Asia sub-region in *Sustainability First* is almost half when compared to the development in *Markets First*. Except for Central Asia, the increase in waste generation in the *Security First* scenario is, in all sub-regions, larger than for *Sustainability First*. In this sub-region, the economic growth rate for *Security First* is much lower than that for *Sustainability First*, and as a result, the increase in waste generation in *Security First* is also small.



Stack order absolute from left to right

South Asia:
India, Iran, Pakistan, Bangladesh, Sri Lanka, Afganistan, Nepal, Bhutan, Maldives

South East Asia:
Indonesia, Philippines, Thailand, Vietnam, Malaysia, Myanmar, Singapore, Laos, Cambodia, Brunei

North West Pacific and East Asia:
China, Dem. Korea, Japan, Rep. Korea, Mongolia

Central Asia:
Uzbekistan, Kazakhstan, Kyrgyzstan, Turkmenistan, Tajikistan

Australia, New Zeeland and South Pacific:
Australia, Papua New Guinea, New Zealand, Fiji, French Polynesia, Vanuatu, Solomon Islands, Samoa, Tonga, Palau, Kiribati, Nauru

Figure 6.14: Municipal solid waste generation in the five sub-regions of Asia and the Pacific

Source: NIES

Note the fine lines within the sub-regional, horizontal, bars. The segments of the bars are values for individual countries. The stacking orders are mentioned in the chart.

6.7 Discussion

This chapter has presented the framework of the Asian-Pacific Integrated Model (AIM) and the modelling results provided for the GEO-3 Outlook chapter. The overall picture emerging in the Asia Pacific region from the emission trends of carbon dioxide, sulphur dioxide and nitrogen oxides, and the generation of municipal waste, is that the region will experience rapid growth of all these environmental pollutants in all four GEO-3 scenarios. Only in a few countries will trends be reversed to a small extent. For both sulphur dioxide and nitrogen oxide emissions, there will be an eventual decrease in all but the *Security First* scenario. Furthermore, the Kuznets effect is more pronounced and occurs earlier for sulphur dioxide emissions than for emissions of nitrogen oxides. The latter are more persistent because the technology for their removal is in a less advanced stage of development than for sulphur dioxide. Secondly, the cost of removal for nitrogen oxides is higher. While it is difficult to predict which, if any, scenario will emerge as the future unfolds, it is clear that immediate actions are required to control the incidence of increased environmental burdens on air, land and water.

The AIM results presented in GEO-3 are limited to a few variables, but as explained in the framework in section 6.1, the model is capable of providing results for other variables for the Asia-Pacific region, as well as for other regions of the world. The AIM/Material model, constructed for assessing policies affecting carbon dioxide emissions and solid waste, for instance, finds application in Japan (Masui, 2001) and India (Rana and others, 2001). New results from AIM are also reflected in the Asia-Pacific Environmental Innovation Strategy Project of the Government of Japan. AIM results have been included in IPCC studies as well as comparison studies under the Energy Modelling Forum (EMF) of Stanford University, USA and the ACROPOLIS project of the University of Stuttgart, Germany.

6.8 Acknowledgements

The AIM team is deeply grateful to Professor P.R. Shukla of the Indian Institute of Management (Ahmedabad, India), Professor Ram Shreshtha of the Asian Institute of Technology (Thailand), Professor Xiulian Hu and Dr. K. Jiang of the Energy Research Institute (Beijing, China) for their input into the development of these models. The AIM team also took benefitted from the fruitful discussions with and advice and comments from participants of ECO-ASIA Long-term Perspective Project Phase-II workshop held in Japan in October 2001 (ECO ASIA, 2001).

References

Adler, M.J., ed., 1994. *International anthropogenic methane emissions: estimates for 1990.* (230R93010). US Environmental Protection Agency.

Central Statistical Organisation (CSO), 2000. *Compendium of Environment Statistics 1999.* New Delhi: Ministry of Statistics and Programme Implementation, Government of India.

ECO ASIA, 2001. *Towards a Sustainable Asia and the Pacific. Report of ECO ASIA Long-term Perspective Project Phase II.* Japan: Institute for Global Environmental Strategies.

Fujino, J., 2001. *Development of AIM-Trend Model as a Communication Tool to Enhance Discussions about Prospect of Energy and Environment in each Asia-Pacific Country.* Yokohama: IFAC Workshop on Modeling and Control in Environmental Issues, 2001, pp. 109 - 114.

Fujino, J., et al., 2001. *Environmental Assessments using Environment-Economy Integrated Models for the Asia-Pacific Innovation Strategy Project.* Joint Workshop on Asia-Pacific Environmental Innovation Strategy Project (APEIS) and Millennium Ecosystem Assessment (MA). Tokyo: United Nations University.

Fujino, J., et al., 2002. AIM/Trend: Policy Interface. In: Kainuma, M., Y. Matsuoka, and T. Morita, eds. *Climate Policy Assessment*. Springer, 2002, pp. 217-232.

International Energy Agency (IEA), 1999a. *Energy Balances of OECD Countries*. Paris: International Energy Agency.

IEA, 1999b. *Energy Balances of Non-OECD Countries.* Paris: International Energy Agency.

IPCC, 1997. *Greenhouse Gas Inventory Reference Manual*. In: Houghton, J.T., et al., eds. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories IPCC/OECD/IEA, Vol. III.* Bracknell: UK Meteorological Office.

Masui, T., 2001. *Quantitative Analysis on Economic Effects of Environmental Policies under Environmental Constraints using Computable General Equilibrium Model.* Yokohama: IFAC Workshop on Modeling and Control in Environmental Issues, 2001, pp. 45-50.

Matsuoka, Y., M. Kainuma, and T. Morita, 1995. Scenario Analysis of Global Warming using the Asian Pacific Integrated Model (AIM). *Energy Policy* 23(4/5), pp. 357-371.

Organisation for Economic Co-operation and Development (OECD), 1999. *OECD Environmental Data: Compendium 1999*. Paris: Organisation for Economic Co-operation and Development.

Rana, A., T. Masui, and P.R. Shukla, 2001. *General Equilibrium Analyses of Effects of Environment Policy on Indian Economy.* Yokohama: IFAC Workshop on Modeling and Control in Environmental Issues, 2001, pp. 51-55.

State Statistical Bureau (SSB), 1996. *China Statistical Yearbook 1996*. People's Republic of China: China Statistical Publishing House.

SSB, 1999. *China Environmental Statistics 1998*. People's Republic of China: China Statistical Publishing House.

United Nations Environment Programme (UNEP), 2002. *Global Environment Outlook 3*. Nairobi: United Nations Environment Programme, London: Earthscan.

United Nations, 1995. *Energy Statistics Yearbook*. New York: United Nations.

7. Emissions, climate, land and biodiversity

Impacts of the four GEO-3 scenarios have been estimated for issues ranging from climate change to soil degradation risk. The analytical method involves a rather detailed interpretation of the scenarios and modelling on a fine spatial grid. Striking delays are found between action and result, underlining the responsibility of current decision-makers for both the next generation and the succeding ones. Many of the impacts show strong differences between and within North and South. For many of the issues analysed, the Sustainability First *world shows a clear turn for the better. Besides, the analysis clearly demonstrates that careful policy co-ordination will be required to make progress; integrated, forward-looking strategies are bound to bring significant benefits, including cost savings.*

7.0 Introduction

This chapter provides the background to the variables supplied by the RIVM for the production of the GEO-3 Outlook chapter (UNEP, 2002). The aim of the chapter is twofold. It first explains the methods used and then presents the actual findings, the major reasons for the changes over time and the policy relevance of the findings.

The IMAGE 2.2 model is generally described in section 7.1, while section 7.2 provides information in brief on the data inputs, assumptions and scenario interpretation used by the RIVM to analyse the environmental consequences of the four GEO-3 scenarios. The main reference is to Chapter 2; see especially section 2.4 for details. The subsequent sections discuss methods and results for the following variables:

- Nitrogen loading of coastal marine ecosystems, in section 7.3
- Energy-related sulphur dioxide emissions, in section 7.4
- Energy-related carbon dioxide emissions, in section 7.5
- Carbon dioxide concentrations, rate of average temperature change and change in precipitation totals, in section 7.6
- Risk of water erosion of soils, in section 7.7
- Natural forest change, in section 7.8
- Terrestrial biodiversity (using the Natural Capital Index), in section 7.9

A discussion and several conclusions on the analysis of these variables can be found in section 7.10.

7.1 Analytical framework

The Integrated Model to Assess the Global Environment (IMAGE) has been the central tool for the analysis reported here. IMAGE, developed at RIVM, initially to assess the impact of anthropocentric climate change (Rotmans, 1990; Rotmans and others, 1990), is a dynamic integrated assessment framework to model global change. Later it was extended to include a more comprehensive coverage of global change issues in an environmental perspective (IMAGE team, 2001a,b). The current main objectives of IMAGE are to contribute to scientific understanding and support decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system.

IMAGE provides dynamic and long-term perspective modelling on the systemic consequences of global change up to 2100. The model was set up to give insight into causes and consequences of global change up to 2100 as a quantitative basis for analysing the relative effectiveness of various policy options for addressing global change. Figure 7.1. provides an overview of the current IMAGE modelling framework.

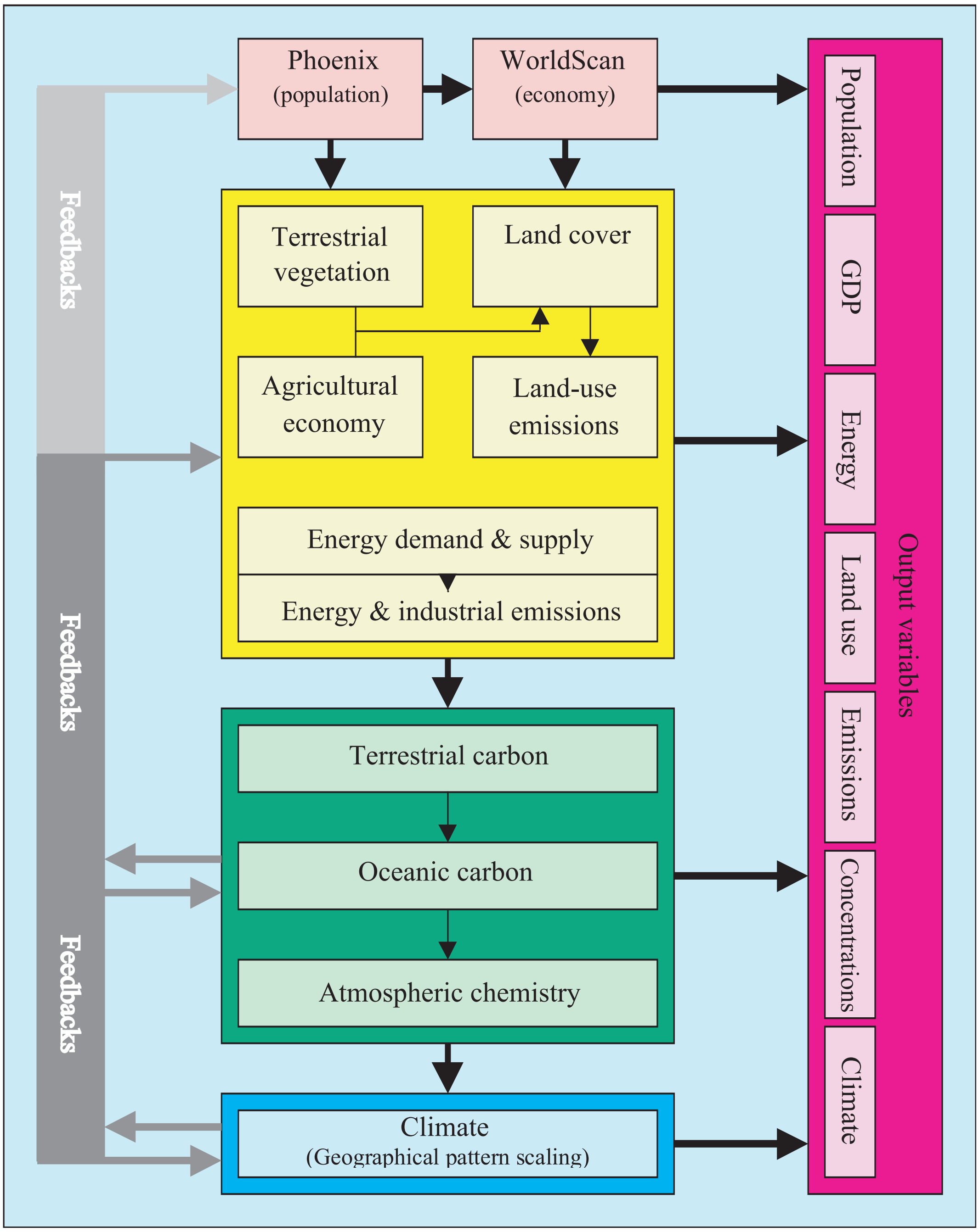


Figure 7.1: The IMAGE 2.2 framework

Source: RIVM

Note: Most variables in this chapter are directly estimated with IMAGE. Although the Natural Capital Index and current nitrogen loading of coastal ecosystems are calculated outside IMAGE, they are based on IMAGE output.

There are two models associated with, but not integrated in, IMAGE; used to provide basic input information for the IMAGE model. These are the general equilibrium economy model, WorldScan (CPB, 1999), and the population model, PHOENIX (Hilderink, 2000). The WorldScan model provides input for IMAGE on economic developments, and - PHOENIX provides input on demographic developments for both IMAGE and WorldScan.

The WorldScan model is a typical Applied General Equilibrium model based on neo-classical economic theory. The model design focuses on international economics, but can also be applied to analyse energy, transport, trade and environmental policies. WorldScan distinguishes twelve world regions, with output being transferred to the IMAGE 2.2 regions (see Table 7.1). Eleven sectors are distinguished in the regional economies. As inputs to production in each sector, WorldScan distinguishes the products, low-skilled labour, high-skilled labour, capital and, finally, a fixed factor (land and resources) from other sectors. It models growth of GDP as a function of the growth of ‘physical’ capital, labour and technology, taking into account those in the labour force in low-income regions working in low-productivity subsistence sectors. Trade is calculated within the model, i.e. endogenously. It is only in the long term that changes in trade lead to changes in the degree of specialisation of the economies modelled in WorldScan. WorldScan calculations allocate macro consumption over time and categories, taking into account that consumer behaviour is region-specific. Moreover, depending on a region’s GDP growth, WorldScan takes into consideration that consumption preferences show a certain convergence towards the OECD (CPB, 1999; Bollen and Manders, 2001).

The PHOENIX model is an interactive tool using an integrated-systems’ dynamic approach to describe, position and analyse a broad spectrum of demographic issues to gain insights into changes in population size and structure (age structure, number of households and urbanisation rates). The two main sub-models of PHOENIX, the fertility and mortality sub-systems, describe historical and future reproductive behaviour and mortality patterns in relation to socio-economic aspects (e.g. income, education and health services) and environmental conditions (e.g. access to food and drinking water and malaria risk areas). Socio-economic input is derived from WorldScan, whereas IMAGE modules provide the environmental input. In return, simulations of population size by PHOENIX are used as input variables for IMAGE and WorldScan, which finally results in consistent scenarios (Hilderink, 2000).

The output of the WorldScan and Phoenix models feeds into two basic parts of IMAGE (see yellow box in Figure 7.1):

- The Energy-Industry System, which calculates regional energy consumption, energy efficiency improvements, fuel substitution, supply and trade of fossil fuels and renewable energy technologies. On the basis of energy use and industrial production, the system computes emissions of greenhouse gases, ozone precursors and acidifying compounds (De Vries and others, 2001).
- The Terrestrial Environment System, which, amongst other aspects, computes land-use changes on the basis of regional consumption, production and trading of food, animal feed, fodder, grass and timber, with consideration of local climatic and terrain properties (Leemans and Van den Born, 1994; Zuidema and others, 1994; Klein Goldewijk and others, 1994; Kreileman and Bouwman, 1994).

Table 7.1: Regions and sub-regions in GEO-3 and IMAGE 2.2 compared

GEO-3 region	GEO-3 sub-region	Corresponding IMAGE 2.2 sub-region(s)	Sub-region name in IMAGE 2.2-based figures	Exact differences in IMAGE 2.2 from GEO-3	Region name in IMAGE 2.2-based figures
North America	North America	Canada USA	North America	with US Minor Outlying Islands	North America
Latin America and the Caribbean	Caribbean Meso America	Central America	Meso America & Caribbean		Latin America and the Caribbean
	South America	South America	South America	with Bouvet Island & South Georgia and the South Sandwich Islands	
Africa	Northern Africa	Northern Africa	Northern Africa (without Sudan)	without Sudan (included in Eastern Africa)	Africa
	Western Africa Central Africa	Western Africa	Western & Central Africa	with Saint Helena	
	Western Indian Ocean Eastern Africa	Eastern Africa	Western Indian Ocean & Eastern Africa (with Sudan)	with Sudan	
	Southern Africa	Southern Africa	Southern Africa	without Saint Helena (included in Western & Central Africa)	
Europe	Western Europe	OECD Europe	Western Europe	without Israel (included in West Asia)	Europe and Central Asia (without Turkey)
	Central Europe	Eastern Europe	Central Europe (without Turkey)	without Cyprus & Turkey (included in West Asia), Estonia, Latvia & Lithuania (included in Eastern Europe)	
	Eastern Europe Central Asia	Former USSR	Eastern Europe & Central Asia	with Estonia, Latvia & Lithuania	
West Asia	Arabian Peninsula Mashriq	Middle East	West Asia (with Iran & Turkey)	with Cyprus, Turkey, Israel, Occupied Palestinian Territory & Islamic Republic of Iran	West Asia (with Iran and Turkey)
Asia and the Pacific	South Asia	South Asia	South Asia (without Iran)	without Iran (included in West Asia)	Asia and the Pacific (without Iran)
	NW Pacific+East Asia	East Asia Japan	NW Pacific+East Asia		
	South East Asia	South East Asia	South East Asia	with East Timor, without Christmas Island (included in South Pacific), Paracel & Spratly Islands (ignored)	
	South Pacific Australia & New Zealand	Oceania	Australia & New Zealand and South Pacific	with Christmas Island, French Southern Territories & Heard Island and Mc Donald Islands, without Jarvis Island, Baker Island, Howland Island, Johnston Atoll, Midway Islands & Wake Island (ignored)	
Polar	Polar regions, Arctic	Greenland; for climate the area North of 66^0 latitude	Arctic		Polar
	Polar regions, Antarctic	Antarctica; for climate the area South of 66^0 latitude	Antarctica	without Bouvet Island & South Georgia and the South Sandwich Islands (included in South America), French Southern Territories & Heard Island and Mc Donald Islands (included in South Pacific)	

Emission and land-use change estimations are used, for example, to calculate changes in atmospheric composition and climatic properties by resolving the changes in radiative forcing caused by greenhouse gases, aerosols and oceanic heat transport (Eickhout and others, 2002). There are, in fact, linkages between the models within each IMAGE system, along with linkages and feedback links across these systems.

IMAGE 2.2 quantifies a broad range of sustainable development and environmental variables. The variables 'nitrogen loading of coastal ecosystems' and 'terrestrial biodiversity (using the Natural Capital Index)' are calculated using additional models on the basis of IMAGE 2.2 output. All variables are organized on the basis of the Pressure-State-Impact-Response framework. A description of each variable, along with corresponding references to the literature, can be found in the user documentation on the CD-ROM 'The IMAGE 2.2 implementation of SRES scenarios' (IMAGE team, 2001a,b). An in-depth overview of IMAGE 2.1 as a whole is given in Alcamo and others (1998).

IMAGE 2.2 simulations cover the period from 1995 up to 2100. Data for 1970-1995 are used to calibrate the Energy Industry System. The Terrestrial Environmental System is calibrated over a longer period (1765-1995), since the biosphere reacts with a time lag to human distortion (Leemans and others, 2002). Simulations up to the year 2100 are made on the basis of scenario assumptions on, for example, demography, food and energy consumption, and technology and trade (see mainly section 2.4).

IMAGE 2.2 is mainly applied to global assessments. However, IMAGE performs many of its calculations either on a high-resolution terrestrial grid of 0.5° by 0.5° (many of the land- related and environmental variables) or for linked world regions (e.g. energy-related variables). The world regions are based on the GEO-2000 sub-regional breakdown (see Table 7.1). The sub-regional breakdown was changed for GEO-3, however, this new breakdown was not applied to the GEO-3 scenario exercise, since it involves a major, time-consuming operation to change a breakdown in large integrated models like IMAGE, AIM and WaterGAP. This requires extensive calibration preceded by the collection of material to calibrate against. In fact, attuning the IMAGE 2.2 sub-regional breakdown to the previous (GEO-2000) revision had just been finalized when preparations for GEO-3 started.

7.2 Input data and assumptions

The scenarios needed to be interpreted further to estimate environmental impacts as described in the following seven sections. For example, inter-linkages, effectiveness of measures and dynamics over time needed to be detailed, paving the way for a coherent quantified impact assessment of the GEO-3 scenarios for the variables listed in secton 7.0 using IMAGE.

How the material has been adapted to the GEO-3 story-lines and quantitative assumptions for population and economic development is described in section 2.4. Annex 1 lists the specific assumptions made on energy production and consumption for the quantitative interpretations of the GEO-3 scenarios, while Annex 2 describes the assumed changes in land-related issues. The resulting developments in land cover and land use affect many of the variables in this chapter. A summary of the changes is provided in Figure 2.2.

7.3 Nitrogen loading of coastal marine ecosystems

7.3.1 Description

The variable 'nitrogen loading of coastal marine ecosystems' quantifies the anthropogenic share in total nitrogen loading of coastal ecosystems. At the sub-regional level employed in GEO-3, nitrogen loading can be taken as a proxy for a wider range of land-based pollution on the coastal ecosystems. It also indicates eutrophication of coastal ecosystems, in particular. The growth of algae in marine waters is often nitrogen-limited (in contrast with many freshwater systems that are phosphorus-limited). Large outflows of nitrogen at the mouth of the river may result in blooms of algae that make water bodies unsuitable[10] for recreational and other uses and, in worse cases, are even toxic to aquatic life.

7.3.2 Modelling

Natural nitrogen compounds, with their origin in groundwater and leached from the soil, are in continual transport by rivers. Activities like agriculture (diffuse nitrogen sources) and discharge of industrial and domestic waste water (point nitrogen sources) cause anthropogenic nitrogen to be added to river water.

The main diffuse sources of anthropogenic nitrogen are the inputs from nitrogen fertilisers, animal manure and biological nitrogen fixation in agriculture, though natural soils may also be subject to considerable atmospheric deposition on top of natural nitrogen (from both natural and anthropogenic sources). Nitrogen in soils occurs mainly as nitrate that may be denitrified to nitrogen gas. This gas leaves the soil and is no longer available. Nitrate also leaves soils through surface runoff or soil leaching. Since nitrate is highly mobile in soils, it is easily leached to shallow and deep aquifers during periods of excess precipitation. Groundwater flowing to surface water is generally a mixture of water with varying residence times. Groundwater recharged more than 50 years ago, when fewer nitrogen compounds were used than today, contributes much less nitrate to surface water than groundwater from more recently infiltrated precipitation. Denitrification, surface-runoff, soil leaching and groundwater transport depend on climate, soil conditions and soil hydrological conditions. As a result of these processes, only a fraction of the nitrogen input to soils will reach river water, often with a considerable delay.

Industrial discharge and domestic waste water are the main point sources of anthropogenic nitrogen to river water. When these discharges, along with atmospheric nitrogen and nitrate from soil and groundwater enter a river, part of the nitrogen is removed from the water, primarily through metabolic processes through which it is then transferred to biota, the atmosphere or the stream sediments. Factors influencing this are temperature, availability of organic matter, nitrate concentration near sediments, and the stream flow regime and water residence time. Urban areas close to a river mouth (thus having a short waterresidence time) will contribute more nitrogen at the river mouth than cities further away from the coast. However, this was not taken into account in this scenario exercise.

---

[10] Eutrophication can cause a decrease in oxygen and finally even a lack of oxygen, both of which appear to have become more prevalent in many estuaries and coastal seas. Low oxygen conditions have resulted in significant losses of fish and shellfish resources.

Global 0.5° by 0.5° resolution quantitative estimates have been made for the fate of nitrogen from diffuse and point sources under the current situation. For point sources – mostly urban agglomerations - the estimates are based on population densities, sanitation coverage and wastewater treatment levels. Estimates for diffuse sources cover atmospheric deposition, agricultural inputs and natural releases from ecosystems. Calculations are based on local hydrology, climate, geology, soils, and land use, combined with 1995 data on crop production, nitrogen inputs from fertilisers and animal manure, and estimates for ammonia emissions, biological nitrogen fixation, and atmospheric nitrogen deposition. Historical nitrogen inputs are also used to describe the nitrogen flows in groundwater (Van Drecht and others, 2001). Van Drecht and others (2001) combined the results from their detailed calculations to estimate current nitrogen loads originating from major drainage basins (see Map 7.1).

Current nitrogen loading estimates were then aggregated per GEO-3 region for the GEO-3 main report, with nitrogen discharge at the river mouth assigned to the corresponding GEO regions as a whole. For this Technical Report, figures are presented in more detail for the GEO-3 sub-regions (see Figure 7.2). The variable shown is the share of anthropogenic nitrogen loading in total loading at river mouths. Zero (0) indicates a pristine situation, while 0.5 indicates a contribution of anthropogenic sources equal to the natural loading. A value close to 1.0 indicates a much larger loading from anthropogenic nitrogen sources than the natural loading.

With reference to the future under the four scenarios presented in GEO-3, the potential increase in human-induced nitrogen loading up to 2032 was estimated in a qualitative, expert-based fashion. The factors considered (also listed in the column heads of Table 7.2) are:

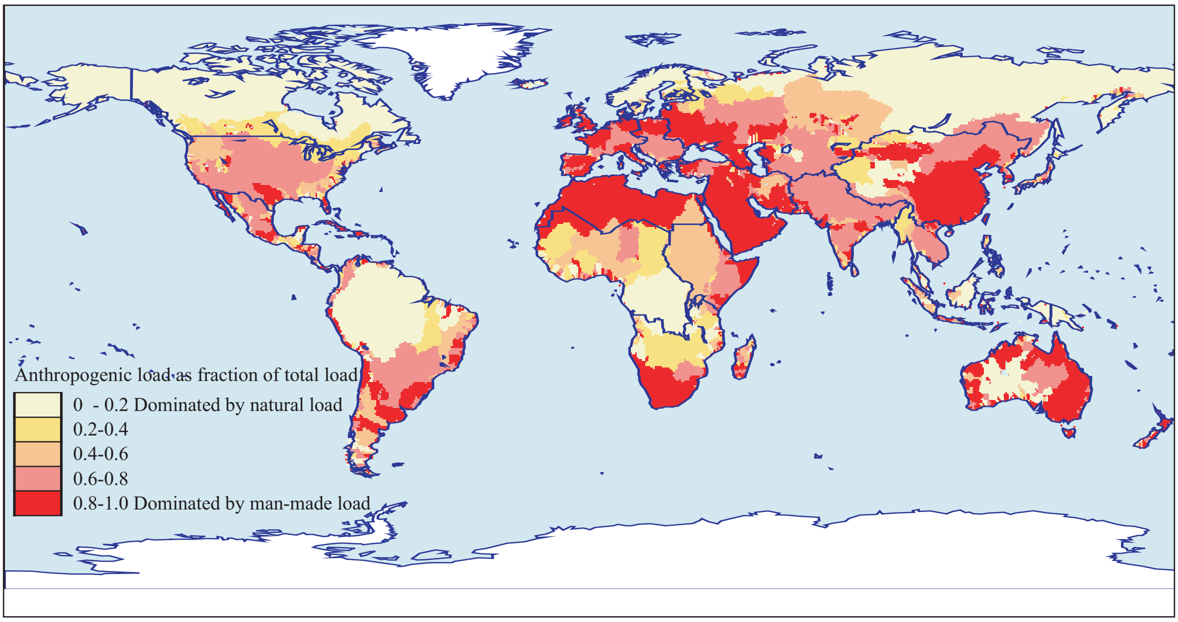
- changes in meat production and handling of related animal manure;
- changes in fertiliser use, considering such aspects as present use, subsidies and policies towards increased agricultural efficiency;
- changes in emission and deposition of nitrogen oxides and ammonia;
- changes in population size and per capita emission (the more meat in the diet, the higher the nitrogen compound content of in human excreta);
- changes in urbanisation, sanitation coverage and sewage treatment.

The combination of these factors was studied in more detail for the current Technical Report, scaling down to sub-regional level. In particular, a possibility has been taken into account that in some sub-regions in some scenarios, sewage pipeline infrastructure will be extended to keep up with urbanisation, while the expansion of sewage treatment facilities will either not take place or will lag behind a few decades. Under such circumstances the anthropogenic nitrogen loading at river mouths would, temporarily, be effectively increased. Thus the sub-regional estimates presented here are somewhat more somber than the regional estimates given in the GEO-3 main report, especially for a world of *Security First* in low-income regions.

7.3.3 Results

Global results

Map 7.1 and Figure 7.2 gave an overall impression of *current* nitrogen loading at the river mouth, assigned to the originating drainage basins On average, global anthropogenic loading is currently slightly greater than natural nitrogen loading. But the differences between the world's drainage basins are large.



Map 7.1: Share of anthropogenic nitrogen in total loading in 2002 at the river mouth, originating from the drainage basin

Source: RIVM

The anthropogenic loading of nitrogen to coastal marine ecosystems is expected to *increase* further in all scenarios. Generally speaking, the potential increase in three decades from now on is largest in a *Markets First* situation and smallest in a *Sustainability First* situation (see Table 7.2). But even when sustainability comes first, there will be an increase of nitrogen load in most regions, driven by population growth, diet changes and policies towards more intensive cropland farming. Only the highest-income sub-regions show a reasonably benign trend in nitrogen load.

For most aspects that determine nitrogen loading, the direction of change within a given sub-region is the same, although there is a large variation between scenarios. These variations mainly occur for nitrogen inputs that are relatively easy to influence through policy action, and that will show effects in relatively short time frames. For instance, the level of sewage treatment in a *Markets First* and a *Security First* world would, in many places, not keep up with urbanisation and sanitation coverage, thus giving sizeable or large increases in terms of nitrogen loading of coastal ecosystems; while sizeable decreases are expected for *Policy First* and *Sustainability First* situations. Clearly, policy action and changes in values in the latter two futures exert a direct positive effect in a relatively short time. On the other hand, population-related changes include slow-changing dynamics. Different trends here, important as they are in the long run, will only result in so much change within a 30-year period.

Regional results

Figure 7.2 shows estimates of *current* nitrogen loading for each GEO sub-region, illustrating the considerable differences among and within regions, with values of the nitrogen export index ranging from 0.25 in Western and Central Africa to above 0.8 in West Asia and in North West Pacific and East Asia.

Table 7.2:Potential change in nitrogen loading of coastal ecosystems in 2002-2032

	Change in determinants																				Increase in man-made nitrogen loading				**Current man-made nitrogen loading** as part of total load (man-made plus natural)
	Meat production				Fertilizer use				Deposition from the air				Population; per capita emission				Sanitation, urbanization, waste water treatment								
	MF	PF	SecF	SusF	MF	PF	SecF	SusF	MF	PF	SecF	SusF	MF	PF	SecF	SusF	MF	PF	SecF	SusF	MF	PF	SecF	SusF	
North America	+	+	+	o	+	+	+	+	+++	+	+	o	+	+	o	+	o	o	o	o	**M**	**S**	**S**	**S**	**0.5**
Meso-America and the Caribbean	++	++	+	++	++	+++	+	+	+	+	+	o	+++	+++	+++	+++	+++	+	+++	o	**L**	**M**	**L**	**S**	**0.6**
South America	+++	+++	+	++	++	+++	+	+	++	++	++	+	++	++	+++	+++	++	--	++	--	**XL**	**L**	**L**	**M**	**0.3**
Northern Africa	++	+++	++	+++	+	++	+	++	+++	+++	+++	++	+++	+++	+++	+++	++	--	++	--	**XL**	**L**	**XL**	**L**	**0.6**
Western and Central Africa	+	+	o	+	o	o	o	o	+	+	o	o	+++	+++	+++	+++	+++	+	+++	o	**L**	**M**	**M**	**S**	**0.3**
Eastern Africa and Indian Ocean Islands	+	+	o	+	o	o	o	o	o	o	o	o	+++	+++	+++	+++	+++	+	+++	o	**M**	**M**	**M**	**S**	**0.6**
Southern Africa	+	+	+	++	+	++	+	++	+++	+++	+++	++	+++	++	+++	+++	++	--	+++	--	**L**	**M**	**L**	**L**	**0.4**
Western Europe	o	o	o	o	o	-	o	-	-	-	-	--	o	o	o	o	o	o	o	o	**o**	***-S***	**o**	***-S***	**0.7**
Central Europe (without Turkey)	++	++	o	++	++	++	+	++	+	+	+	-	++	++	+	+	--	--	-	--	**M**	**M**	**S**	**o**	**0.7**
Eastern Europe and Central Asia	++	++	o	++	+++	+++	++	++	+	o	o	-	+	+	+	+	o	-	++	--	**M**	**M**	**S**	**o**	**0.5**
West Asia (with Iran and Turkey) revised	++	++	+	+	++	++	+	+	++	++	++	-	+++	+++	++	+++	+	--	++	o	**L**	**M**	**L**	**S**	**0.8**
South Asia (without Iran)	+++	+++	+++	+++	++	++	++	++	+++	++	++	o	++	++	++	++	+++	+	+++	+	**XL**	**L**	**XL**	**L**	**0.7**
North West Pacific and East Asia	+++	+++	+	++	+	o	o	-	++	+	++	-	++	++	+++	++	++	o	++	o	**L**	**M**	**L**	**S**	**0.9**
Greater Mekong and Southeast Asia	+++	+++	++	++	+	+	o	+	+	+	+	o	++	++	++	++	+++	+	+++	o	**L**	**L**	**L**	**M**	**0.5**
Australasia and the Pacific	o	o	o	o	o	o	o	o	o	-	o	-	o	o	o	o	o	o	o	o	**o**	**o**	**o**	**o**	**0.4**

legend for determinants
0 small
+/- noticeable increase/decrease in terms of nitrogen loading
++/-- sizeable increase/decrease in terms of nitrogen loading
+++/--- large increase/decrease in terms of nitrogen loading
++++/---- very large increase/decrease in terms of nitrogen loading

legend for combined change in nitrogen loading
-S noticeable decrease
o small increase or decrease
S noticeable increase
M sizeable increase
L large increase
XL very large increase

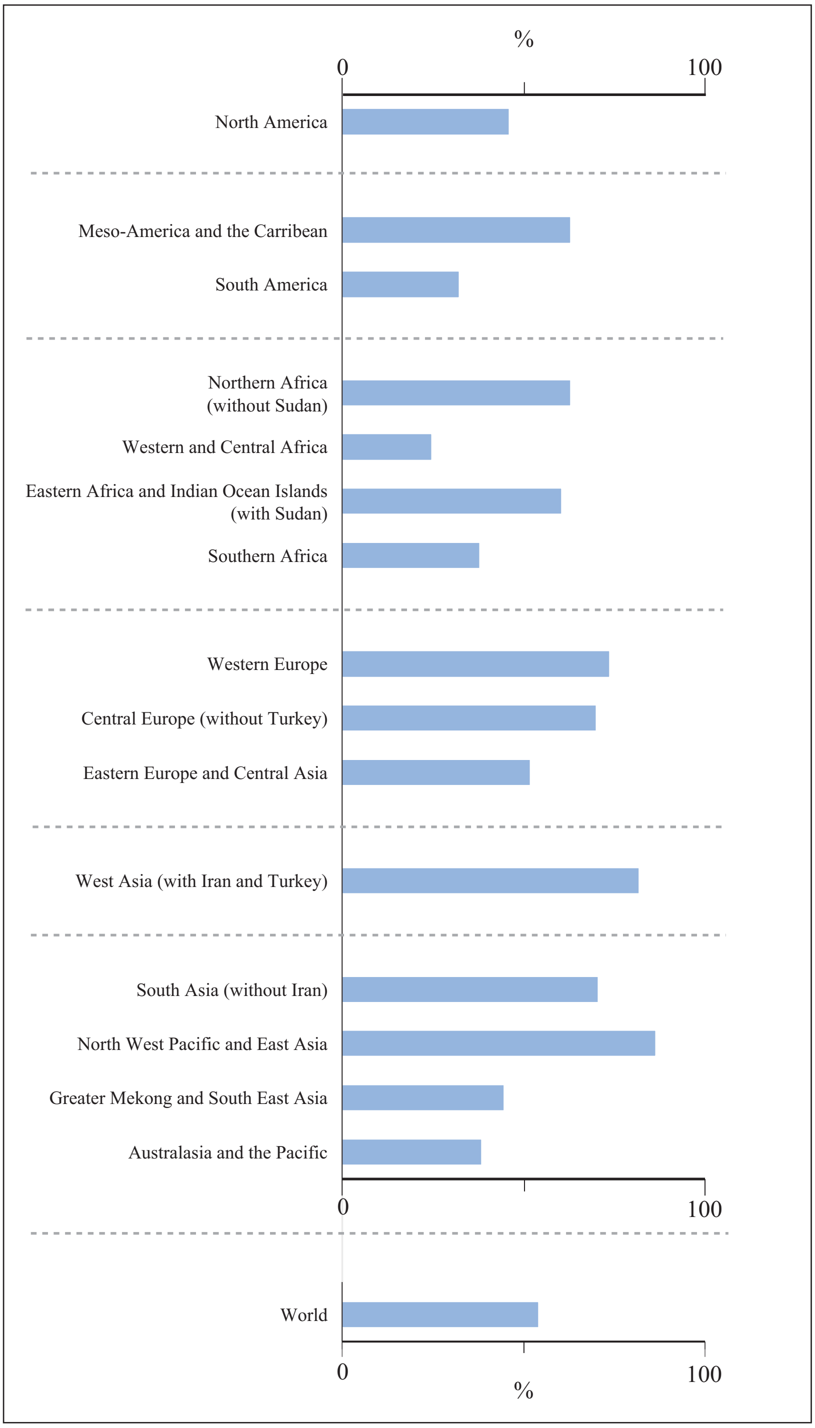


Figure 7.2: Average share of anthropogenic nitrogen in total loading at major river mouths in 2002

Source: RIVM

Over the next 30 years there will be an *increase* in anthropogenic nitrogen loading in almost all sub-regions in every scenario, albeit with clear differences (see Table 7.2). In imagining the impact 30 years from now, one should take into account the prospects for increase or decrease in combination with the current situation. If the prospect for increases is rated as small, and if current nitrogen loading is already large, the future pressure will also be large (compare, for example, South America, Western Europe and West Asia in Table 7.2).

The anthropogenic nitrogen loading in predominantly high-income areas such as Western Europe and Australia, and parts of the Pacific, will typically increase only slightly, or even slightly decrease, in all scenarios. However, in North America, overall increases are rated as being noteworthy or considerable as a result of noticeable increases in all nitrogen sources, partly driven by a larger population increase than in Western Europe.

In predominantly low-income regions, the *current* situation varies among and certainly within regions: Southern, Western and Central Africa show relatively small anthropogenic nitrogen loading; Eastern and Northern Africa, relatively large; South America, small; Meso-America and the Caribbean large. Differences are the result of characteristic patterns in population density, agricultural activity and intensity (Van Drecht and others, 2001).

In most of Asia, Africa and Latin America, as well as in West Asia, the potential *increase* in nitrogen loading is larger than in the high-income regions. Increases are mainly due to increases in population and in per capita emissions, following changes in affluence and hence in diet. More and more intensive agricultural production also contributes to the increases. A particularly important factor for the differences between the scenarios in the next 30 years is that in some sub-regions in some scenarios, sewage systems would be extended to keep up with urbanisation, while the expansion of sewage treatment would not take place or lag behind by a few decades. Co-ordination of sewer pipeline network extension and sewage treatment can make a big difference.

Overall, the combination of heavy current loading with prospects for extreme increase is most worrying. This combination seems to occur in South Asia, North West Pacific & East Asia, and West Asia. In particular, South Asia emerges from the analysis as being a prospective 'candidate' for large increases in nitrogen loading of coastal marine ecosystems, even in the *Sustainability First* world.

Somewhat less extreme, but also not really reassuring, are the ratings for Meso-America and certainly Northern Africa. The Mediterranean (bordering on a mixture of higher and lower income countries) comes under special pressure because of a combination of heavy current loading and trends like urban growth with inadequate wastewater treatment, tourism and intensively farmed land situated close to major river mouths.

Western and Central Europe, and Eastern Africa and the Indian Ocean islands are currently already showing relatively high loading, but future increases are less worrying.

Overall policy implications

Increasing urban populations with increasing sanitation coverage will give rise to more than proportionally increasing nitrogen loading of coastal marine ecosystems. Investments in sewage water treatment can solve much of this problem, but only if it keeps up with urbanisation and sanitation. Well co-ordinated sewage treatment can make a large difference.

Agricultural activities will expand and intensify in most regions, leading to increasing inputs into groundwater and surface waters. Policies in areas with high-density agriculture should aim at improving the efficiency of nitrogen use to prevent leaching losses from soils.

7.4 Energy-related sulphur dioxide emissions

7.4.1 Description

The variable 'energy-related sulphur dioxide emissions' relates to all sulphur dioxide emissions resulting from all energy uses.

Deposition of sulphur dioxide and sulfate is one of the main causes of acidification in soils and water. Acidification may damage terrestrial and aquatic ecosystems if critical levels are exceeded. Sulphur dioxide also has direct impact on vegetation, and causes damage to materials, buildings and monuments. Sulphur dioxide can also be directly toxic to humans, its main action being on the respiratory system. Indirectly, it affects human health as it is converted to sulfate in the form of fine particles. These particles reflect sunlight and therefore have a cooling effect on climate. Due to the relatively short lifetime of the particles, this effect is concentrated in regions where the emissions occur (mainly in the Northern Hemisphere).

7.4.2 Modelling

IMAGE results are presented for all regions in this Technical Report. In the GEO-3 Outlook chapter, however, AIM results were used for Asia and the Pacific (as documented in Chapter 6 of this report; IMAGE and AIM results are compared in Chapter 8).

Regional energy-related emissions of sulphur dioxide are calculated in the 'energy emissions' submodel of IMAGE 2.2 by applying emission factors to energy consumption and production for the nine energy sectors and five energy carriers. The energy sectors are listed below:

- five energy end-use sectors, i.e. industry, transport, residential (households), services (commercial and public) and others (agriculture, etc.)
- energy consumption by electric power generation
- other energy transformation
- fossil fuel production (coal production, flaring of gas associated with oil production, gas transmission, etc.)
- marine bunkers (international shipping).

The energy carriers include solid fuel (coal and coal products), heavy liquid fuels (HLF; diesel, residual fuel oil and crude oil), light liquid fuels (LLF; LPG and gasoline), gas (natural gas and gasworks gas) and modern biofuels (such as ethanol).

The most important energy-related sources of sulphur dioxide in most regions are coal and oil combustion in the electricity generation and industrial sectors. Most of the sulphur contained in fuel is oxidized to sulphur dioxide during fuel combustion.

OECD regions have implemented emission controls for sulphur dioxide in electric utility plants. These are switching from coal to natural gas for power generation, flue de-sulphurisation, construction of new, more energy-efficient power plants, and decreasing the sulphur content in coal. Other energy sectors implemented other sulphur emission reduction controls, such as flue gas desulphurisation in industry and tightening sulphur standards for fuel for road transport.

Future sulphur dioxide emissions under all GEO-3 scenarios are modelled as sulphur-control scenarios with changes in fuel mix (substitution of direct use of coal by other fuels, and lowering fuel sulphur standards), transition to clean coal technologies (Flue Gas Desulphurisation) and other measures. Emission factors for sulphur dioxide from coal combustion depend primarily on the implementation of Flue Gas De-sulphurisation.

The 1995-2010 period assumes full implementation of current national and international emission policies (such as the 1999 UN-ECE Gothenburg Protocol for Europe and the Amendments of the Clean Air Act in the USA), and implementation of various other sulphur control policies for the long term. The timing of convergence of these factors to the final level of OECD regions depends mainly on the income level (*Markets First*), environmental awareness (*Policy First* and *Sustainability First*) and the seriousness of environmental impact (*Security First*).

Sulphur dioxide emissions represent a model output in itself, but are also used as model input in the atmospheric chemistry model of the atmosphere-ocean system (see also section 7.1). The issue here is that sulphur oxides form sulfate aerosols that reflect sunlight and therefore have a cooling effect on climate. Due to their relative short lifetimes, the effect of the aerosols is concentrated in regions where the emissions occur (mainly in the Northern Hemisphere).

7.4.3 Results

Global results

Figure 7.3 shows the trends in energy-related sulphur dioxide emissions featuring sharp divergence among the four GEO-3 scenarios. Despite strong economic growth, and thus more industrial activity, sulphur emissions in lower-income regions continue to decrease under the *Sustainability First* scenario at the same speed as over the last decade due to two important factors. One factor is the

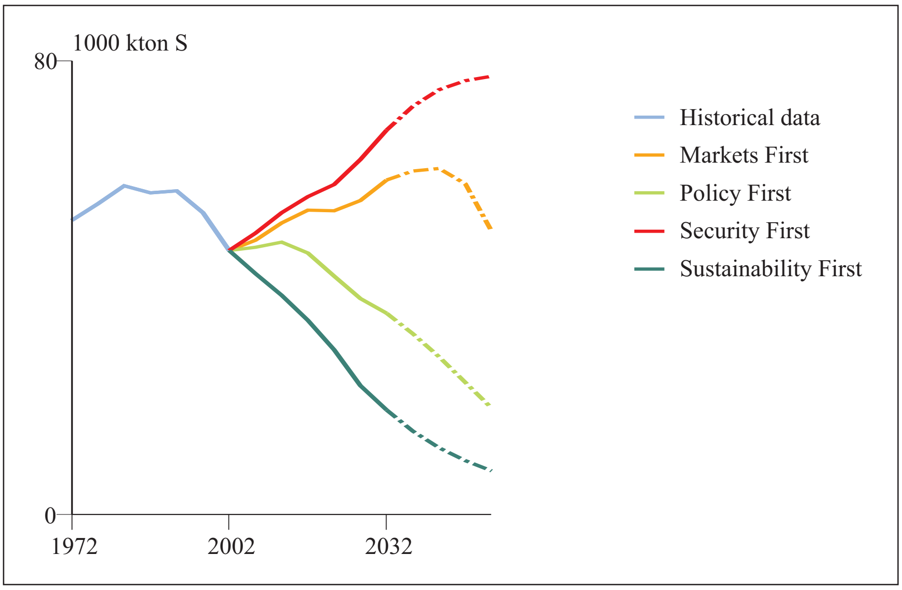


Figure 7.3 Global energy-related emissions of sulphur dioxide
Source: RIVM

strict sulphur policies all over the world. Second, and at least as important, is that systematic changes in the energy system – bending strongly towards energy efficiency, the use of sustainable energy sources and, in the shorter term, fuels switches from coal to natural gas – also strongly decrease sulphur emissions. In this way, the *Sustainability First* scenario is shown to be an important example of the synergies that can be established between changes in the energy system to decrease greenhouse gas emissions and decrease regional and local air pollution.

The situation under *Sustainability First* clearly contrasts with *Security First*, where sulphur emissions start to increase sharply due to weak environmental policies and increasing use of coal in both higher and lower income regions. The use of coal in many regions is partly a result of the fact that regionalisation assumed in the *Security First* scenario forces regions to use their domestic energy sources – which in some regions is mainly coal. The sharp increase in sulphur emissions worldwide seems to signal a remarkable trend breach over the last decade with its clear decreases. But in fact, the global historical trends are introduced by a time-specific combination of factors, including the economic decline in Central Europe and the Former Soviet Union, the emission decreases in high-income regions and, at the same time, a strong growth in sulphur emissions in low-income regions.

Developments under *Markets First* are only slightly less dramatic than under *Security First*. Continuing decreases in sulphur emissions in higher income regions are more than nullified by increasing emissions in lower income regions. Severe environmental deterioration will nevertheless stimulate these countries to apply stricter environmental policies. Eventually, by 2040, this results in a bending of the trend towards overall global decrease in sulphur emissions.

The situation under *Policy First* resembles *Sustainability First*, though sulphur dioxide decrease only becomes visible around 2010. Again, the larger share of the emission decreases are driven by systematic changes within the energy system. Similar to a *Markets First* future, continuing decrease in sulphur dioxide emissions in higher income regions is initially nullified by increasing emissions in lower income regions. Around 2010 the slow overall increase quickly changes to a clear decrease thanks to a gradual replacement of coal by gas and in the longer term by renewable energy.

Decreases in sulphur dioxide emissions are a classic example of pollution abatement that closely follows policy measures. Measures, such as fuel switching or large-scale desulphurisation, are typically large-scale and have an all-or-nothing character. Sharp decreases in sulphur emissions are coupled with a strong cooling effect (see section 7.6). Careful coordination with climate policies will therefore be needed, especially in the coming decades.

Regional results

The bar charts on absolute emissions and changes in 2032 relative to 2002 show interesting differences between the sub-regions (see Figure 7.4). Some of the largest emitters, the OECD regions in particular, will move to the group of smaller emitters over the coming decades, changing positions with present medium to large contributors in Latin America, the Caribbean and Asia, and the Pacific. Only North West Pacific and East Asia will remain top emitting sub-regions, though large decreases are achieved under *Policy First* and *Sustainability First* conditions. Responsible mechanisms behind those trends were already described for the global level in the previous section. Each region has its own explanation, however.

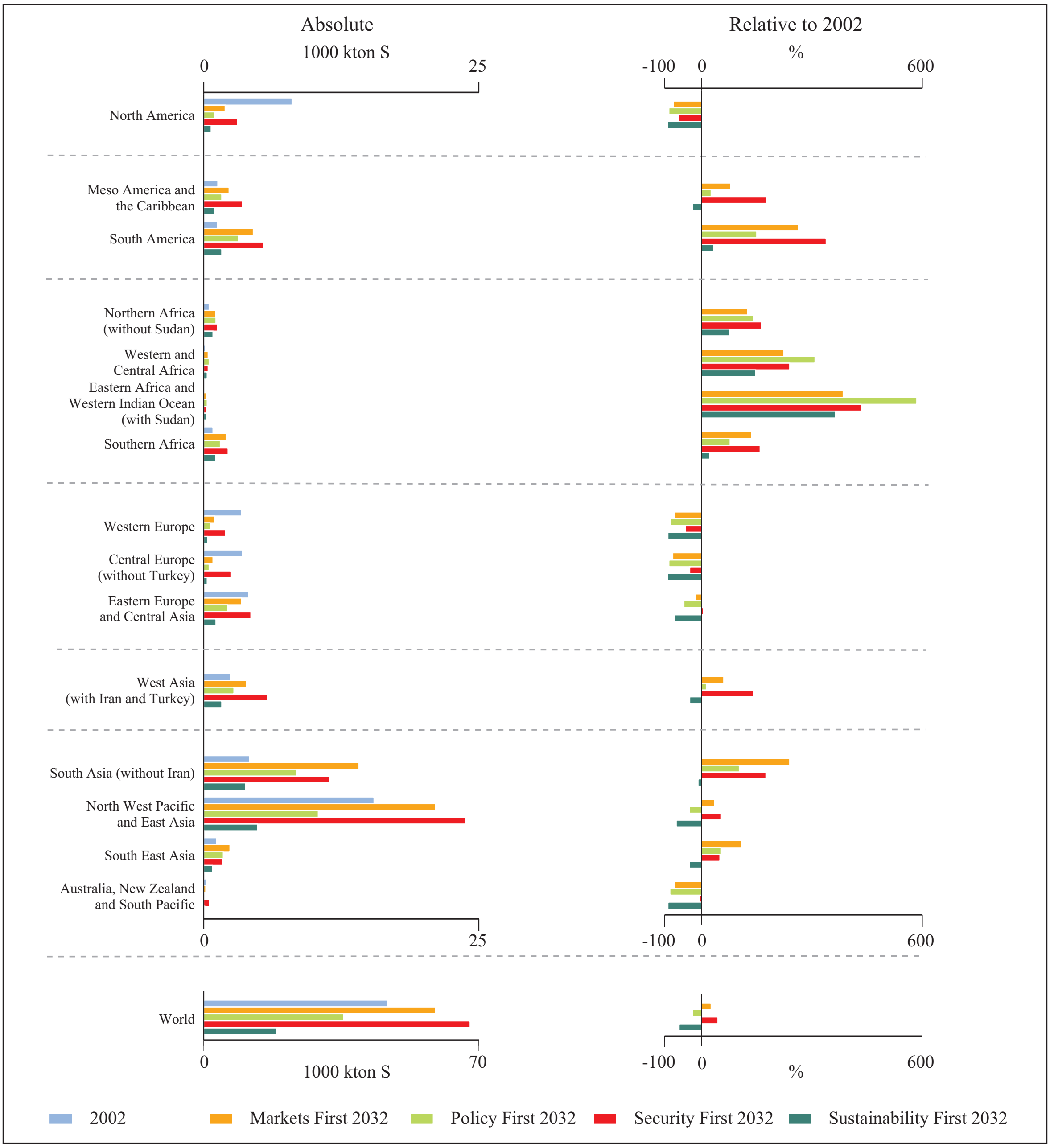


Figure 7.4 Energy-related emissions of sulphur dioxide
Source: RIVM

North America currently belongs to the largest emitters of sulphur dioxide (certainly per capita), but this situation will change drastically for all scenarios over the coming decades due to continued implementation of strict sulphur policies as found in the amendments of the Clean Air Act in the USA.

Similar to North America, emissions in Europe and Central Asia will continue to decrease sharply. Current national and international emission policies, under the umbrella of the 1999 UNECE Gothenburg Protocol for Europe, aim at considerable reductions by 2010. These trends will be continued after 2010 in all scenarios, although less intense under *Security First* than *Sustainability First*. The downward trend in emissions under *Security First* is even nullified in the European region due to increased use of coal.

The increased emission of energy-related sulphur dioxide by 2032 in Latin America and the Caribbean is the combined result of increasing population, growth of production and consumption. This leads to more than a doubling of emissions by 2032 in a *Security First* world, still showing remarkable increases under *Markets First* and *Policy First*, but with less dramatic consequences under *Sustainability First*. Replacement of fossil fuels by renewables (sun and wind) in the *Policy First* scenario is supplemented in *Sustainability First* with other measures. In Meso-America and the Caribbean this even results in a decrease by 2032 compared to the current emission levels.

Emissions of sulphur dioxide are currently very small in Africa, and will remain so in the coming decades, though they do increase significantly percentagewise. Similar mechanisms are behind the changes in Africa, and Latin America and the Caribbean.

Emissions in West Asia and Asia and the Pacific are *currently* moderately large, with the exception of the North West Pacific and East Asia sub-region (very large), and the Australia, New Zealand and South Pacific sub-region (very small; with future trends similar to those in North America and Europe). The *increases* anticipated in South Asia (without Iran) and North West Pacific and East Asia are alarming. They play a dominant role in the global increase as foreseen in the *Security First* and *Markets First* scenarios. Emissions in all sub-regions in West Asia and Asia and the Pacific (with exception of Australia, New Zealand and South Pacific) will continue to grow as the combined result of economic growth and increasing population.

Overall policy implications

The only way to turn around the alarming sulphur dioxide emission trends in Asia and the Pacific, and to a lesser degree in Latin America and the Caribbean, is by introducing stringent environmental policies. In three of the scenarios, relatively strict policies are assumed, that is in *Markets First* and *Policy First* (in particular, driven by considerations on human health protection), as well as in *Sustainability First*. However, in the *Markets First* scenarios the impacts of these policies are completely offset by an increase of activities – which results in rising sulphur emissions. In *Policy First* and to an even larger degree in *Sustainability First*, the sulphur policies are combined with systematic changes within the energy system. Only in *Sustainability First* does this result in actual decreasing sulphur emission in Asia and the Pacific.

The *Sustainability First* scenario is an important example of the synergies that arise between changes in the energy system to address greenhouse gas emissions and decrease of regional and local air pollution.

Sulphur dioxide is converted to sulfate particles that reflect sunlight and therefore have a cooling effect on climate. Due to the relatively short lifetime of the particles, this effect is concentrated in regions where the emissions occur (mainly in the Northern Hemisphere). Thus, decreasing the emission of sulphur oxides will necessarily ‘unveil’ a certain level of climate change that thus far has been counteracted by sulfate aerosol. Careful co-ordination with climate policies will therefore be needed, especially in the coming decades.

7.5 Carbon dioxide emissions

7.5.1 Description

Climate change is widely recognized as a serious potential threat to the world's environment and its inhabitants. The potential consequences of further increases in global temperature include rising sea levels, changing patterns of precipitation, floods and droughts, changes in biota and food productivity, and increase in infectious diseases. Although the greenhouse effect, the major process behind climate change, is a natural phenomenon, atmospheric concentrations of anthropogenic greenhouse gases have grown over the past century, and an increase (in historical terms) in global mean temperatures has been observed (see section 7.6). There is new and stronger evidence that most of the warming observed over the past 50 years is attributable to human activities (IPCC, 2001). This exercise considers only carbon dioxide, the biggest contributor to global warming.

The variable 'carbon dioxide emissions' covers emissions from land use, industrial production and energy use. Industrial sources include emissions from non-energy use of fossil fuels (mainly feedstock) and industrial activities such as cement production. Land-use sources of carbon dioxide include burning forest biomass (after deforestation) and fuelwood; releases during waste treatment after disposal of such consumer goods as paper, furniture and building materials; and vegetation restoring to its potential natural state through growth. This last source arises after forest clearing or after agricultural land is abandoned. In the initial stage of re-growth, carbon is released due to soil respiration, but is followed by a net uptake of carbon, expressed as a negative emission value. The majority of energy-related carbon dioxide emissions, however, arise from the combustion of fossil fuels for energy production and consumption, including emissions from gas flaring.

7.5.2 Modelling

In this report IMAGE results for carbon dioxide emissions are presented for all GEO regions, while in the GEO-3 Outlook chapter AIM results were used for Asia and the Pacific, as documented in Chapter 6 of this report. IMAGE and AIM results are compared and discussed in Chapter 8.

Energy-related carbon dioxide emissions are calculated, similarly to energy-related sulphur dioxide emissions (see section 7.4.2), i.e. by multiplying energy use by emission factors. Again, emission factors for 1995 are taken from the EDGAR 3.0 database (Olivier and others, 2001). Net carbon emissions from biofuel combustion (both traditional and modern) going into the atmosphere are assumed to be zero. Note that the demand for biofuels is used as input to the Land Cover Model of IMAGE, where it influences the need for agricultural land and subsequent land-use emissions due to deforestation.

For carbon dioxide emissions from industry, the two sources included are cement production and non-energetic use of fossil fuels (feedstock). The historical (1970-1995) activity level of these industrial processes is based on data from the literature. For the 1995-2100 period, the cement production is related to population growth, and the level of other industrial activities to energy end-use consumption in industry, as simulated by the TIMER model (see Figure 7.1). Final emissions are calculated by applying the same methods as used for energy-related emissions, except for chemical feedstock emissions, for which the atmospheric release fraction is taken into account.

In 1995, about 25 per cent of the global carbon dioxide emissions from land use was released through wood and biomass burning during deforestation or shortly thereafter as fuelwood. Carbon dioxide emissions from wood products (the so-called timber pools) are divided into two categories:

- pulpwood and particles (with an average lifetime of 10 years);
- saw logs, veneer and other industrial round wood (with an average lifetime of 100 years).

Biofuel demand is estimated using the energy demand module in TIMER, whereas food, feed and timber demand is calculated in the agricultural economy model. Population and economic growth are used as input for both, applying scenario-dependent assumptions.

7.5.3 Results

Global results

Figure 7.5 clearly illustrates the dominance of energy-related carbon dioxide emissions over carbon dioxide emissions from industrial production and land use. The current share of energy-related emissions in total emissions is about 75%. The other two sources become even less important over time in all scenarios. This is due to a steady increase of energy consumption and accompanying carbon dioxide emissions (in lower income regions, in particular). Future emissions from industrial production and land use remain roughly the same in most scenarios. Only in the world of *Sustainability First* do agricultural efficiency improvements, decline of population and reforestation rapidly decrease the contribution from land use to almost zero in the third decade of this century. The decrease in land-use emissions in *Markets First* is mainly due to the decline in the population.

More important is the shift between 2020 and 2030 under the *Sustainability First* scenario: global energy-related carbon dioxide emissions change course from increasing to decreasing. This is also visible in the *Policy First* scenario, although it is not as strong and starts later. This shift marks the decoupling of carbon dioxide emissions and energy consumption. It results from efficiency improvements and replacement of coal by renewables, nuclear energy and biofuels; changes that are stimulated by strong climate policies under *Sustainability First* and *Policy First* scenarios. Climate policies and sustainability values do not play a major role in the worlds of *Markets First* and *Security First*. Here, energy consumption and accompanying carbon dioxide emissions grow considerably, leading to a strong divergence of emission trends between the four scenarios by 2032, further reinforced in the succeeding period.

Compared to the emissions related to energy consumption, the share of carbon dioxide emissions from land use is small and is anticipated to decrease over time. The role of decreasing land-use related emissions in achieving the Kyoto targets will thus be limited. Forests, agricultural land and other terrestrial systems, nevertheless, offer a significant mitigation potential through carbon sequestration. In addition, these systems may allow time for other options to be further developed and implemented.

Regional results

The divergence described above is also visible at regional and sub-regional level (see energy-related carbon dioxide emissions in Figure 7.6). Emissions in the *Markets First* and *Security First* scenario strongly increase in most regions, compared to the other two scenarios. Under the *Sustainability First* scenario emissions from higher income regions are the same or even considerably smaller in 2032 than in 2002. Emissions in lower income regions are typically larger in 2032 than in 2002 for

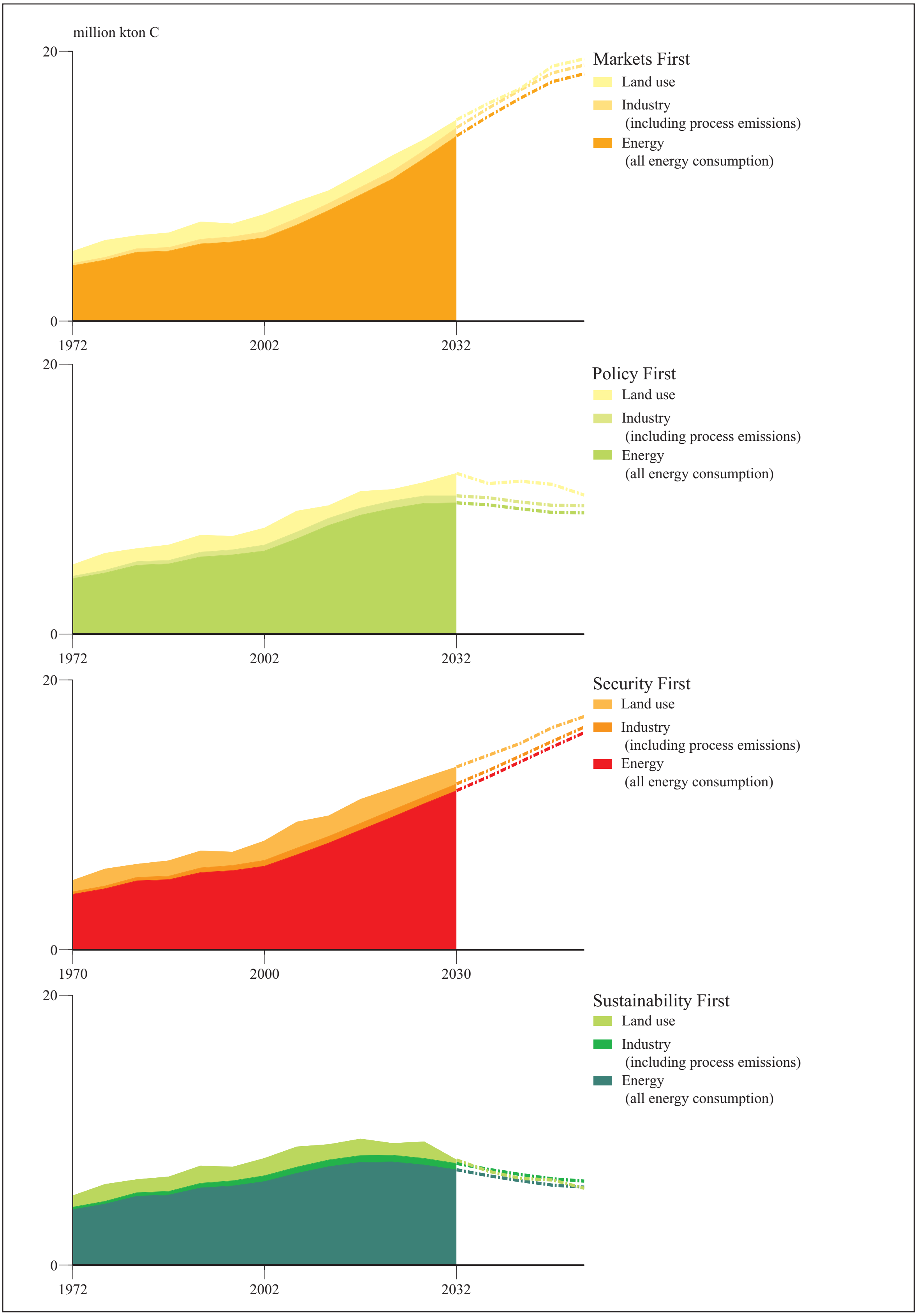


Figure 7.5: Global carbon dioxide emissions from all sources

Source: RIVM

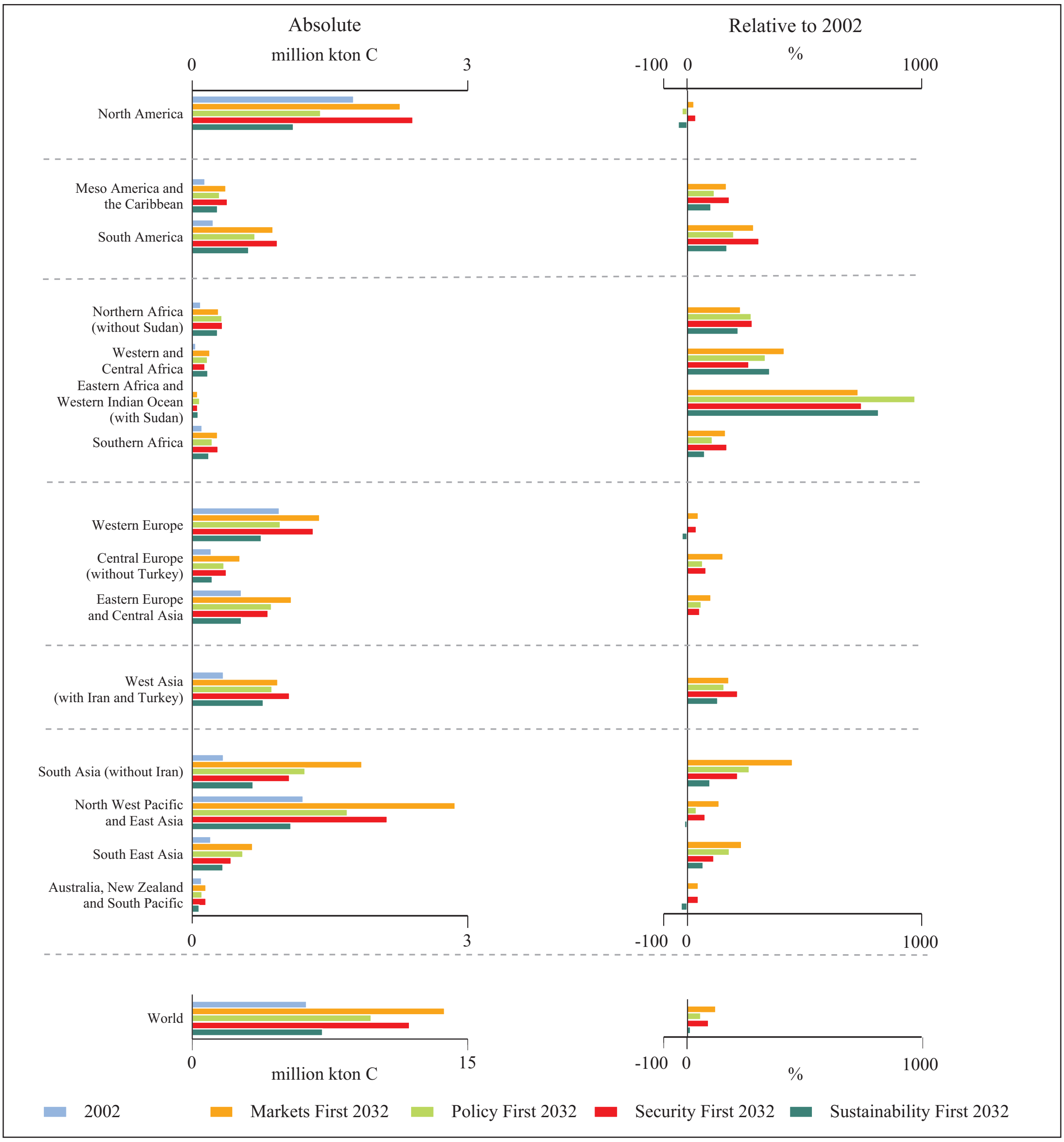


Figure 7.6: Energy-related emissions of carbon dioxide

Source: RIVM

Note: The energy-related emissions originate from all energy consumption, including the energy sector itself, but also transport and domestic heating, for example.

all scenarios, a pattern linked to the growing energy consumption resulting from growing economic activity and an increasing population.

The 2032 emissions of energy-related carbon dioxide in North America in the *Policy First* and *Sustainability First* scenarios will be well below 2002 levels. However, realisation of these trends requires a clear re-orientation of current practice, since current policies are not effective enough with regard to sustainability and climate change.

Energy-related carbon dioxide emissions in Europe and Central Asia increase under most scenarios, except in the *Sustainability First* world, where a slight decrease occurs for Western Europe. The shorter term target of the Kyoto Protocol is met in *Policy First* and *Sustainability First* worlds, but not in our *Markets First* or *Security First* scenarios.

As a result of both population and economic growth, energy-related emissions of carbon dioxide will show a sharp increase over the coming decades in all scenarios in Latin America and the Caribbean, and in Africa. In Eastern Africa and the Western Indian Ocean islands the increase is even more than 700 per cent. Dramatic as this figure may seem, such extremes are merely a consequence of the current emissions in these sub-regions being small. Per capita emission levels will remain lower than of those in high-income regions. They will account, in absolute terms, for most of the considerable global increase of carbon dioxide emissions by 2032.

Developments in Asia and the Pacific very much reflect the situation as described for the sub-regions above. South Asia and South East Asia show more resemblence to the lower income regions. The other sub-regions compare more to the trends in the higher income regions.

Emissions in West Asia, including Iran and Turkey, also will increase over the coming decades in all scenarios due to growth in population and economic activity.

Overall policy implications

The potential for increase of greenhouse gas emissions in the next 30 years is huge. Trends in carbon dioxide emissions in this period will strongly determine climate change in the rest of the 21st century, as explained in section 7.6.

In this light, it is important to note that the scenarios feature widely different yet conceivable emission trajectories. The two scenarios that assume deliberate social and environmental policies (*Policy First* and *Sustainability First*) lead to a stabilization of global emissions, or even a decreasing trend, respectively, by the end of the scenario period. In contrast, the other scenarios (*Markets First* and *Security First*) feature continous increases in emissions. The latter holds for the world as a whole and in particular for the regions that carry most weight in terms of future emissions: North America; South Asia; and North West Pacific and East Asia.

In other words, there is large scope for policy. As more than 80 per cent of emissions comes from the energy system, climate policy can only be effective if it leads to fundamental changes in the production and consumption of energy.

In addition, strengthening the capacity of ecosystems to sequester carbon – by aforestation and reforestation – could modestly contribute to a net decrease in global carbon emissions.

7.6 Carbon dioxide concentration and climate change

7.6.1 Description

(see also section 7.5.1)

The variable ‘atmospheric concentrations of carbon dioxide’ presents the global carbon dioxide concentration in the atmosphere as the net balance between carbon dioxide emissions from fossil fuel combustion, industrial production, deforestation and carbon dioxide uptake by mature vegetation, vegetation after re-growth and oceans.

Carbon dioxide is the major greenhouse gas contributing to change in global average temperature, accounting for roughly 80 per cent of the warming effect. The variable ‘change in average temperature’ represents the rate at which temperature is changing. Apart from absolute temperature and temperature change, the rate of temperature change is important since sensitive ecosystems may not be able to adapt at high rates of change. Research has shown that extensive damage to ecosystems is probable at rates greater than 0.1 degree Celsius per 10 years (Vellinga and Swart, 1991). Results are also presented for changes in annual total precipitation.

7.6.2 Modelling

The atmospheric carbon dioxide concentration is determined by the carbon fluxes from earth to atmosphere and vice versa (see Figure 7.7). The largest fluxes are natural; these used to be in equilibrium in pre-industrial times but are now disturbed by human combustion of fossil fuels for energy use, and industrial and deforestation activities. The atmospheric concentration of carbon dioxide is increasing as a consequence, causing a larger uptake of carbon by oceans and terrestrial vegetation (usually referred to as carbon dioxide fertilization). Table 7.3 compares reported values for the 1980s from IPCC (2001) and corresponding IMAGE 2.2 values.

Carbon fluxes represented in IMAGE 2.2 include atmospheric carbon dioxide emissions from energy use, and production and industrial processes, as well as global fluxes between biosphere,

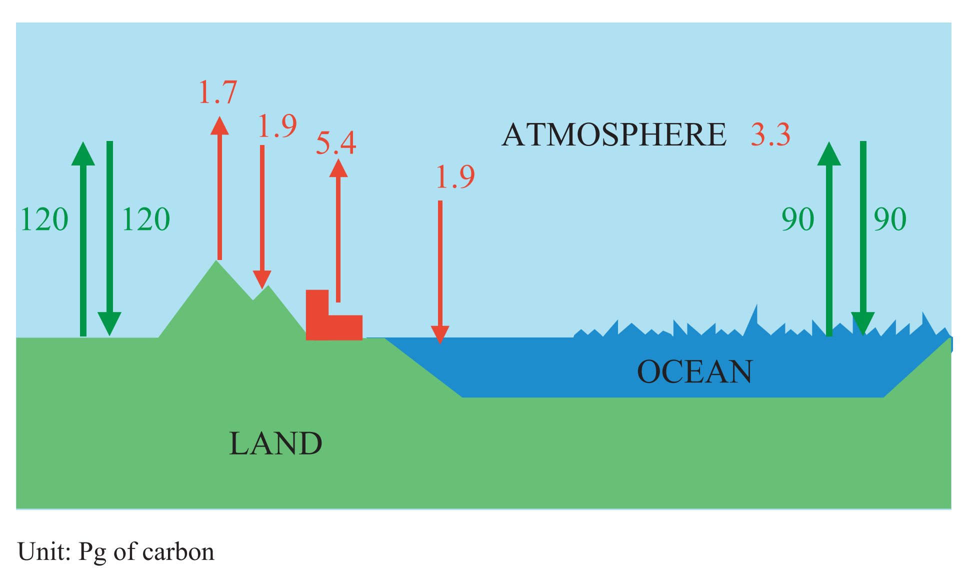


Figure 7.7: The most important global carbon fluxes

Unit: Pg carbon per year

Note: These numbers are taken from IPCC (2001) and account for annual fluxes averaged over the 1980s (Eickhout et al, 2002). The natural, and largest, fluxes are in equilibrium.

Table 7.3: Global carbon fluxes in the 1980s as reported by IPCC and calculated with IMAGE 2.2.

	IPCC	IMAGE 2.2
	Pg of carbon per year	
Atmospheric increase	3.3 ± 0.1	3.5
Emissions (fossil fuel, cement)	5.4 ± 0.3	5.7
Ocean-atmosphere flux	-1.9 ± 0.6	-1.9
Land-atmosphere flux	-0.2 ± 0.7	-0.3
comprising:		
Land-use change[1)]	1.7 (0.6 to 2.5)	1.1
Residual terrestrial sink[2)]	-1.9 (-3.8 to 0.3)	-1.4

Sources: RIVM (Eickhout and others, 2002); data sources: IPCC (IPCC, 2001) and RIVM (IMAGE team, 2001a and b)

1. 'Land-use change' in IMAGE 2.2 is determined by the emissions caused by deforestation for agricultural expansion and the timber industry, and by the use of traditional biomass as a fuel and emissions due to decay of timber products (short-lived, with lifetimes up to 10 years - e.g. paper and pulpwood - and long-lived, with lifetimes up to 100 years - e.g. industrial round wood for construction). The uptake by re-growth of forests after timber extraction or abandonment of agricultural land is subtracted from these land-use emissions to determine the carbon dioxide land-use emissions caused by anthropogenic activities (see also section 7.9 on the Natural Capital Index).
2. The terrestrial sink calculated by IMAGE 2.2 as mentioned in this table is the uptake by natural, full-grown vegetation. Hence, this uptake is mostly determined by the fertilization effect.

Note: One Pg equals one million kilotons

oceans and atmosphere. The atmospheric increase or decrease is the sum of all carbon fluxes. Carbon dioxide emissions from energy and industry are the sum of emissions from energy use and industrial production (mainly cement), as computed by the TIMER emission model (see section 7.1 and Figure 7.1).

The land-use related carbon fluxes caused by anthropogenic activities are calculated with the terrestrial carbon model of IMAGE and include:

- emissions caused by deforestation for agricultural expansion and the timber industry
- emissions caused by the use of traditional biomass as a fuel
- emissions caused by decay of timber products (short-lived with lifetimes up to 10 years, for example, paper and pulpwood and long-lived with lifetimes up to 100 years, for example, industrial roundwood for construction)
- uptake by re-growth of forests after timber extraction or abandonment of agricultural land (Net Ecosystem Production of re-growing vegetation).

Fluxes from natural, full-grown vegetation are mainly driven by carbon dioxide fertilization: increasing atmospheric carbon dioxide concentration results in a net uptake by vegetation. This natural flux is calculated with the terrestrial carbon model as well. Carbon uptake by oceans is the sum of the oceanic uptake of carbon dioxide by dissolution and biological uptake by phytoplankton. These processes are simulated with the ocean carbon model.

Net carbon fluxes are distributed equally over the troposphere (the lowest meteorological layer in the atmosphere), resulting in global concentration levels. These are expressed in parts per million by volume (ppmv). In IMAGE 2.2 the carbon dioxide concentration is calculated as 0.4688 ppmv carbon dioxide per petagram carbon net emitted.

Climate change is modelled in IMAGE 2.2 with the Upwelling-Diffusion Climate Model. It represents the core model of the Atmospheric Ocean System and converts concentrations of different greenhouse gases and sulphur dioxide emissions into radiative forcing and subsequent temperature changes of the global mean surface and the oceans. It is based on the MAGICC model of the Climate Research Unit (CRU) (Hulme and others, 2000). The MAGICC model is the most widely used simple climate model within the IPCC (IPCC, 2001). More details on MAGICC can be found in Raper and others (1996) and Hulme and others (2000). The implementation of MAGICC in IMAGE 2.2 and the calculation of the radiative forcing is described by Eickhout and others (2002).

Climate-change *patterns* are not simulated explicitly in IMAGE. Instead, the global mean temperature increase as calculated by IMAGE is subsequently linked with the climate patterns generated by a general circulation model (GCM) for the atmosphere and oceans, and combined with observed climate means over the 1961-1990 period (New and others, 1999). Linking takes place using the standardized IPCC pattern-scaling approach (Carter and others, 1994) and additional pattern-scaling for the climate response to sulfate aerosols forcing (Schlesinger and others, 2000). GCMs are currently the best tools available for simulating the physical determining global climate dynamics and regional climate patterns. Most GCMs agree on the global patterns of climate change:

- temperature increases above land are more rapid than above the oceans
- temperature of land at high latitudes increases more sharply than at low latitudes
- temperature of land in winter increases more sharply than in summer
- total precipitation increases with increasing temperature
- maritime regions generally get wetter
- continental regions could become dryer.

Regionally, however, there are large differences between the different GCMs, especially in precipitation-change patterns. When regional-specific climate results are shown, four different GCM patterns are used to indicate the differences in the possible regional climate results. Differences in the runs indicate some of the uncertainty caused by regional variation in climate-change patterns (not the global mean).

We analysed the GEO-3 scenarios for four different GCM runs from the IPCC Data Centre:

- ECHAM4 of the Deutsches Klimarechenzentrum DKRZ in Germany
- CGCM1 of the Canadian Centre for Climate Modelling and Analysis in Canada
- GFDL-LR15-a of the Geophysical Fluid Dynamics Laboratory in the USA
- HADCM2 of the Hadley Centre for Climate Prediction and Research in the UK

To take the uncertainties in the forcing by sulfate aerosols into account, IMAGE 2.2 uses results from a GCM from the University of Illinois at Urbana-Champaign (UIUC), where specific analyses are performed to take the non-linear effects of sulfate aerosols into account (Schlesinger and others, 2000). The influence of sulfate aerosols depends very much on where they are emitted. Consequently, reductions in sulphur emissions in Asia can have a different impact on grid-specific climate results than reductions in sulphur emissions in Europe. Therefore in our approach, we superimpose specific GCM sulfate results on the greenhouse-gas-only results.

In contrast to the other regions, projections for temperature changes in the Polar regions have already been presented in the GEO-3 main report since these changes are so large. These projections, too, were based on results from four different Global Circulation Models in combination with IMAGE 2.2. For each of the GCMs, the spatially differentiated pattern of temperature change (1 per cent per annum growth in equivalent greenhouse gas concentration from 1990 onwards) for a reference scenario was taken north of 66° north and south of 66° south latitude. This pattern was then scaled on the basis of global average temperature changes for each of the scenarios, as calculated by IMAGE 2.2. Finally, the temperature change for the Arctic and Antarctic was calculated. The GCM results, taken from the IPCC Data Distribution Centre for Climate Change and Related Scenarios for Impact Assessment (IPCC-DCC, 1999) are used for the Polar regions. Results come from HadCM2, ECHAM4, CSIRO Mk2 and CGCCM1.

7.6.3 Results

Global results

Figure 7.8 shows the development of the atmospheric concentration of carbon dioxide over time for the four GEO-3 futures. The trajectories, which are close to each other, start to diverge only by 2020. This delay is the result of the long residence time of carbon dioxide. The concentration of this greenhouse gas in the coming decades arises from the legacy of the emissions in past decades. The build-up of concentrations of greenhouse gases follows the trends in emissions, but with considerable delay between emissions and the resulting concentrations. Although emissions under *Sustainability First* and *Policy First* show a shift from increase to decrease around 2030, this only results in slowing down the build-up of atmospheric carbon dioxide in the *Sustainability First* world after 2050.

Only the *Sustainability First* scenario is situated in a trajectory for stabilization of the carbon dioxide concentration at 450 ppmv. The 450 ppmv stabilization level is associated with a global temperature

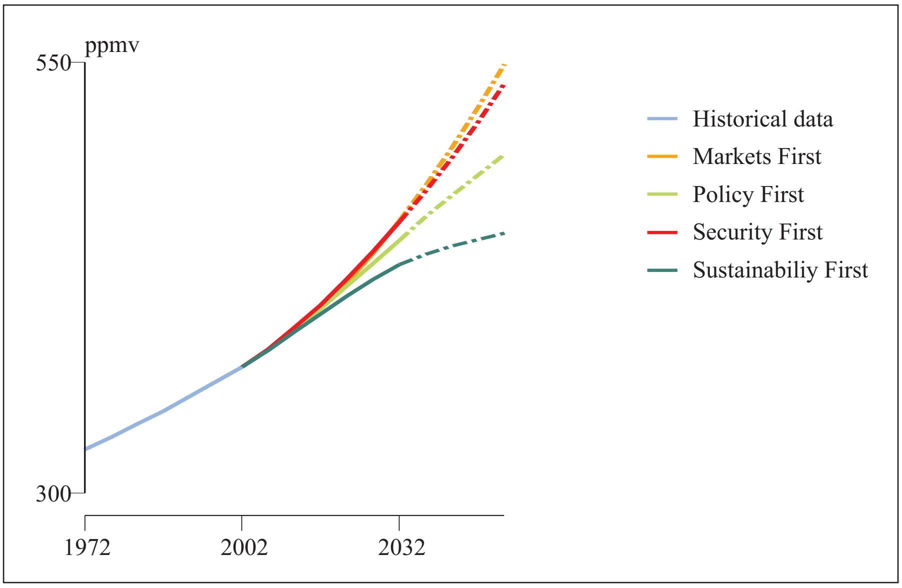


Figure 7.8: Global atmospheric concentration of carbon dioxide
Source: RIVM

change that is anticipated to carry a relatively small risk for effects from climate change, i.e. 2 degrees Celsius above pre-industrial levels in 2100. Total greenhouse gas concentration, including methane and nitrous oxide, follows a similar trajectory to carbon dioxide but is approximately 100 ppmv higher (expressed in carbon dioxide equivalents).

Largely due to emissions in past decades, but also given the maximal feasible emission reduction options for the coming years, atmospheric carbon dioxide will continue to increase and temperature change cannot be avoided. Figure 7.9 shows that this change will exceed 0.1 degrees Celsius per 10 years. In *Sustainability First* the rate at which the temperature changes over a 10-year period levels off and actually slows down before 2032. However, even in 2050 it is still well above the 0.1 degrees Celsius per 10 years. The high rates of change for *Policy First* and *Sustainability First* during the first quarter of the century correspond with the rapid abatement of emissions of sulphur dioxide under these scenarios.

These reductions have partly already been set down in several international agreements (such as the 1999 UN-ECE Gothenburg Protocol for Europe and the Amendments of the Clean Air Act in the USA); however, in the case of *Sustainability First* and *Policy First* they are also a result of changes in the energy system corresponding to the climate policies assumed. Sulfate aerosols reflect sunlight and accelerate cloud formation and therefore have an assumed cooling effect on climate. Due to their relative short lifetime, the effect is concentrated in regions where the emissions occur (mainly in the Northern Hemisphere). The short-term upward pressure on the rate of climate change (by reducing the cooling effect of aerosols) from abatement of sulphur dioxides might be less if climate and acidification policies were carefully coordinated.

Regional results

Regionally differentiated estimates for climate impacts of the scenarios were not available for the GEO-3 main report except for the Polar regions. However, after GEO-3, such estimates were prepared for this Technical Report in view of its deeper consideration of regional significance.

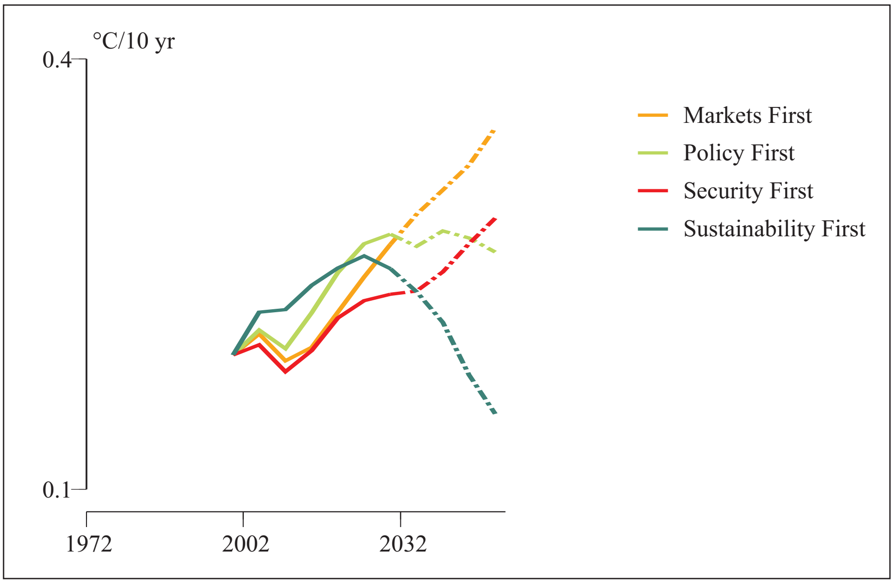


Figure 7.9: Global rate of temperature change

Source: RIVM

Before discussing the findings on change in average annual temperature, we should note that by averaging the temperature increase per region, we have masked significant signals that might appear on a more detailed scale. For example, Western and Eastern Europe will experience clearly different trends in North (stronger warming and wetter) and South (often drier). The following pattern emerges (Fig 7.10):

No cooling is projected for any region in any scenario.

Canada, Greenland and Alaska, as well as Eastern Europe will show warming according to all climate patterns applying to the scenarios. The largest warming is projected in *Markets First*: up to more than 2.5 degrees Celsius increases of annual average temperature by 2052. Even *Sustainability First* features an average annual warming of over 2 degrees Celsius over this period. But the global rate of change is, at least, levelling off for the latter scenario (see Fig 7.9).

For other regions, less consistent messages are obtained by applying the scenarios to different climate patterns. But clearly, the *Sustainability First* scenario delivers annual average temperature

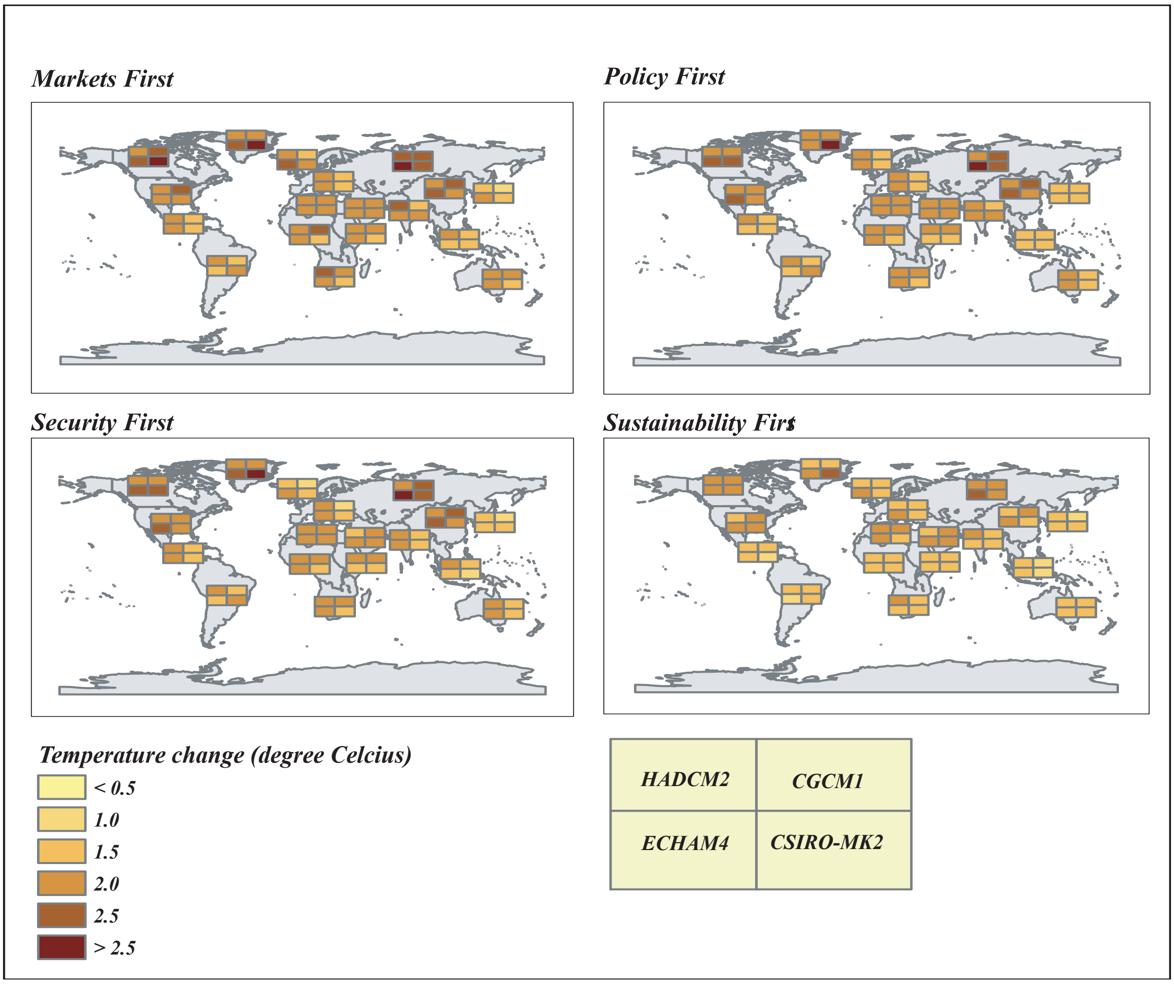


Figure 7.10: Change in regional annual temperatures 2002 – 2052, based on four global circulation models.

Source: RIVM, based on four global circulation models. See text for details increases of approximately 1 degree Celsius by 2052 in Latin America and the Carribean, Africa, South East Asia, East Asia and Australia & New Zealand. In contrast, warming in these regions or sub-regions could be doubled in the *Markets First* scenario. Differences between *Security First* and *Policy First* in these regions or sub-regions are not very large judging by the temperature increase between 2002 and 2052. However, considering the rate of temperature change, *Policy First* seems to be heading in the 'right' direction, as opposed to *Security First*.

Most of the warming is foreseen near the North Pole. This is a consistent message in all climate patterns to which the scenarios were applied. In fact, almost all studies indicate that Arctic temperature increases by a factor of two larger than the average global change (compare Figures 7.9 above and 7.11 below; note the difference in unit). Figure 7.11 shows that large increases in average polar temperature can be expected for each of the scenarios, especially in the Arctic. *Policy First* and *Sustainability First* feature the largest increases up to 2032. This corresponds with rapid abatement of emissions of sulphur oxides under these scenarios. The diversions only start to show later in the century, due to the fact that temperature change in the coming decades is largely the legacy of changes in greenhouse gas emissions over the past decades. Figure 7.11 clearly shows that the change in temperature between 2002 and 2032 is far larger than the spread of results between the models. The warming in Antarctica is less pronounced, supposedly due to buffering ocean currents near Antarctica.

In summary, North America and West Asia will experience increasing climate change impacts in all scenarios, but at a somewhat less steep rate in the *Sustainability First* scenario. Remarkably, Canada and other northern parts of North America as well as Eastern Europe feature large and increasing

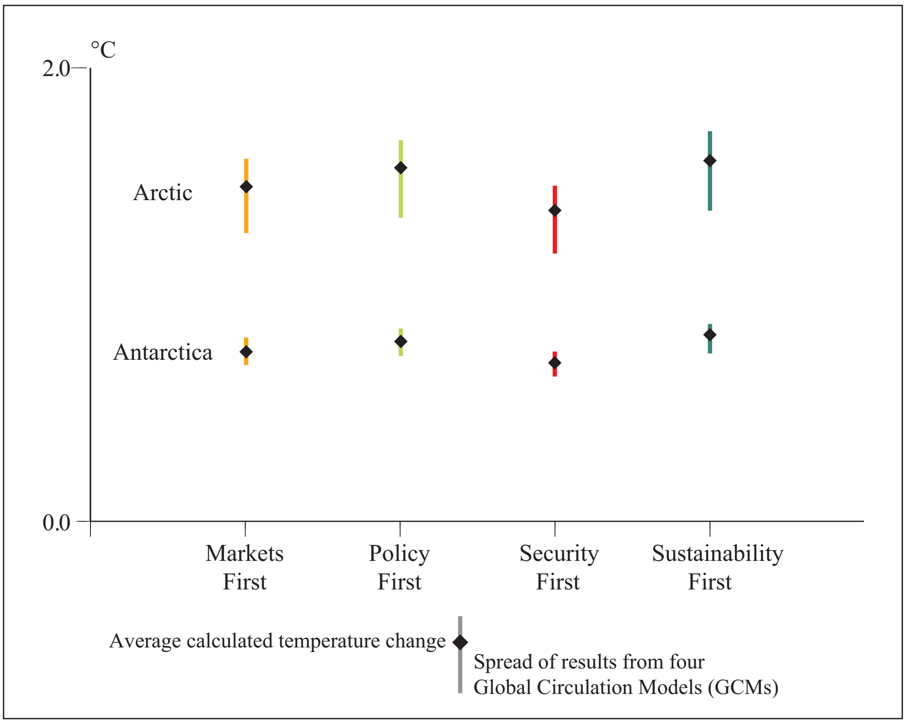


Figure 7.11: Change in average temperature in the Polar regions between 2002 and 2032
Source: RIVM

changes in all scenarios, even in *Sustainability First*. Western and Central Europe face increasing changes in *Markets First* and somewhat slower warming in the other scenarios. For Africa, Latin America and Asia and the Pacific, warming does occur, but the favourable change of trends in a world of *Sustainability First* (viz. a slowing down of temperature increase by the middle of the century) is rather outspoken for these regions.

Adding changes in precipitation to the analysis makes the picture more complex, because the various projections of precipitation changes are less consistent. Moreover, precipitation changes in combination with temperature change are less straightforward to translate into ‘good’ or ‘bad’. Furthermore, changes in annual regional totals are only part of the story when it comes to changing precipitation patterns. For example, there is much difference between extra precipitation falling evenly distributed over time or in the form of extreme downpours. Likewise, if the typical winter precipitation in elevated areas shifts from snow to rain, many factors in the drainage basin will change without necessarily changing the annual precipitation total.

Notwithstanding these limits to the analysis, precipitation changes are presented here (Figure 7.12) to show that there is more to regional impacts of climate change than temperature change alone.

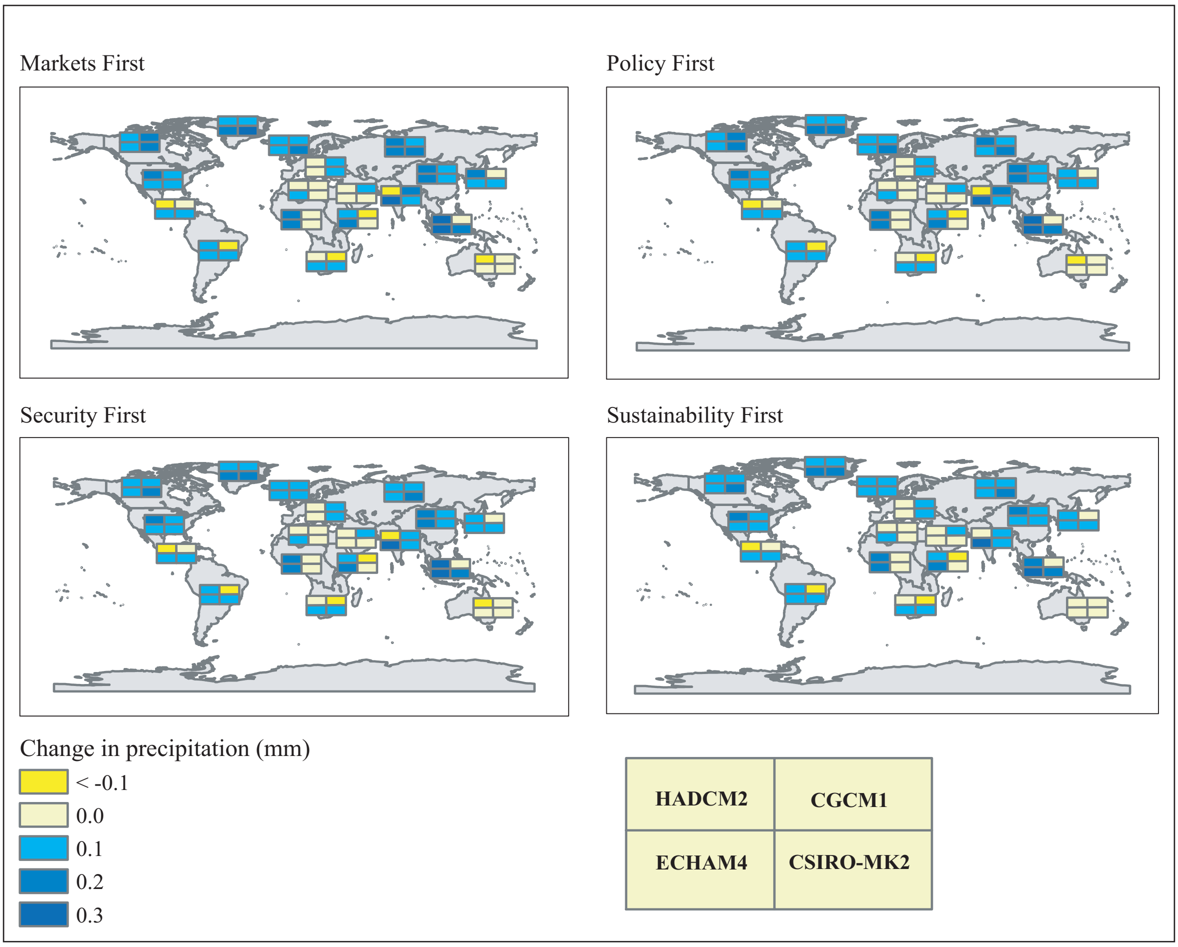


Figure 7.12: Change in annual total precipitation 2002 – 2052, based on four global circulation models

Source: RIVM

Clearly, between 2002 and 2052 North America will become wetter in all scenarios according to all climate patterns. From a perspective of overall agricultural yield, this will soften the unfavourable effects of the rapidly increasing temperature.

The combined result, drier and warmer, is equally unfavourable for all scenarios. The Australia and New Zealand sub-region, too, becomes not only warmer but also drier in line with all climate patterns. The combined result is unfavourable for all scenarios, but least so for *Sustainability First*. The rest of Asia and the Pacific is a notoriously difficult part of the world in climate modelling. Here, the projected differences between the four climate patterns tend to be larger than those between the four GEO-3 scenarios. Furthermore, if the area as a whole gets wetter, as suggested by three of the four climate patterns, it is still difficult to judge at this level of analysis whether the combined effect on ecosystems and livelihoods will be mostly favourable or unfavourable.

Relatively large changes in precipitation totals are projected for Africa, but the direction of change is not consistent across the various climate patterns. While GEO-3 scenarios seriously differ in the projected change in average temperature for Africa, *Sustainability First* being least unfavourable and *Markets First* most unfavourable, they do not greatly differ in projected precipitation total.

The pattern for Latin America and the Carribean resembles that of Africa: no consistent signs of scenario-related differences for the projected changes in precipitation total. *Sustainability First* is still clearly the least unfavourable because it features the slowest temperature increase.

Overall policy implications

This study clearly shows the long delays with which the effects of current and future emissions start to become visible in atmospheric concentrations, and possibly in the enhanced rate of global temperature and as changes in precipitation. These long delays make it difficult to adjust policies and values well enough in advance. In low-income countries in particular, it will be difficult to prioritize: obviously economic growth will, in the first place, be used to reduce poverty and improve one's well-being. However, to anticipate in time and act upon the negative side-effects of growth in production and consumption, such as enhanced carbon dioxide emissions from increasing energy consumption, it is likely that changes in energy production and consumption will be required in the short term in all sub-regions. Only then can the long-term trend in climate change, due to increasing carbon dioxide emissions, be slowed down and eventually stopped.

7.7 Risk of water erosion of soils

7.7.1 Description

The proportion of an region that will be sensitive to water erosion of soils is used here as an indicator of the change in physical risk of water erosion of soils, not considering possible human actions to counter or prevent erosion.

The world's land resources play an important role in the production of food used to feed the world's population. When these resources are degraded through activities such as deforestation or lack of proper agricultural management, the productive capacity is reduced. The main types of soil degradation are wind erosion, water erosion, chemical degradation (e.g. salinisation), and physical deterioration (e.g. soil compaction). Water erosion, as one of the soil degradation processes occurring most extensively at global level, has been singled out for this study. Water erosion is influenced by natural conditions in and around the soil and terrain, but also in the way the soil is used. Good integrated soil management practices can prevent much potential damage.

7.7.2 Modelling

The risk that water erosion will occur is calculated in IMAGE 2.2 by combining three indices, for terrain erodibility, rainfall erosivity and land cover (see Figure 7.13):

- The terrain erodibility index is based on soil (bulk density, texture, soil depth) and terrain properties (slope angle), both of which are assumed to be constant in time.
- The rainfall erosivity index is an expression of the intensity of rainfall, calculated as maximum monthly rainfall divided by the number of days it rains (rain days) for each month. Since we assume that the number of rain days does not change, a change in monthly rainfall will lead to a change in the rainfall erosivity.
- The land-cover pressure expresses the type of land cover. It is large for most agricultural crops, and small for natural land-cover types such as forests. The risk of water erosion is always largest in agricultural areas, independent of the soil and climatic conditions; this is so for both temperate and tropical regions. Changes in land cover and land-cover pressure are related to technological developments, changes in diet (for instance, in meat consumption), the food trade and other factors.

Noteworthy here is that this modelling effort simplifies the issue, since, given the changing *risk*, management practices can make an enormous difference in *actual* erosion. Mechanical conservation measures (contour ploughing, deviation ditches, and terracing, in combination with clever water-harvesting techniques and agronomic soil conservation practices, such as mulching and reduced or zero-tillage) will prevent much water erosion in the real world.

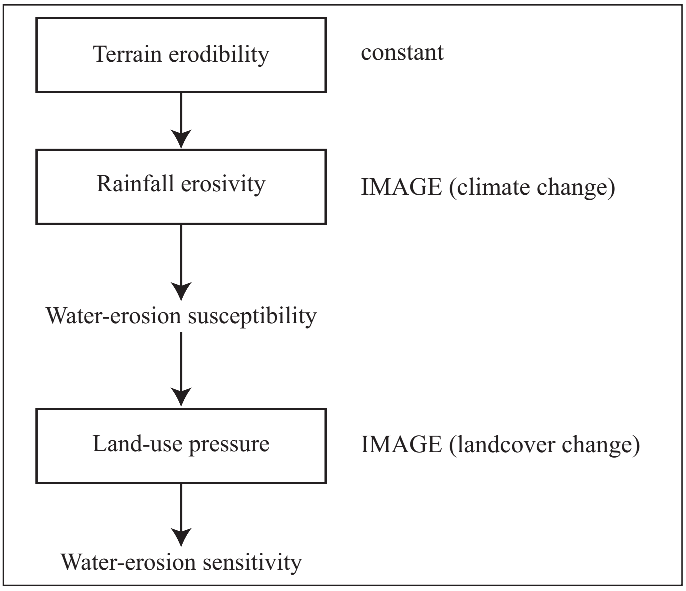


Figure 7.13: Concepts applied in the estimation of the risk of water erosion of soils
Source: RIVM

Conversely, another simplification is that the land-cover changes as modelled here are not influenced by the gradual decrease in overall land productivity caused by degradation. In reality, land transformations in some regions (for instance, from forest to agricultural land needed to maintain the existing total production level in the area) may be larger than in a situation without land degradation.

To guide the analysis of the risk index for water erosion of soils, we made a comparison between the IMAGE index values and the erosion severity classes of GLASOD (Oldeman and others, 1991). Four classes were defined to roughly correspond with the GLASOD classes (see table below). Using this classification of the water-erosion risk index, we found that modelled estimates for the global land area for 1990 corresponded for approximately 85 per cent with the GLASOD inventory, which combines area extent and degree of degradation:

IMAGE water-erosion risk index		**GLASOD severity class**
< 0.15	≈	no/low
0.15-0.30	≈	medium
0.30-0.45	≈	high
> 0.45	≈	very high

Details on the IMAGE 2.2 Land Degradation Model (LDM) used for this analysis can be found in the user documentation on the IMAGE 2.2 CD-ROM (IMAGE team, 2001a,b). This documentation includes a qualitative description of the water erosion process, as described in detail by Hootsmans and others (2001). The water erosion model is based on the work of Batjes (1996), who used a simplified version of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978).

7.7.3 Results

Global results

Compared to the present situation, the soil area with a high water erosion risk increases by 2032 by approximately 35 per cent in all scenarios (see solid lines in Figure 7.14). The main cause is the expansion of areas cultivated for food and biofuel crops, accompanied by a low degree of protection of the soil surface and, in some regions, increasing rainfall erosivity under all scenarios due to climate change (see section 7.6). Climate changes are more or less equal for all scenarios, because the changes in the coming 30 years are the result of emissions of the past few decades. It is only after 2032 that results start differentiating per scenario (see dotted lines in Figure 7.14). This is partly due to ongoing increases in agricultural land conversions (needed to meet the increasing demand for agricultural produce as a result of population growth and dietary patterns) and partly to delayed climate change impacts of the 2002-2032 emissions. When looking to 2052, the areas at high risk in the *Sustainability First* scenario smooth out to a level below the *Markets First* level. The *Policy First* world level approaches the *Security First* world level due to the larger demand of biofuels. Details are presented in Figure 7.15 and discussed below.

A glance at Figure 7.14 next to Figure 3.2 provides a rough indication of the amount of land management effort that is implied in the bending of trends under the *Policy First* and the *Sustainability First* scenarios. (Figure 7.14 relates to all agricultural land; water erosion only; biophysical erosion risk without extra management effort; based on detailed spatially explicit

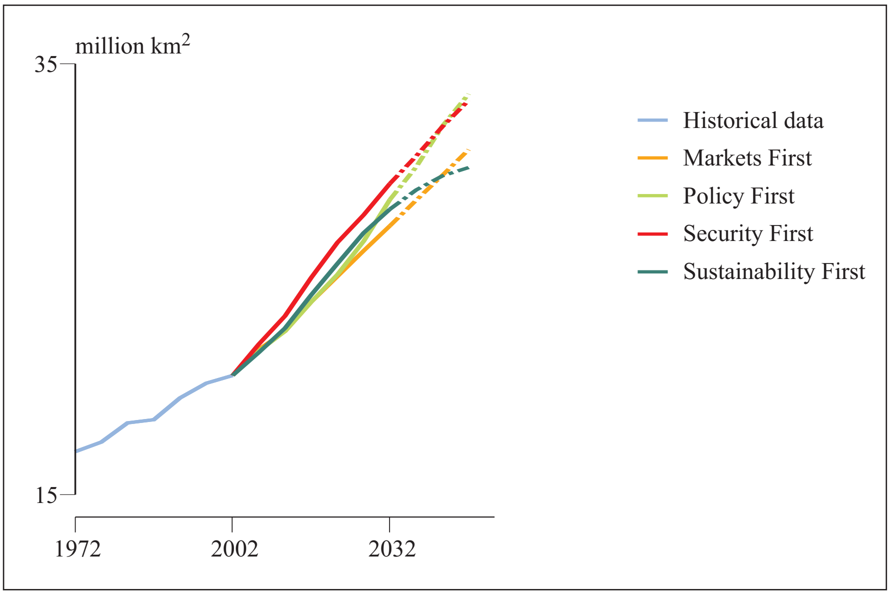


Figure 7.14: Global area of soils with high water erosion risk.
Source: RIVM

modelling. Figure 3.2 relates to cropland only; all forms of degradation; based on assumed departures from historical trends of net degradation, reflecting the story-lines.)

Regional results
Figure 7.15 shows the area with high water-erosion risk to increase significantly in nearly all regions. Exceptions are Central Europe (without Turkey), Australia and New Zealand, where the area with a high erosion risk decreases, mainly as a result of gradually decreasing grazing areas. In general it is clear that the changes in areas with a high risk of water erosion of soils will be considerable within a 30-year period, while the differences among scenarios are small.

In the Americas, and also in Africa and West Asia, increases in areas with a high water erosion risk occur most in a *Security First* world, mainly due to a larger food demand (due to larger population growth) combined with slower technological improvements. These two trends lead to the most rapid expansion of agricultural land (both to feed the population and for fodder) at the cost of forest land. To make matters worse, improvements in land management seem least likely in a *Security First* world; in all regions. Western Europe seems least influenced by a *Security First* situation (lower increases in high risk areas than under the other scenarios).

The *Security First* world shows little demand for biofuels in most regions, leading to a smaller increase in the associated agricultural land. Although the production of biofuels is not regarded as high risk in terms of water erosion of soil, this smaller increase still translates to a somewhat smaller water erosion risk in the *Security First* scenario, for example, in Western Europe. Erosion risks in Meso-America and the Caribbean, already large by global standards, increase in all scenarios but to a different degree. South America follows the same pattern but at lower risk levels. On the one hand, increasing incomes, especially in a world of *Sustainability First*, lead to shifts in consumption patterns (more meat at the cost of cereals and starchy roots). On the other hand, agricultural technology increases land-use efficiency at different speeds in the various scenarios. In addition, the

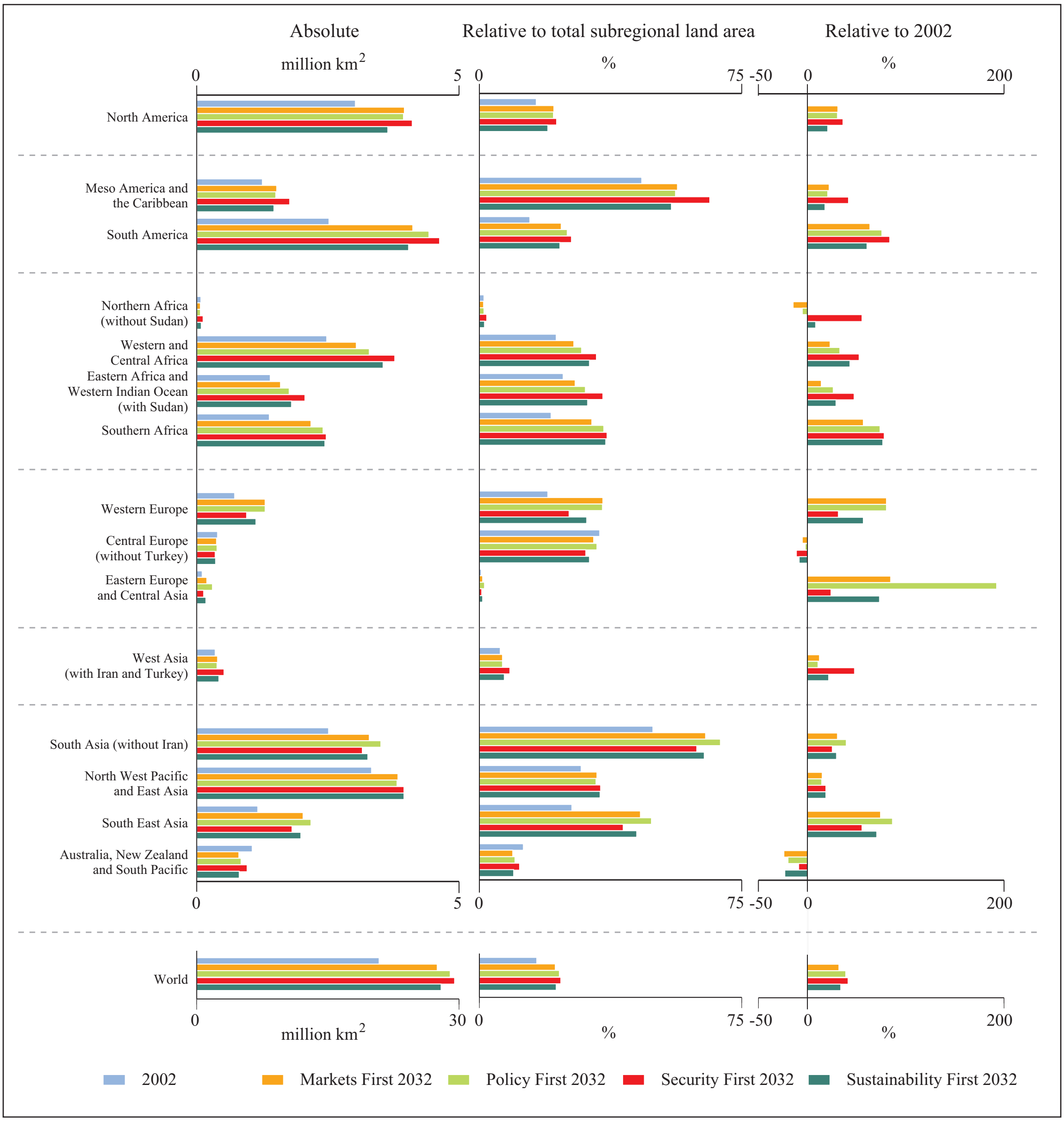


Figure 7.15: Area of soils with high water erosion risk.
Source: RIVM

world of *Markets First* shows a particularly strong tendency towards intensification in livestock farming. As a consequence, the grazing land required is less, while the agricultural land required for concentrates (feed and fodder crops) is more.

In Latin America and the Caribbean, soil and forest degradation are still numbered among the most prominent environmental issues in all scenarios. In *Markets First*, but even in the *Policy First* situation, and much more pronounced in *Security First* worlds, the area with a high risk of water erosion increases sharply and the agricultural frontier continues to expand into rainforest ecosystems. This expansion is driven by large-scale commercial livestock farming and industrial cropping, along with influxes of immigrants attracted by these developments and new infrastructure projects (see also chapter 4). Exacerbated by drought, many more desertification hotspots are evident by 2032.

In much of Africa, growing populations, increasing average income and changes in climate all contribute to an increasing water erosion risk. The greater demand for agricultural products under *Policy First* and *Sustainability First* conditions implies a risk of water erosion that may be larger than in *Markets First*. The sharper increase apparent in a world of *Security First* (see, for example, West and Central Africa on the bar charts in Figure 7.15) reflects the greater area of land brought into agriculture under this scenario in order to meet the demands of the still rapidly increasing population. It also indicates a relative inability to fall back on food imports as well as diminishing rates of return from improving agricultural practice.

In the *Markets First* and *Security First* scenarios in West Asia, transformation of agricultural land to built-up areas (urbanisation, industrial activities, infrastructure and tourism) continues in the absence of effective land protection policies. The land remaining under agriculture is sensitive to water erosion. In *Policy First*, implementation of a regional food demand management strategy results in more food being imported from other regions, which spares agricultural land from increased pressure for local food production. The same trends are shown in the *Markets First* and *Sustainability First* situations. Agricultural land comes under the most pressure in a *Security First* situation (least food imports).

In Asia and the Pacific, the growing populations, and the spread of agriculture and climatic changes imply an increasing risk of water erosion in many parts of the region in all scenarios, especially in mountainous areas. The oceanic sub-regions – the South Pacific and Australia & New Zealand – are the least threatened, while South and South East Asia feature high risks of water erosion and large increases in all scenarios. In the *Policy First* and *Sustainability First* scenarios, the effect of less sulfate aerosol and thus more rapid climate change leads initially to a somewhat higher risk; however, in the longer term, other drivers dominate.

By global comparison, differences between the scenarios in Europe are small. The changes are driven mainly by the net expansion of cultivated areas for food to meet changing diets, and are indirectly driven by increased land use for the large-scale production of modern biofuels. In *Markets First* a slow shift in Eastern Europe from grazing-dependent livestock to reliance on feedstock somewhat increases the agricultural area at risk. Under *Policy First,* land use for biofuel production increases faster, especially in Eastern Europe. *Security First* shows a slower increase in land at risk. In Western Europe this is due to slower increases in crop, grazing and biofuel land. Central Europe experiences less growth in especially the production of biofuels. In Eastern Europe grazing land decreases less rapidly. Agricultural land at risk increases less in *Sustainability First* because per capita consumption of meat and milk is smaller, leading to a smaller area required for grazing and for feed and fodder production in all sub-regions.

Overall policy implications

Measures to maintain the productivity of agricultural land have always been important, for example, for the protection of marginal grazing land and low-potential agricultural land. If our projection for water erosion risk of soils is anything to go by, such measures will be increasingly important in the next 30 years for:

- adaptating to climate change
- avoiding a still larger demand for agricultural land to compensate for productivity losses
- addressing the consequences of intensifying livestock production, which will drive the conversion of grazing land to land for feed and fodder production.

The key areas on the global scale here are still Meso-America and the Caribbean as well as South and East Asia and sub-Saharan Africa.

7.8 Change in natural forest area

7.8.1 Description

Natural forest cover is seriously deteriorating in most parts of the world. In regions around the Mediterranean, this deterioration has occurred since the Roman Empire, while in most other regions, the process started more recently, although it can still go as far back as several hundred years. Forests are cleared to open up new agriculture land, including grazing land for livestock and land for industrial exploitation (such as timber and pulp), but also to create space for urban development and infrastructure. Furthermore, long-range atmospheric pollution from heavily industrialized areas is a relatively new threat to forests. Besides, natural forests are destroyed through, and do not always recover from, large-scale and re-current fires. As a result, the world's wood resources are under serious threat, while forests are a key repository of biological diversity; furthermore, the species, communities and ecosystems they form play a central role in the functioning of the biosphere and the climate system.

The variable 'natural forest area change', is the area of mature forests that has not been harvested using clear-cutting since 1972. The current analysis is made from a biodiversity perspective, considering changes in the area of forest of 100 years or older (see also section 7.9 on the Natural Capital Index). Consequently, younger re-growth and plantations are excluded from the analysis.

7.8.2 Modelling

This analysis is designed to shed light on the impact of the four GEO-3 scenarios in terms of loss of natural mature forest. The causes considered are limited to clearing natural forest for timber or for agricultural use of the land. Other analyses for GEO-3 considered the more comprehensive impact of the scenarios on ecosystems, including forests (see also section 7.9 on the Natural Capital Index and Chapter 4 on the GLOBIO contributions).

The Terrestrial Vegetation Model and the Land Cover Model of IMAGE 2.2 were used to model change in forest area (IMAGE team 2001 a, b). The natural forest area is quantified based on the actual distribution of natural vegetation, as well as potential vegetation and actual land cover. More precisely, each natural land-cover class is assumed to contain a particular percentage of forest cover. Based on a comparative study of different forest classifications, the forest fractions for each natural land-cover class are defined as follows: 10 per cent of a tundra vegetationis considered to be forested, 30 per cent of grassland, steppe and wooded tundra, 50 per cent savannah, 60 per cent of scrubland, 90 per cent of tropical woodland and 100 per cent ofcool coniferous and boreal forests, temperate forests, and warm and tropical forests. Some natural land-cover types do not contain any forest, such as deserts and ice.

For GEO-3 natural forest is defined as the area of forest *excluding plantations* that has not been harvested using clear-cutting for at least 100 years. This is the minimum time considered necessary for forest re-growth to become ecologically valuable again. In fact, this restoration time varies strongly between regions and ecosystems. The 100-year period is merely an average estimate (see section 7.9 on the Natural Capital Index for details).

In the next step future natural forest clearing is simulated for each scenario on a global 0.5° by 0.5° grid cell resolution. Clearing is modelled as a function of the demand for wood, pulp and fuelwood/charcoal. This demand is to be satisfied by natural forest and regrown forest – the latter including plantations in the IMAGE modelling. The production of wood, pulp and fuelwood/charcoal is spatially allocated considering the distance of each grid cell from population centres or ports and the demand for additional agricultural land. The latter is spatially allocated considering each grid cell's suitability and location.

Finally, all areas covered with forest in 1972 that are used during the scenario period for logging through clear-cutting or cleared for agricultural production after 1972 are taken as showing a decrease. The year 1972 was chosen as the reference year because GEO-3 looks back 30 years and forward 30 years. In fact, it is an arbitrary choice. Although the forest area will increase in certain scenarios due to re-growth after clear-cutting (for instance, in plantations) or after abandonment of agricultural land, the scenario period up to 2032 or 2052 is not long enough for such re-growth to sufficiently restore biodiversity values. Therefore, the results from this analysis will show shrinkage of mature forest for all scenarios. The question is: how much?

7.8.3 Results

Global results

Figure 7.16 shows the overall shrinkage of the global natural forest area under each of the four GEO-3 scenarios, though this trend is more profound in *Security First* than in the other scenarios[11]. The large decreases in forest area in the *Security First* future start occurring immediately in 2002. Until around 2020 a less dramatic, but nonetheless, downward trend exists for the other three scenarios. In the first two decades the trends do not differ among these three futures. Between 2020 and 2032 the *Policy First* world starts showing more drastic decreases. Differences in trends become more pronounced in the period between 2032 and 2052, with decreases in a *Policy First* world approaching those in the *Security First* scenario. The reason for this decrease in *Policy First* stems from an increasing demand for biofuels as a result of increased carbon taxes in the energy system. Given the slow rate of substitution of energy suppliers, this demand for biofuels only picks up significantly after 2020.

---

[11] The projections shown can be compared with trends in the preceding thirty years as follows: for the globe as a whole, the area of natural forest, excluding re-growth since 1972, decreased by 11 per cent between 1972 and 2002. The next thirty years, the worlds of *Markets First*, *Policy First*, *Security First* or *Sustainability First* will show global average decreases – re-growth excluded – of 9, 11, 14 and 9 per cent, respectively.

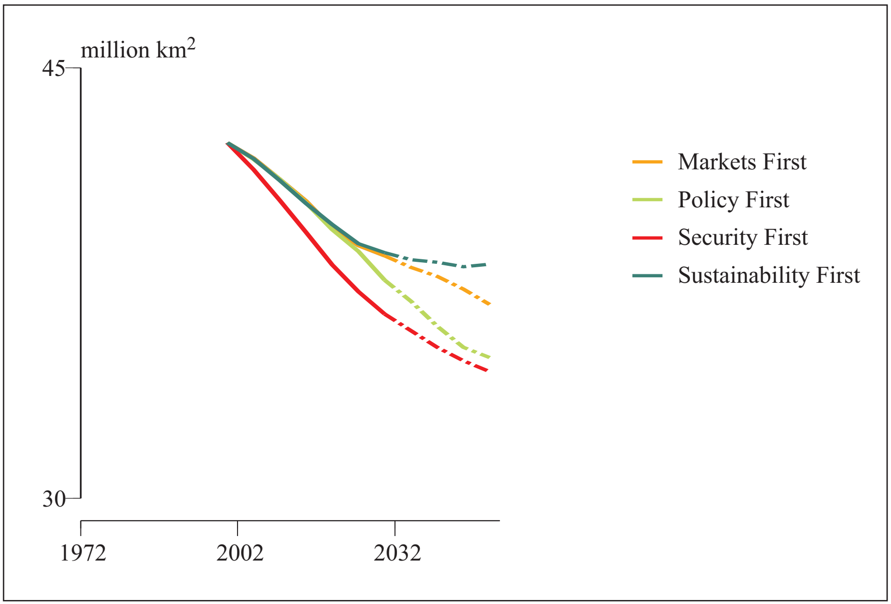


Figure 7.16: Global natural forest area, excluding re-growth
Source: RIVM

The sharp decrease under *Security First* in most sub-regions is caused by a complex of factors. There are, in fact, two mechanisms influencing change, which often balance out: i.e. explosive population growth on the one hand, and relatively low economic growth on the other. The low economic growth, combined with self-reliance, results in a slower transition to a more meat-intensive and high caloric intake per capita. This effect offsets the pressure caused by an increasing population in *Security First*. However, the same regionalized world is also characterized by a slower rate of technological improvements, resulting in a greater need for land to obtain the same amount of food as in *Policy First*, for example.

Thus, although some areas are protected for the exclusive benefit of the elites, the aim of self-reliance, causing over-exploitation of forestland for fuelwood, food and shelter, results in dramatic natural forest losses in a world of *Security First*. In most higher income regions populations also increase but at a lower rate than elsewhere; forests are less protected than in other scenarios and technological efficiency is less. However, the slower growth in average per capita income combined with less drastic population increase also results in slower growth in regional demand for wood. In addition, there is less use of biofuels in this scenario and thus a correspondingly smaller increase in crop area. The latter two aspects can result in smaller forestland conversion. The degree to which forest land decreases thus varies among sub-regions, depending on which of the pressures dominates (see some detailed examples below in Regional Results).

The area with natural forest in *Markets First* is decreasing. Due to technological advances in agricultural efficiency and to efforts of government and business to protect forests, however, the need to convert forests into agricultural land is less pronounced (from 2020 onwards even less than in a *Policy First* world).

The trend in a *Policy First* scenario is less positive than in a *Markets First* situation, due to, for example, carbon taxes and investments in non-fossil-fuel energy sources, which result in some regions in an increased use of biomass as energy sources. Although this is considered good environmental practice in general, it does have adverse implications on the forest area since modern, large-scale cultivation of biofuels increases the demand on agricultural land and thus on forest land to be cleared.

In *Sustainability First* the behaviour of consumers changes in favour of natural forests. There will be government policies to protect natural forests and their biodiversity, as well as local initiatives such as community-based natural resources management programmes. For all of this to happen it is assumed that economic growth too will show a positive development so that poor people indeed have an alternative. As a result the natural forest area stabilizes soon after 2032.

Regional results

Figure 7.17 illustrates that sub-regions with the largest forest areas in absolute terms are not the sub-regions with the largest potential decreases in forest area. The largest forest surfaces in absolute numbers exist in North America, South America and Eastern Europe, but decreases in the four futures and differences among them are smaller than in the other sub-regions (only the *Security First* world in South America shows rather drastic negative changes). Note, however, that biodiversity in coniferous and boreal forests is clearly less than in tropical forests (Rodenburg and others, 1995). Thus, although relatively greater amounts of forest land will be maintained in North America and Northeastern Europe, these are not the most valuable forestlands from a biodiversity point of view.

Moderately large forest surfaces exist in Central and Western Africa, and South East Asia. Here, decreases are large under all scenarios (much larger than in the previous thirty years). Differences among the scenarios are moderate. Western Europe and the Australia, New Zealand and South Pacific sub-regions have relatively small forest surfaces and show small changes (the latter sub-region even shows a small increase – see Figure 7.17) and little variation among scenarios. Meso-America and the Caribbean, Eastern and Southern Africa, Central Europe, South Asia and North West Pacific and East Asia all have very small forest areas in absolute terms, with Northern Africa and West Asia having almost no forest land. Decreases in forest area are serious over time for all scenarios and differences between scenarios vary according to the region.

Compared to the previous thirty years (not shown in the graphs), North West Pacific and East Asia is the only sub-region where the decrease in natural forest area slows down. But this is after the almost 60 per cent decrease – re-growth excluded – in this sub-region between 1972 and 2002. Meso-America and the Caribbean, as well as Eastern Africa, will see the rate of decrease in natural forest area continue at the previous rate or be faster, with *Security First* almost doubling it. The projected decrease for South Asia and South East Asia would mean an almost doubling of the rates during 1972-2002, up from 30 per cent in South Asia and 12 per cent in South East Asia.

In lower income regions forest area decreases are mainly the result of cutting forests to increase the agricultural production. This is most prevalent in Meso-America and the Caribbean, Africa and much of Asia. Reasons are described above (see global results) under a *Security First* world. The process of increased use of biofuels, as described above for the *Policy First* world, also has a clear influence in these regions. The *Security First* future illustrates all these developments more profoundly, but the results are mixed, depending on the dominating factor in the sub-region (as described above).

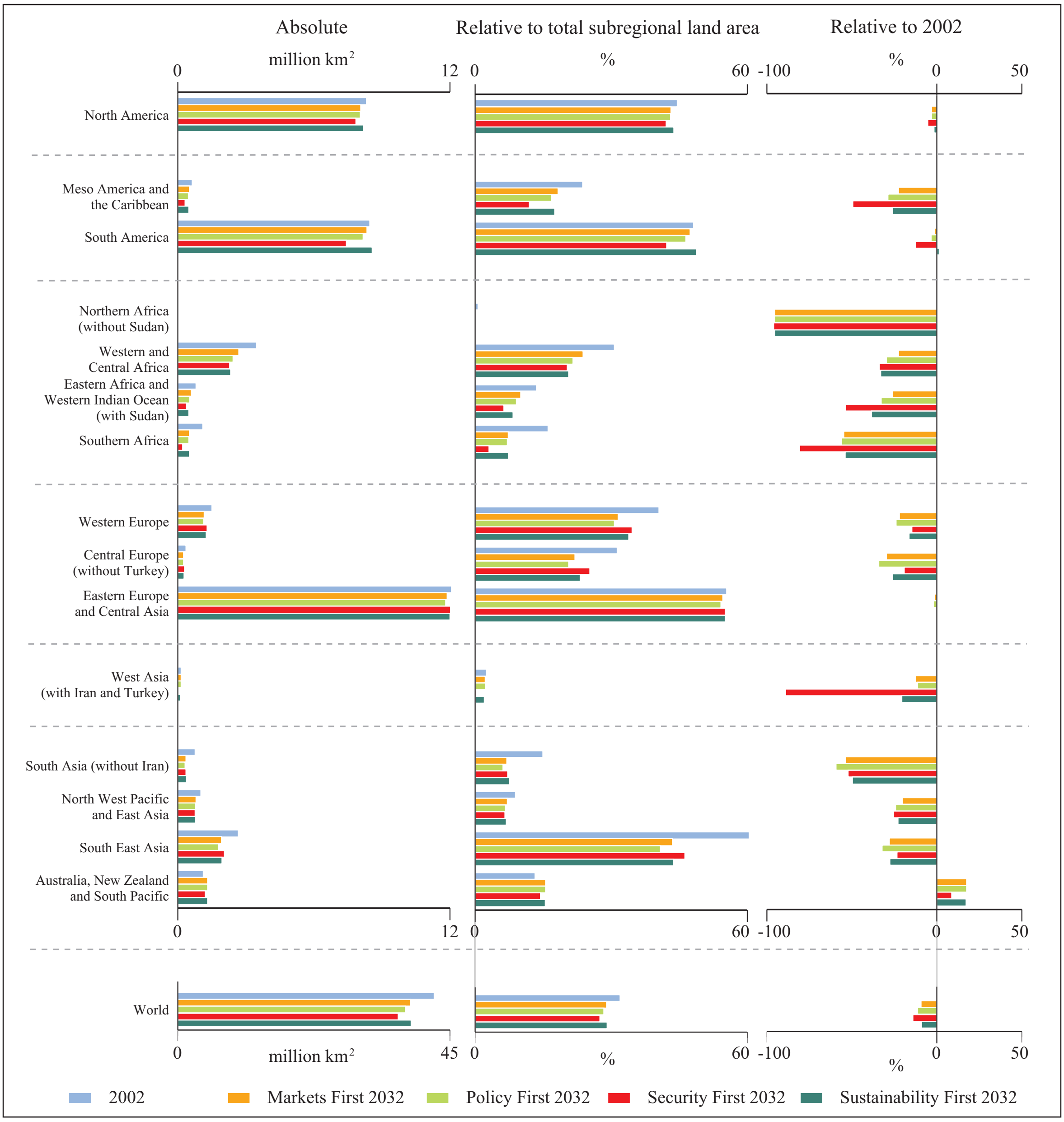


Figure 7.17: Natural forest area, excluding re-growth
Source: RIVM

The decrease in mature forest area in Western Europe is also caused by an expansion of agricultural land. This reversal of the trend in the past thirty years is related to increasing exports of food products and cultivation of modern biofuels. Interestingly, this sub-region shows a slower decrease in mature forest area in the world of *Security First*. This is because of a slowdown in increasing demand on the world food market; lower per capita income also results in lower per capita demand for wood. This scenario also shows less use of biofuels. Central Europe features almost the same pattern of changes in mature forest areas, but these changes are driven by clear-cutting forests for timber (with re-growth not considered here).

In North America, on the contrary, decreases in the *Security First* world are larger, compared to Europe, where the larger population and lower technological efficiency are the dominating factors.

After the loss of almost half the natural forests in South America in the past thirty years, there is now is a positive move to integrate forestry and economic development. Especially in the world of *Policy First* and *Sustainability First* this trend will continue and spread. These scenarios are characterized by more supportive administrations and compliance monitoring, making these strategies more successful. In the world of *Sustainability First,* a small increase in forest area is even realized due to the transition of other vegetation types into forest under the influence of climate change. In contrast, in the world of *Security First,* the aim of self-reliance results in a substantial loss of natural forest due to the increased need for agricultural land to answer the increased demand for regional food. Economic growth and export developments in South America are also not as low as in other regions under a *Security First* situation. This, too, results in relatively more forest loss in *Security First*.

Large deforestation in Africa can be expected, especially in the *Security First* world and, in particular, in Eastern and Southern Africa. An estimate for the fate of the small forest area in Northern Africa is difficult to make, but pressures on this forest area will be large in any scenario. The decrease in natural of forests in Western and Central Africa in the *Markets First* scenario is, in comparison to the other scenarios, limited due to technological improvement in the agricultural sector.

The natural forest area in Asia and the Pacific decreases considerably, especially in South Asia and South East Asia. Differences among scenarios are small. The main reason is again that a complex of factors lead to an increasing demand for agricultural land at the cost of forested land. Only in Australia and New Zealand does an increase in forest area occur due to the natural transition of other vegetation types to forest under the influence of climate change.

Overall policy implications

Forest protection is very much needed in large parts of the world (and is already taking place in some mainly higher income regions); however, protection can be least expected in those situations where it is most required (under conditions of *Security First*).

Given the large decreases in forest land in all scenarios, forest certification (a voluntary, market-based instrument focusing on quality of forest management rather than on quality of forest products) is considered a necessary, and at the same time, promising approach for the future of natural forests. Conceivably, the scenarios differ in the degree to which this approach can be backed up with government rules and public information.

There is a global trend towards greater reliance on plantations as the source of industrial wood (see GEO-3 [page 93] and FAO 2001– Global FRA 2000). Plantations can provide for many of the forest functions, such as providing industrial wood and other forest products, watershed protection, carbon sinks and the like, while at the same time protecting valuable biodiversity in natural forests.

This analysis is better at identifying downward trends, such as occurring in the *Security First* world in a number of currently low-income regions. However, history over the past thirty years as assessed in Chapter 2 of GEO-3 strongly suggests that policy regulation and better technology in a higher income situation as in the *Policy First* scenario will not be enough either for altering trends in deforestation. Eventually, a change in behaviour and values is required – much more like the *Sustainability First* scenario. Improvements in human well-being, economic growth and reduced population growth form a pre-requisite for positive change. For instance, even gradual, small-scale infiltration into natural forests by a poor local population has dramatic results in the long term and can not be avoided through environmentally sound policies alone.

7.9 Terrestrial biodiversity

7.9.1 Description

The variable 'natural capital index' is an index that approximates terrestrial and aquatic biodiversity of natural ecosystems and agricultural land. Biological diversity – or biodiversity - is the term given to the variety of life on earth and the natural patterns formed. This diversity is often understood in terms of the wide variety of ecosystems (terrestrial and aquatic), plants, animals and micro-organisms, including genetic diversity of food crops and domestic animals. Biodiversity loss at the specis level occurs when natural ecosystems are reduced through conversion to agricultural or urban use (loss of quantity) and/or when natural ecosystems are degraded (loss of quality). Such degradation of terrestrial and aquatic systems occurs due to a mix of human influences, such as climate change, chemical pollution, disturbance due to fragmentation from infrastructural developments or due to forms of exploitation such as tourism, hunting and gathering. All such influences reduce both the distribution and the abundance of animal and plant species. A general effect is that the abundance of many rare species declines, while the abundance of some – mostly common – species increases, resulting in increased uniformity.

7.9.2 Modelling

Data availability
A crucial question is whether the current trends of species biodiversity loss are likely to continue in the future. Ideally, to assess and foresee changes in extinction rates and species abundance, species and ecosystems must be monitored, using comprehensive methods for sampling and analysis. Unfortunately, much of the relevant information on the status of species and the condition of ecosystems do not exist globally, and then when available, are highly qualitative and generally fragmented. The lack of a quantitative overview of global trends makes it difficult to project development trends into the future, such as for the four GEO-3 scenarios in this exercise. As an alternative, it is worthwhile to focus on the causes (drivers or pressures) of biodiversity loss to obtain a proxy view of biodiversity trends in certain futures.

The Natural Capital Index
To by-pass species biodiversity data problems, a pressure-based version of the Natural Capital Index (NCI) was developed using a number of proximate drivers (or pressures) as a crude measure for ecosystem quality. This pressure-based NCI (NCI-pb) provides an indication of the future state of natural terrestrial ecosystems compared to the current state as a result of four pressures. The Nature Capital Index is defined as the product of the ecosystem area size – or habitat - (quantity) and its

quality measured against a baseline situation. Changes in habitat are caused by conversion of natural ecosystems into agricultural and built up land, and vice versa. In this GEO-3 Technical Report, future trends in such land-cover changes (quantity) have been estimated using models. Next, current and future ecosystem quality has been approximated through an analysis, again using models, of four proximate pressures assumed to have a major influence on biodiversity.

The NCI principle

The pressure-based Natural Capital Index ranges from 0 to 100. An NCI-pb of 100 indicates a situation where the total area under consideration is undomesticated and where the pressures on this area do not exceed the minimum thresholds set (see below). An NCI lower than 100 indicates a certain level of loss in ecosystem quantity and/or quality. An NCI of 0 means that the quality of the entire ecosystem has been reduced to zero (converted into agricultural land or built-up area). Only terrestrial and freshwater natural ecosystems were considered for the GEO-3 main report and this Technical Report, even though the NCI can also be applied to marine and agricultural ecosystems.

Ecosystem quality

Four proximate quality pressures

Four pressures were selected to approximate ecosystem quality: i) population density; ii) primary energy use; iii) rate of temperature change; and iv) clear-cutting of forest and abandoning agricultural land. Pressure (iv) addresses re-conversion processes, such as re-generation from logging and restoration of abandoned agricultural land. These four pressures were chosen because:

- they could be quantified for 2002 and 2032 per 0.5° by 0.5° grid cell for the entire world (using the IMAGE 2.2 model);
- knowledge on dose-effect relationships and critical levels, i.e. how various levels of the selected pressures affect biodiversity, was available from literature (Ten Brink, 2000);
- they are different in the way they exert their effect on biodiversity:
- temperature change and clear-cutting have a direct effect on biodiversity, although on different time-scales;
- population density represents various local pressures such as disturbance, fragmentation, habitat loss, water extraction and exploitation;
- energy use represents more large-scale pressures such as acidification, eutrophication and pollution.

The range for each proximate quality pressure

Based on a literature review the range of each selected pressure was defined as follows:

- P1 = population density: min-max range is 10-150 persons per km^2 (Source: Hannah and others, 1994; Harrison, 1992; Terborch, 1989);
- P2 = primary energy use: min-max range is 0.05 - 100 Peta Joule per km^2;
- P3 = rate of temperature change: min-max range is 0.1-1.0 °C in the final 10 years of the projected period (Source: Hootsman and others, 2001); and
- P4 = time past after clear-cutting of forest or after abandoning agricultural practice: min-max range is 0–100 years (derived through expert judgement by RIVM staff). This pressure has a memory effect. In operation it is the remaining time required to restore biodiversity after forest has been clear-cut or agricultural practice abandoned. It is assumed that a 100-year restoration period after cutting or abandonment will return maximum ecosystem quality. Quality is assumed to be zero right after cutting or abandonment. Obviously this is a simplification, which ignores differences in regeneration speed between the various forest ecosystems.

The calculation protocol for ecosystem quality

Eosystem quality per sub-region, or biome, is estimated as a function of the above four ecosystem quality pressures. For each of the four pressures, the range was divided into 1000 pressure points: from no effect (0 pressure points) to complete deterioration (1000 pressure points). Within each range, the number of pressure points was calculated by interpolation between minimum (0 points) and maximum pressure (1000 points).

Overall ecosystem quality was then assessed by multiplying the ongoing effect of clear-cutting or past agriculture (P4) with the aggregated effect of the three other pressures, all scaled between 0 and 100 to express a percentage:

Equation 7.1: $\text{Ecosystem Quality} = P4 \times (1 - (P1 + P2 + P3) / 1500)$

Note that the total number of pressure points for the aggregated three pressures could, theoretically, become 3000. However, when one single pressure exerts maximum pressure (1000 points), this will already have such detrimental effects on the quality of the ecosystem that additional points from one or two of the other pressures will not make much difference. For the purpose of this study, it was therefore decided to set the maximum number of total pressure points for P1+P2+P3 at 1500. Consequently, the estimated quality will be minimal in areas with a total number of pressure points of 1500 or more. See for details Ten Brink (2000 and 2001), and Ten Brink and others (2000).

Calculating the NCI

As a final step the Natural Capital Index (NCI) can be calculated by multiplying the two components (quantity and quality), both scaled between 0 and 100 to express a percentage. The outcome of the multiplication is also found between 0 and 100 (see Equation 7.2 and also under Results below).

Equation 7.2: $\text{NCI} = \text{Ecosystem Quantity} \times \text{Ecosystem Quality}$

Limitations of the pressure-based NCI

It should be emphasized that these results are rough estimates only and based on pressures that are model outcomes in themselves. The pressure-based NCI allows aggregation and projection into the future only because it is a crude measure. Above all, the key limitation is that the NCI treats the biodiversity value of all ecosystems alike, whether tundra or tropical rainforest. With regard to especially dynamics of change, many local, but significant, factors that make a difference to biodiversity are not included, such as extensive grazing, fire and exploitation. In reality, impacts of the various pressures are probably not linear. Furthermore, effects related to climate change and density of energy use are long-term. This means that in ecosystems in the northern regions, which are already under significantly large pressure from the current rate of climate change, the effects shown by a decrease in the pressure-based NCI have not yet materialized (Ten Brink, 2000 and 2001). Finally, whereas the key strong point of the NCI is that it can be aggregated across regions on the one hand, it may also mask changes over time by averaging on the other. For example, averaging gains in Chile against losses in Mexico.

7.9.3 Results

Global results

The current (2002) Natural Capital Index-pb score for terrestrial and freshwater ecosystems in the entire world is 59 per cent, based on a quantity value of 79 per cent and an aggregated quality value of 75 per cent (see Figure 7.18 and Equation 7.2).

Estimates of the NCI-pb for 30 years from now on indicate that none of the GEO-3 futures can prevent biodiversity loss in that period. Besides, differences between the scenarios are small. The indices would end up between 52 and 55 (see bar chart in Figure 7.21). Only when looking more than 30 years ahead does the picture become more diverse (see Figure 7.19).

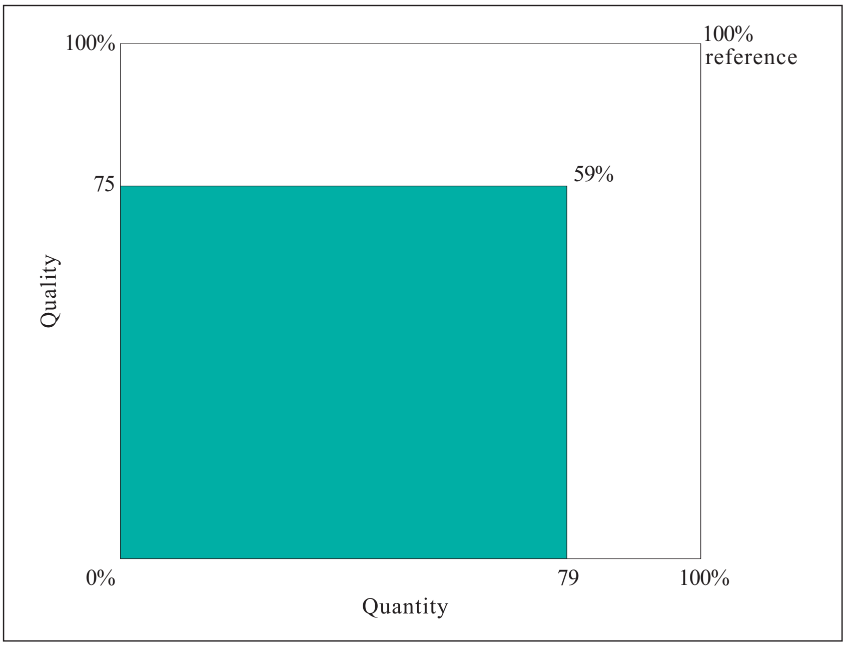


Figure 7.18: Conceptual scheme of the Natural Capital Index
Source: RIVM

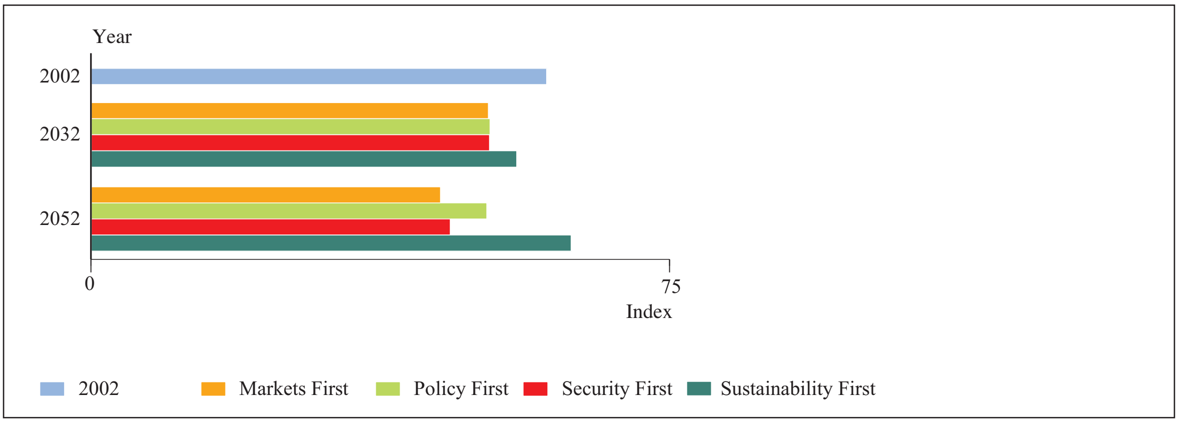


Figure 7.19: Globally aggregated pressure-based Natural Capital Index
Source: RIVM

In a *Sustainability First* world, where changes in values are featured as well as vigorous biodiversity protection policies, a recovery towards the 2002 situation would occur between 2032 and 2052 (apart from extinct species), mainly due to lowering of the pressures and consequently expected improvements in ecosystem quality. Under *Policy First* circumstances the index would not change between 2032 and 2052. It drops even further between 2032 and 2052 in *Security First* and *Markets First* futures, due to both decreasing ecosystem quality and habitat loss (quantity).

Regional results
Changes are relatively small in the Northern Hemisphere compared to often more drastic negative changes in the Southern Hemisphere (see details in Figures 7.20 and 7.21). This is partly due to the fact that much (semi-)natural area in the North has already disappeared or is already heavily affected, while in the Southern Hemisphere, the current situation is often still relatively positive so that there is much more to lose in future. Furthermore, biodiversity in the cold and temperate natural areas in the high latitudes is generally lower than in the tropical regions nearer the Equator.

Figures 7.20 and 7.21 show the combined effect of habitat loss (ecosystem quantity) and ecosystem quality. The bar charts show absolute changes in natural capital by 2032; the maps show changes by 2032 and 2052 relative to the 2002 situation. These clearly illustrate that the biodiversity impacts of the scenarios really start to differ in the 2032-2052 period. Before 2032 the four GEO-3 futures do not show too much difference; trends become more pronounced by 2052. The general tendency is a reduction of nature quality, concentrated mainly in the Southern Hemisphere and especially the Andes region, Central and South Africa, and Asia and the Pacific, as well as the boreal forest belt of Europe. These negative trends are the result of pressures from growing populations, accompanied by increased resource use in growing economies. All this results in more and more conversion of natural areas into domesticated land (reduced quantity) and in more and more disturbances in still relatively natural areas (reduced quality).

From 2032 onwards trends begin to differentiate, with only *Sustainability First* moving towards a sharp decrease in pressures by 2052. Certainly, 50 years from now the strongest increases in pressures will occur in a *Markets First* situation; *Policy First* and *Sustainability First* worlds showing roughly comparable results in the 2002-2032 period.

All futures show strong conversions from natural to domesticated land in Central Africa and in large parts of Asia. In a *Security First* world, and to a less degree in a *Markets First* situation, conversion to domesticated land occurs scattered all over the world. Under *Sustainability First*, and certainly under *Policy First* circumstances, domestication is concentrated mainly in Central Africa and parts of Asia.

Much of the domestication occurs at the cost of forest, savannahs and grassland. Some sub-regional details are described in Box 7.1 to illustrate changes in natural capital of savannahs and grassland. Pronounced trends develop over time in the natural capital of savannahs and grasslands in Africa, West Asia, some other parts of Asia, parts of Europe and parts of the Americas, all with clear differences for the various futures. Box 7.1 also discusses briefly how underlying causes of trends can sometimes be masked at the aggregated natural capital index level, which is a combination of both quality and quantity.

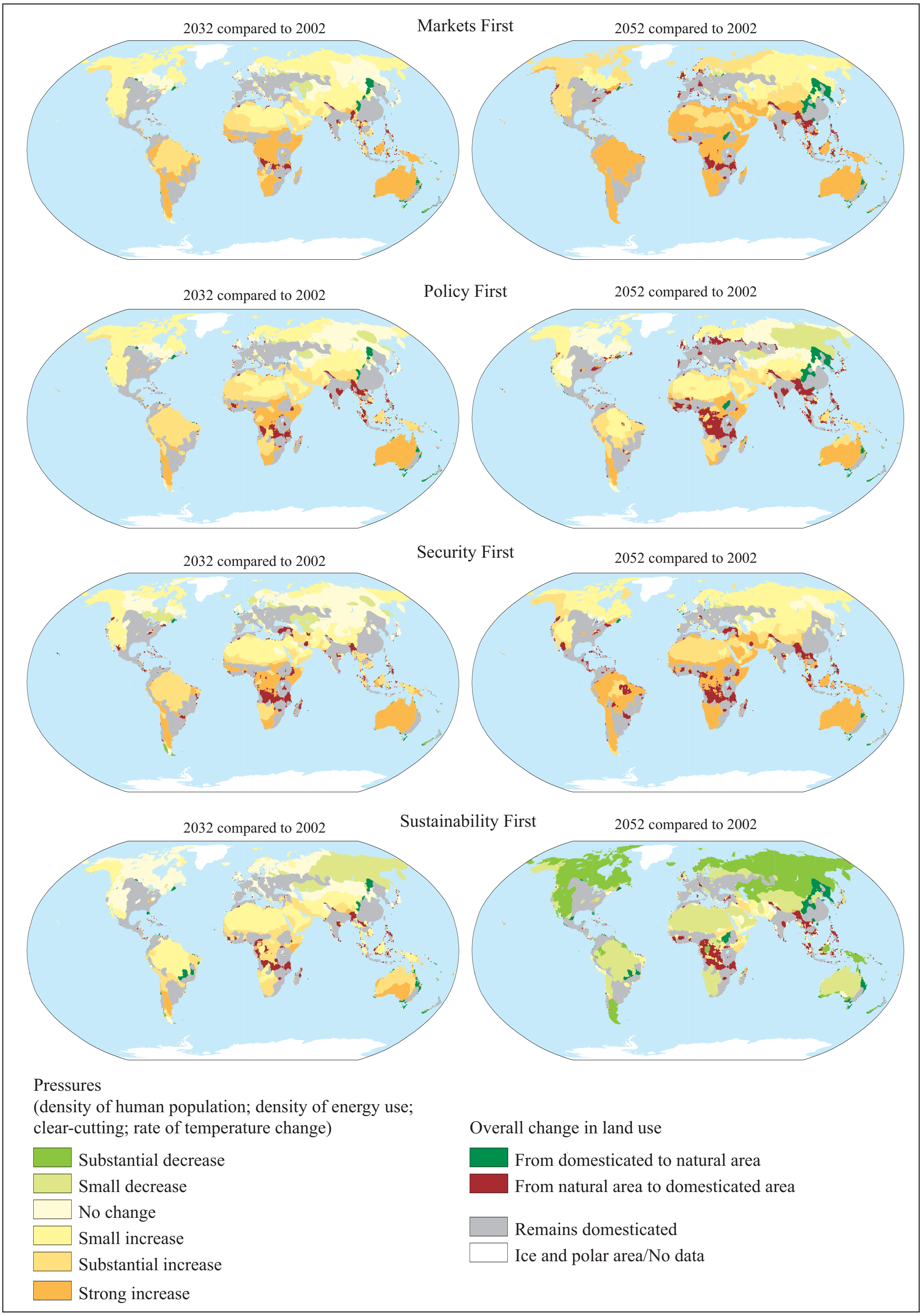


Figure 7.20: Changes in selected pressures on natural ecosystems
Source: RIVM

Figure 7.21: Pressure-based Natural Capital Index

Source: RIVM

Box 7.1: Detailed sub-regional differences in future natural capital of savannahs and grassland

Focusing only on those sub-regions where reasonably large areas are currently covered with savannah or grassland, differences between the sub-regions are listed below:

- In Sub-Saharan Africa sizeable to extra large decreases occur for all futures by 2052, even in a *Sustainability First* situation. Only in Eastern Africa, in a world of *Sustainability First,* will the decrease be small

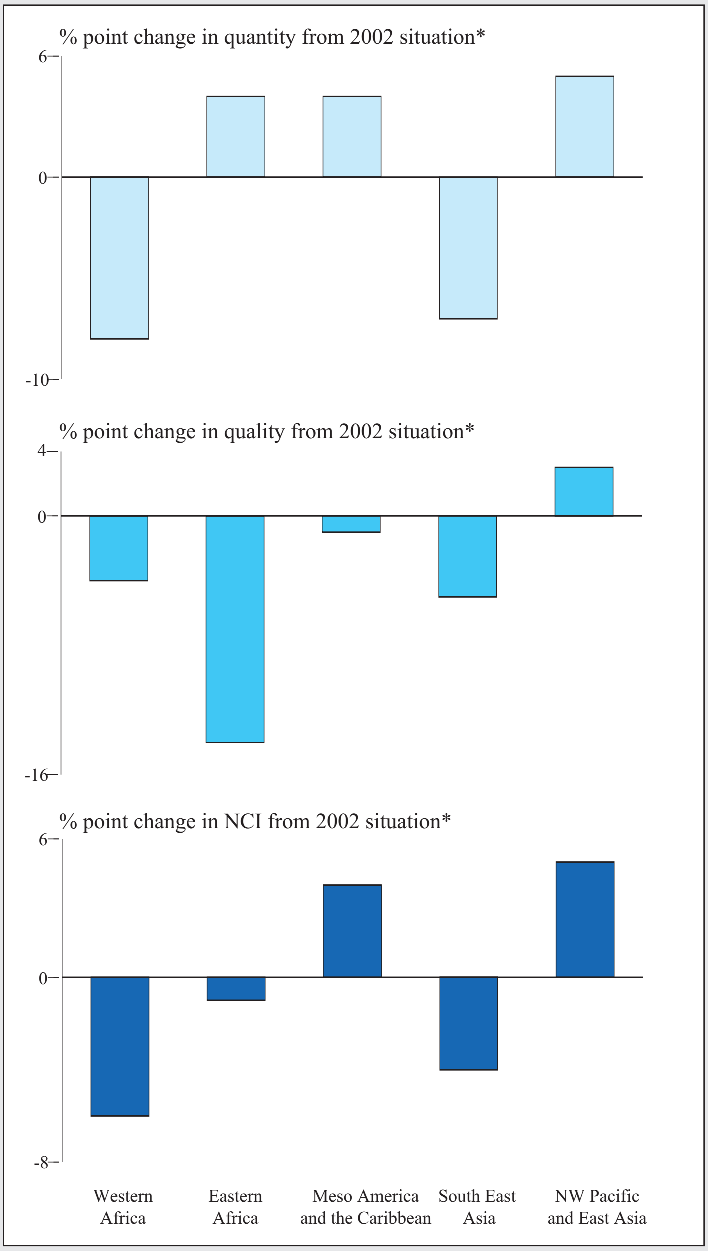


Figure 7.22. NCI of savannah grasslands for five sub-regions and underlying quantity and changes for *Sustainability First* scenario

* Note: 100% is the 'no impact' situation; see the 'NCI principle' in Section 7.9.2

- In Latin America and the Caribbean noticeable decreases occur under *Policy First* and *Markets First* circumstances; sizeable decreases occur in a *Security First* situation. While a *Sustainability First* world shows only a small decrease occurring in the regional NCI of the grasslands and savannahs in South America, Meso America shows a sizeable decrease by 2032, followed by a recovery later on.
- In the USA no changes will occur under the *Security First* situation; small increases will appear in the *Markets First* and *Policy First* worlds; noticeable increases by 2032 under *Sustainability First* circumstances will even become sizeable increases by 2052.
- In West Asia sizeable to large decreases will occur under all scenarios and from values that are already low to start with. The decrease is extra large under a *Security First* situation.
- In South and South East Asia large decreases will occur in the natural capital of grasslands and savannahs, with only small differences between the scenarios. In contrast, East Asia would only see small changes occurring, with even sizeable increases under *Sustainability First* and *Policy First* situations by 2052. In Australia and New Zealand sizeable increases would occur under all future scenarios

As illustrated above, differences in natural capital trends in grassland and savannah are large for the various sub-regions. The underlying causes of trends can sometimes be masked at the aggregated natural capital index (NCI) level, which is a combination of both quality and quantity (see Figure 7.22)

For Meso America and the Caribbean and North West Pacific and East Asia, Figure 7.22 shows the NCI slightly increasing in both sub-regions (4 and 5 percent point increase respectively). The quantity of savannah in both sub-regions increases.

However, the bar chart also shows that while the quality component of the NCI improves slightly in North West Pacific and East Asia it is slightly reduced in Meso America and the Caribbean. The gain in savannah area in Meso America and the Caribbean, which takes place at the expense of other natural systems, will be accompanied by a decrease in ecological quality of the savannah. In other words, a gain in the overall NCI is not by definition positive in all respects.

Likewise, the modelling results for Eastern Africa and the Indian Ocean Islands in terms of the overall NCI show a very small decrease only. However, a look at the quality and quantity components separately shows the increase in savannah area in the sub-region to mask a drastic future quality decrease.

An examination of the projections in Figure 7.22 for two sub-regions within one region, for instance South East Asia and NW Pacific and East Asia, illustrates that sub-regional differentiation is necessary. A rather modest regional average change in quality or quantity may be the average of a clear increase in part of the region and a serious decline in another. Future impact on biodiversity can thus best be analysed at a fairly detailed special resolution (in the GEO framework: sub-regional or more detailed), while highlighting the underlying components of biodiversity change and at least distinguishing impacts on quantity and quality.

In some regions domesticated land is actually converted into natural areas (the dark green patches in the maps). This is mainly due to re-forestation and climate changes. In Western Europe the conversion into natural land is even larger in a *Security First* world than under the *Sustainability First* scenario. This is due to the assumption that agricultural demand in Western Europe decreases under *Security First*, which results in a smaller area required for grazing and the production of concentrates, thereby creating an opportunity for re-growth and an increase in biodiversity. In biodiversity terms, however, domesticated land that is converted into natural areas is of low quality during the first decades. Furthermore, the circumstances of Security First make it somewhat doubtful that this opportunity will be used. In contrast, the circumstances of *Sustainability First* make it likely that grazing in Western Europe is to some degree extensified, i.e. enlarging the agricultural area while increasing its biodiversity value.

Overall policy implications

The development of a well co-ordinated biodiversity monitoring programme is urgently required. Such a programme would provide adequate information in support of policy development and decision-making on the conservation and sustainable use of natural resources.

The NCI shows pressures on global biodiversity to increase, but with large regional differences. This emphasizes the urgency of developing effective responses. A continuation of current trends, in terms of growing populations, increasing consumption, growth of greenhouse gas emissions and further exploitation of natural resources, will not only impact biodiversity negatively in the directly foreseeable future but will also limit possibilities to effectively restore biodiversity in the long-term. Unfortunately, policies and actions taken now do not have an immediate effect. Often, the desired results only become apparent in the long term.

7.10 Discussion

The modelling of environmental impacts described in this chapter took advantage of recent regionally differentiated work with the IMAGE model for the IPCC mitigation scenarios. A pre-analysis has shown that the generally slower GEO-3 growth of GDP per capita could be reconstructed using assumptions that are plausible in both GEO-3 and IPCC scenarios. Therefore, we concluded that the already existing IPCC material could indeed be adapted to the GEO-3 scenarios (see for details section 2.4).

Specific interpretation needed to be added to the GEO-3 scenarios, in particular, for energy and agricultural policies. This implied a tendency towards high-tech approaches in the worlds of *Policy First* and *Sustainability First*. For the latter, the assumed policies are even more ambitious and come in addition to the changes in lifestyle and governance.

Due to the ambitious pursuit of productivity and efficiency increases in agriculture, changes in land use play a central role in the findings presented in this chapter. The emphasis on land use follows, in part, from the method of analysis. However, the projected large pressure on land resources is not artificial. While it is well known that production and use of energy is a key to many of the world’s environmental problems, the role of changing land use is now highlighted as being equally important. The scenario impacts on the third key resource, fresh water, are presented in Chapter 5.

Striking differences between pathways represented by the scenarios have been found for land conversion and energy-related carbon dioxide emissions. In terms of regional differences, the land-use driven changes in Africa (Western and Central) and Asia (South and South East) stand out. Energy-wise, the overall distinction is hardly surprising: North America, Europe and Australasia with, at best, stabilising carbon dioxide emissions (and, at worst, steep increases), and the rest of the world with large variations in increase. However, in a world of *Sustainability First,* the important region of North West Pacific & East Asia approaches stabilisation of energy-related carbon dioxide emissions.

The increase in pressures on biodiversity stands out as being particularly ominous in all scenarios, but, in particular, in *Markets First* and *Security First*. A look beyond the global averages reveals even bleaker prospects for land-based biodiversity in currently low-income regions, holding much of the earth's remaining richness in terms of species diversity. This sombre outlook, with not much variation between the scenarios during the first decades, is in line with the projections of GLOBIO (Chapter 4).

Overall results specifically for the seven variables analysed in this chapter:

- Potential increases in nitrogen loading (a proxy for a wider range of land-based sources of pollution in coastal marine ecosystems) seem largest in Northern Africa and South Asia, even in a *Sustainability First* situation. Generally, a world of *Markets First* shows the largest increases. For nitrogen sources that are relatively easy to influence through policies, such as wastewater treatment, the degree of change in an area varies considerably among scenarios.
- Decreases in sulphur dioxide emissions form a classic example of pollution abatement that closely follows policy measures. This is one of the reasons why future energy-related sulphur dioxide emissions show a large diverence among the four GEO-3 scenarios. Some of the largest current emitters will move into the group of smaller emitters. The latter will change position with the present medium to large contributors.
- There also is a strong divergence in carbon dioxide emission trends among the four scenarios. Under *Policy First* and *Sustainability First* futures a de-coupling of emissions from GDP growth occurs in the third decade. Emissions continue to increase in *Markets First* and *Security First* worlds. Not unexpectedly, lower income regions will account for most of the considerable global increase in carbon dioxide emissions by 2032.
- Overall, atmospheric carbon dioxide will continue to increase and temperature change cannot be avoided in the first half of this century. In the Polar Regions, temperature increases are twice as large as the average global change. The rate of change that is slowed down in *Sustainability First* is moving in the right direction, but even in 2050 it is still far beyond the limit at which damage to ecosystems is regarded likely.
- The greatest increases in water erosion risk of soils occur where water erosion is already serious, such as sub-Saharan Africa, Meso-America and the Caribbean and South and East Asia. In most regions, the risk of water erosion increases most in a *Security First* world. To make matters worse, the likelihood of effective soil management seems smallest in this future.
- Decreases in global forest area are profoundly large in the *Security First* future, a downward trend that picks up immediately in 2002. Until around 2020 a less dramatic, but downward, trend also exists for the other three scenarios. Between 2020 and 2032 the *Policy First* world starts showing more drastic decreases. In light of the assessment over the past 30 years, the better management, better technology and more efficient agriculture of *Policy First* do not seem enough to really compensate for the rapid increase in agricultural demand and expansion of other domesticated land; thus altering trends in deforestation.
- Up to 2032, natural capital will decrease in all parts of the world for all futures chosen, especially in Central Africa, Latin America and West Asia. The negative trends are smallest in the Northern Hemisphere, but this is mainly due to the fact that much biodiversity has already been lost there in the past. A look beyond the 30-year horizon reveals strong negative trends continuing in a world of *Markets First* and *Security First* but veering back in some regions in the world of *Sustainability First*.

For many of the above issues, only a world of *Sustainability First* shows a clear positive turn. Sometimes the turn is visible only beyond 2032. *Policy First*, ambitious as it may be in terms of environmental and social goals, if pursued through better governance, management and technology, would seem to be insufficient in the long run. Climate change is a point in case. The world of *Security First* bluntly illustrates poverty in many situations as a major cause/driver of environmental problems.

Part of the challenges of *Policy First* is that future environmental policies require careful coordination. Conclusions from GEO-3 (in Chapter 5: Issues for Action) therefore underline the link of global environmental strategies with such issues as poverty, lifestyle and governance. However, when focusing on environmental policies proper, co-ordination issues become visible from the scenario analyses with IMAGE, emerging at first sight as dilemmas e.g.:

- Land use for biofuels (a measure to decrease carbon dioxide emissions) competes with land requirements for food production and nature.
- An increase in intensive farming reduces the need for converting nature into agricultural land, but often leads to more nitrogen loading of coastal ecosystems.
- Efforts to conserve special nature areas are partly cancelled out by climate change if classical fixed perimeter conservation is not adapted
- Decreasing large-scale air pollution also decreases its cooling effect; however, energy and climate policies will eventually more than make up for this.

These dilemmas stem from the adverse effect that an environmental measure in one area can have on another issue. The other side of the coin is that integrated, forward-looking strategies are bound to bring large benefits, including cost savings, when compared with piecemeal, defensive approaches.

In addition, many issues are laced with legacies from the past that dominate the present and even the coming decades. Conversely, action taken may not have an immediate effect. In other words, the results of significant actions now only become apparent in the long-term future. The delays are not only caused by biophysical systems such as the climate system, but education, demographics, capital stock and infrastructure can change only so much per year. Obviously this ‘supertanker’ character of global change is a political handicap in reaching the proverbial global deal that will link environmental and developmental goals.

On a different note, the delays between action and result also visualize the need for policies on adaptation to mid-term changes that can no longer be avoided.

References

Alcamo, J., et al., 1998. *Global modelling of environmental change. An overview of IMAGE 2.1.* In: Alcamo, J., R. Leemans and E. Kreileman. *Global change scenarios of the 21st century. Results from the IMAGE 2.1 model.* Oxford: Elsevier Science.

Batjes, N. H., 1996. *Documentation to ISRIC-WISE global data set of derived soil properties on a 0.5 by 0.5° grid.* (Report 96/05). Wageningen: International Soil Reference and Information Centre.

Bollen, J. and T. Manders, 2001. *Final Report of NRP project 'Economic Impacts of GHG Stabilization Scenarios and regional differentiation of targets based on burden sharing rules'* (NRP report). Bilthoven.

Carter, T.R., M.L. Parry, H. Harasawa and S. Nishioka, 1994. *IPCC Technical Guidelines for Assessing Impacts of Climate Change*. (IPCC Special Report 0904813118). Intergovernmental Panel on Climate Change, WMO and UNEP, Geneva. pp 59.

CPB, 1999. *The WorldScan model, the Core Version*. The Hague: CPB.

De Haan, C., H. Steinfeld and H. Blackburn, 1999. *Livestock and the environment. Finding a balance.* Rome: Food and Agriculture Organization of the United Nations.

De Vries, H.J.M., et al., 2001. *The Timer IMage Energy Regional (TIMER) model.* (RIVM Report 461502024). Bilthoven: National Institute for Public Health and the Environment (RIVM).

Eickhout, B., M.G.J. den Elzen and G.J.J. Kreileman, 2002. *Atmosphere-Ocean System of IMAGE 2.2. A global model approach for climate and sea level projections.* (RIVM Report 481508017). Bilthoven: National Institute for Public Health and the Environment (RIVM).

Food and Agriculture Organisation of the United Nations (FAO), 2000. *Global Forest Resources Assessment 2000. Main Report.* (FAO Forestry Paper 140). Rome: Food and Agriculture Organisation of the United Nations.

Hannah, L., J.L. Carr, and A. Lankerani, 1994. *Human disturbance and natural habitat: a biome model level analysis of a global data set; Human disturbance of Biomes.* Washington, D.C.: Conservation International.

Harrison, P., 1992. *The third revolution; Environment population and a Sustainable world.* In association with WWF. London/New York: I.B. Taurus & Co Ltd.

Hilderink, H., 2000. *World Population in transition: an integrated regional modeling framework.* Thela Thesis, Amsterdam.

Hootsmans, R.M., et al., 2001. *Modelling land degradation in IMAGE 2.* (RIVM Report 481508009). Bilthoven: National Institute for Public Health and the Environment.

Hulme, M., et al., 2000. *Using a climate scenario generator for vulnerability and adaptation assessments: MAGICC and SCENGEN version 2.4 workbook*. Norwich.

IMAGE team, 2001a. *The IMAGE 2.2 implementation of the SRES scenarios. A comprehensive analysis of emissions, climate change and impacts in the 21st century.* (RIVM CD-ROM publication 481508018) Bilthoven: National Institute for Public Health and the Environment.

IMAGE team, 2001b. *The IMAGE 2.2 implementation of the SRES scenarios: Climate change scenarios resulting from runs with several GCMs.* (RIVM CD-ROM Publication 481508019). Bilthoven: National Institute for Public Health and the Environment.

IPCC, 2000. *Special Report on emissions scenarios*. Cambridge: Cambridge University Press.

IPCC, 2001. *Climate Change 2000. The science of climate change. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

IPCC Data Distribution Centre (IPCC-DDC), 1999. *Providing Climate Change and Related Scenarios for Impacts Assessments.* CD-ROM, Version 1.0.

Klein Goldewijk, K., et al., 1994. Simulating the carbon flux between the terrestrial environment and the atmosphere. *Water, air and soil pollution,* 76, pp. 199-230.

Kreileman, G.J.J. and A.F. Bouwman, 1994. Computing land emissions of greenhouse gases. *Water, air and soil pollution*, 76, pp. 231-258.

Leemans, R., et al., 2002. The consequences of uncertainties in land use, climate and vegetation responses on the terrestrial carbon. *Science in China.*

Leemans, R. and G.J. van den Born, 1994. Determining the potential global distribution or natural vegetation, crops and agricultural productivity. *Water, air and soil pollution,* 76, pp.133-161.

New, M., M. Hulme and P. Jones, 1999. Representing twentieth-century space-time climate variability. Part I: Development of a 1961-90 mean monthly terrestrial climatology. *Journal of Climate,* 12, 829-856.

Oldeman, L.R., R.T.A. Hakkeling and W.G. Sombroek, 1991. *World map of the status of humaninduced soil degradation - an explanatory note (GLASOD).* 2nd revised edition. Wageningen / Nairobi: ISRIC / UNEP.

Olivier, J., et al., 2001. *Applications of EDGAR. Including a description of EDGAR V3.0: reference database with trend data for 1970-1995.* (RIVM Report 773301). Bilthoven / Apeldoorn: National Institute for Public Health and the Environment / Netherlands Organization for Applied Scientific Research.

Raper, S.C.B., T.M.L. Wigley and R.A. Warrick, 1996. *Global sea-level rise: past and future.* In: J.D. Milliman and B.U. Haq, eds. *Global sea-level rise: past and future*. Dordrecht: Kluwer Academic Publishers, The Netherlands, pp. 11-45.

Rodenburg, E., D. Tunstall and F. van Bolhuis, 1995. *Environmental Indicators for Global Cooperation.* (Global Environmental Facility, Working Paper 11, pp36). Washington, D.C.: The World Bank.

Rotmans, J., 1990. *IMAGE. An Integrated Model to Assess the Greenhouse Effect.* Dordrecht: Kluwer Academic Publishers.

Rotmans, J., H. de Boois and R.J. Swart, 1990. An Integrated Model to Assess the Greenhouse Effect: the Dutch approach. *Climatic Change,* 16, pp. 331-356.

Schlesinger, M.E., et al., 2000. Geographical distributions of temperature change for scenarios of greenhouse gas and sulphur dioxide emissions. *Technological Forecasting and Social Change*, 65, 167-193.

Ten Brink, B., 2000. *Biodiversity indicators for the OECD Environmental Outlook and Strategy, a feasibility study.* (RIVM Report 402001014), Bilthoven: National Institute for Public Health and the Environment.

Ten Brink, B., et al., 2000. *Technical report on biodiversity in Europe: an integrated economic and environmental assessment.* Prepared by RIVM, EFTEC, NTUA and IIASA in association with TME and TNO. (RIVM Report 48150519). Bilthoven: National Institute for Public Health and the Environment.

Ten Brink, B., 2001. *The state of agro-biodiversity in the Netherlands. Integrating habitat and species indicators.* Paper for the OECD workshop on agro-biodiversity indicators, 5-8 October in Zurich, Switzerland.

Terborch, J., 1989. *Where have all birds gone?* Princeton: Princeton University Press.

United Nations Environment Programme (UNEP), 2002. *Global Environment Outlook 3.* London: Earthscan.

Van Drecht, G., et al., 2001. Global pollution of surface waters from point and non-point sources of nitrogen. *The Scientific World*, 2001 (1).

Vellinga, P. and R. Swart, R., 1991. The greenhouse marathon: a proposal for a global strategy. *Climatic Change*, 18, pp. vii-xii.

Wischmeier, W. H. and M.D. Smith, 1978. *Predicting Rainfall Erosion Losses - a Guide to Conservation Planning.* (Report 537). Washington, D.C.: US Department of Agriculture.

Zuidema, G., et al., 1994. Simulating changes in global land cover as affected by economic and climatic factors. *Water, air and soil pollution*, 76 (1994), pp. 163-198.

8. Cross-comparisons and review of the analytical process

GEO-3 was produced by various teams – including regional experts – using a variety of analytical tools. But did these teams, working in parallel, base their work on a similar interpretation of the scenarios? What does a comparison of the projections by the various teams tell us about the uncertainty in the models? To what extent did the analytical set-up contribute to the aim of truly involving the GEO network in the assessment?

8.0 Introduction

Models and related tools were used to quantify scenarios in GEO-3, as they can add greater rigour, precision and consistency to qualitative story-lines. In order to arrive at high-quality results for a broad spectrum of environmental issues, the GEO-3 Outlook was written using specific modelling frameworks and teams – each authoritative in its own field of environmental science – to estimate specific variables (see Table 8.1 and S.1).

Working with multiple modelling frameworks raises a number of issues, such as possible divergence in the backstage interpretation that the teams may have given to many aspects of the scenarios in order to arrive at quantification and assessment.

As a first step in exploring these issues, a background description (Section 8.1) briefly considers the nature of the GEO-3 scenarios and that of the tools used in the quantification. It covers the current use of the analytical tools, including the intended process of iteration between model-based quantification and narrative story-lines (Sub-section 8.1.3), the interpretation of the narrative story-lines by the different analytical teams (Sub-section 8.1.5), and the allocation of roles. Among other things, this section compares GEO-3 with two recent exercises that also combined narrative story-lines with quantitative modelling: the IPCC SRES and World Water Vision (WWV) (Sub-section 8.1.6).

Building on this, in Section 8.2 a closer look is taken at the quantitative results of the GEO-3 scenario exercise. Overlapping outcomes from some of the teams – using different tools – are compared and differences and similarities are evaluated. This analysis is based on GEO-3 data, but it was carried out after the main report was published. Sub-section 8.2.1 compares the results obtained with AIM and IMAGE 2.2, while Sub-section 8.2.2 compares PoleStar results with IMAGE 2.2 outcomes. Incongruent outcomes based on the same narrative may be attributable to differences in input data and assumptions among analytical teams (i.e. different interpretations of the story-lines), but they may also be the result of differences in the characteristics of the tools described in Section 8.1. A comparison of the outcomes can provide an indication of at least part of the uncertainty involved.

Table 8.1: Analytical tools and the impact variables they provided for the GEO-3 Outlook Chapter

	Variables provided for the GEO-3 Outlook Chapter
PoleStar	Cropland severely degraded Extent of built environment People living with hunger
GLOBIO	Ecosystems impacted by infrastructure expansion
WaterGAP	People living in areas with severe water stress
AIM (here used only for modelling Asia & Pacific)	Energy-related carbon dioxide emissions Energy-related nitrogen dioxide emissions Energy-related sulphur oxide emissions Municipal solid waste generation
IMAGE	Nitrogen loading of coastal marine ecosystems Energy-related sulphur dioxide emissions Energy-related carbon dioxide emissions Carbon dioxide emissions from all sources, rate of average temperature change & change in annual total precipitation Risk of water erosion of soils Natural forests excluding re-growth Pressures on natural ecosystems & Natural Capital Index

Finally, in Section 8.3 the findings of this chapter are discussed. Questions such as the following are addressed:

- Was the GEO-3 multiple modelling approach useful, given the priorities of the overall GEO-3 process?
- How well do the overlapping outcomes of the analytical tools compare, and what does this say about the consistency of the teams' interpretation of the GEO-3 narratives?
- Did the process of quantifying the GEO-3 Outlook measure up to UNEP's goal of strengthening its regionally distributed assessment network?

8.1 Background

8.1.1 The blend of analytical approaches used in the GEO-3 Outlook Chapter

An important aspect related to the interpretation of the narrative story-lines that must be clear at the outset is the question of whether the scenarios are seen as explorative or backcast scenarios. The key issue here is to what extent the future image, or vision, constrains the scenario. An explorative scenario begins with the question 'What if the following were to happen?' It then maps out the paths of possible futures, usually involving statements on a set of assumptions about the current state of the world, the way the world works, and how people will respond to future events. These assumptions do not necessarily reflect the conventional wisdom on what is most likely, but they do need to be plausible.

Alternatively, a backcast scenario begins with a vision of the future and asks the question: ‘How can we get there from where we are today?’. This also requires a set of assumptions about the current state of the world, the way the world works, and how people will, or could, respond to future events. These assumptions are, however, tailored to finding and following one of the possible paths that will lead to the postulated future. Of course, in answering this question, one may come to the conclusion that this vision of the future is extremely unlikely or impossible, given the time-frame. This can be one of the most important insights gained from such a backcasting scenario exercise.

Backcasting thus places greater restrictions on both the storytelling and the use of quantitative tools, as the choice among different plausible sets of assumptions is constrained by the need to reach a particular final state of affairs. Of course, the extent to which this is the case will depend on how detailed the definition of that state is.

In GEO-3, the *Policy First* scenario was originally intended to be a backcast scenario and it had specific policy goals. However, as the process of elaboration and analysis progressed, *Policy First* was increasingly treated as one of four explorative scenarios. As far as model-based quantification is concerned, two problems emerged. One was that a number of modelling frameworks were not primarily designed to develop or analyse backcast scenarios. The other was that some of the targets appeared difficult to achieve under the assumptions of this specific scenario. Eventually, the GEO-3 scenario set came to include characteristics of both types of scenarios, explorative as well as backcast.

The various teams involved in GEO-3 have different perspectives as regards this issue. The PoleStar team, for instance, stayed close to the roots of the scenarios in the Global Scenario Group and to the ideas initially tabled in September 2000. As a consequence, PoleStar simulations for *Policy First*, *Security First* as well as those for *Sustainability First* were constrained by the attributes of the 2032 vision in all of these scenarios. For other teams, recent experiences with the WWV and IPCC-SRES scenarios influenced their contributions to the GEO-3 scenario exercise.[12] These teams approached all four scenarios of the GEO-3 set as explorative scenarios.

8.1.2 The nature of the analytical tools used

An important issue in scenario development is ascertaining to what extent system behaviour in the past is valid for the future. The two extremes with respect to this issue are ‘free storytelling’ and ‘fully deterministic modelling’. Unconstrained storytelling allows any new thought about the future to be considered valid. Full determinism – the classical scientific way of looking at small and well-defined systems – presumes that the future will unfold according to fixed rules that can be derived from empirical observations and theories derived from historical behaviour. The tools chosen for the GEO-3 Outlook represent positions on a spectrum between these two extremes.

---

[12] Chapter 2 provides a detailed description of both the narrative (Section 2.2) and quantitative (Section 2.3) development of the GEO-3 scenarios, as well as an account of efforts to harmonize scenario assumptions for growth in GDP per capita among the various teams (Section 2.4).

Related to this is the balance that each scenario-developing tool[13] strikes between the conflicting goals of internal consistency and flexibility. While all scenario designers strive to build consistent scenarios, the actual tools used differ with respect to built-in consistency. A large degree of built-in consistency makes the scenario designer's work easier, since less detailed checking and review are required per iteration. However, it has the drawback that the scenarios may miss important features of how real social, environmental and economic systems actually behave – after all, the consistency is internal; it does not, in fact cannot, mean that the model is consistent with all the possible dynamics that are found in real systems.

In practice, the gap between the relatively deterministic models used in the GEO-3 Outlook (IMAGE 2.2, AIM and WaterGAP) and 'simple' tools such as PoleStar and GLOBIO is smaller than it might at first appear, since the parameters in the deterministic models can be changed to extend the possible range of scenarios. One area where there is a difference is the fact that PoleStar and GLOBIO are modified by scenario designers at a 'general' level, for example, according to a trend in average agricultural land area per capita in a region over the whole scenario period. Deterministic models, however, are modified at a 'detailed' level. An example is the 'sub-model project' level, at which the growth or decline in various types of agricultural land use are projected onto a map according to separate developments for a series of determinants such as exports, disposable income, diet and agricultural technology.

The most appropriate level of modification will depend on the particular scenario exercise for the tool being used. For instance, in some scenario exercises an interactive dialogue with a non-expert audience is more important than in others. The tools discussed in this report each have different potential for use in flexible interaction with non-experts. A broad study like GEO-3 benefits from the complementary strengths of each approach.

Moving towards the deterministic end of the spectrum, WaterGAP, AIM and IMAGE 2.2 attempt to describe the environmental system in the context of socio-economic developments using an interdependent set of mathematical models. These models are defined by starting conditions and a set of algorithms allowing the future to unfold in a continuous, incremental manner. In regional socio-ecological systems this can be described as a premise of structural continuity, since structural relationships based on observations from the past limit the scope for 'possible' futures. Some of these relationships are widely accepted (such as features of energy systems that cannot change faster than investment rates allow). Other relationships, however, are more contentious (e.g. the impact of changes in savings rate on changes in an energy production mix).

The requirement for consistency between such assumptions is an important reason for pleading structural continuity in deterministic models. The move towards energy intensity modelled in IMAGE 2.2, for example, depends on such factors as energy demand, the price development of energy carriers and economic growth. Within their structural constraints, however, the models can explore a range of possible futures, as assumptions at the parameter level can represent different directions in future developments, producing fundamentally different results. The advantage of

---

[13] The analytical tools used for this GEO-3 scenario exercise are AIM, GLOBIO, IMAGE, PoleStar and WaterGAP. Each tool is described separately in Chapters 6, 4, 7, 3 and 5, respectively.

deterministic models is that they provide a measure of feasibility, i.e. if certain developments (such as major changes in agricultural productivity or capital stock) are achievable, given constraints of population growth and economic development. A drawback is that it is more time-consuming to employ these detailed models than a tool like PoleStar.

In contrast, the emphasis in GLOBIO and PoleStar is on assumptions rather than structural continuity. Tools like PoleStar were designed to easily quantify scenarios with structural breaks and discontinuities. The framework allows the user to decide on a set of exogenous assumptions that are not as strictly constrained by such consistency rules, as is the case with the more deterministic IMAGE 2.2. PoleStar is based on fundamental balances (economic accounts, energy, land, water and food balances) that only impose broad constraints on how the world can change. Specific scenarios are then constructed by drawing on a range of tools (including mathematical models such as inequity as a function of income, but also external studies, qualitative descriptions and expert review). Nevertheless, there are clearly constraints in PoleStar, such as accounting rules in which fractions cannot exceed the whole, or where a system changes at a certain rate.

As discussed in Section 8.1.1, several of GEO-3 scenarios were, in fact, originally developed from backcasts that were geared to creating visions of the future in 2032. Unlike WaterGAP, AIM and IMAGE 2.2, the PoleStar simul ations are constrained by quantitative attributes, allowing the scenario to bridge the gap between initial and future conditions. The more 'deterministic' models may reflect the future state in their internal algorithms, which is why multiple runs will be required to realize the conditions postulated for the future. In contrast, the ability to quantitatively specify future conditions as a constraint in simulation was fundamental to the design of PoleStar.

Thus, if we compare the final and intermediate outcomes derived using the different tools, we would expect more drastic changes and differences in the results generated by PoleStar and GLOBIO than in those coming from WaterGAP, AIM and IMAGE 2.2, where changes tend to be slower and smoother, and differences more gradual.

In addition to the degree of determinism, the tools used for the GEO-3 Outlook differ in at least one other key aspect, namely, the spatially explicitness of the impact projections. While PoleStar provides impact projections at the same resolution as the assumptions (i.e. those from the GEO-3 sub-regions), models such as IMAGE or WaterGAP deliver their land and water-related output mapped onto a 1/2 x 1/2 degree grid (equivalent to approximately 50 x 50 km at the equator) or all 10 000 'first order' rivers. Much of the effort expended in designing and updating these models is being devoted to ensuring that the integration in their projections also holds at the grid-cell level. The AIM model, too, is capable of delivering land-related results on a high-resolution grid, although this capability was not used in the projections for emissions and waste generation provided for GEO-3 by AIM. GLOBIO even delivers map-based output on a 1 x 1 km grid, which is enormously detailed for a global tool, but it compensates for the detail by keeping the modelling very simple.

Spatially explicit models have an important influence on regionally differentiated studies such as GEO because the spatial pattern can be used to either refute or support the aggregated regional or sub-regional figures. In other words, they help to tell the story of the significance and plausibility of particular projections. They can also be used to highlight changes that are averaged out in regional/sub-regional totals, such as large spatial shifts in agriculture under the influence of climate change (see for example Alcamo and others, 2003). Yet, as with any set of underlying data in forward-looking analysis, the maps themselves should be interpreted with care – they are more useful for pattern analysis than for pinpointing actual changes on the map.

8.1.3 How the analytical tools were used

In developing scenarios that combine narrative and quantitative elements, a number of options exist, providing different answers to the following questions: 1) to what extent is there iteration between the development of the narrative stories and the quantification?; 2) how are the narrative storylines interpreted while doing the quantification?; and 3) if more than one framework is used for quantification, to what extent do they complement each other (i.e. does each quantify a different aspect of the scenario) and to what extent do they overlap (i.e. with each providing its own quantification of the same aspects of the scenario)?

Before comparing quantitative findings across the teams, the remainder of section 8.1 briefly characterises the analysis of environmental impacts for the GEO-3 Outlook in terms of the above questions, comparing the GEO-3 Outlook process with other recent global scenario studies. This is the subject of sub-sections 8.1.4 through 8.1.6.

8.1.4 Iterating between developing story-lines and model-based quantification

In an ideal scenario exercise, there would be a number of iterations during which the narratives and quantification provide mutual feedback. This would allow for greater integration of the strengths of the two approaches, leading to richly described, empirically grounded, consistent, coherent scenarios. The drawback lies in the amount of time and resources this requires.

In the IPCC SRES process, the modelling tools were only used to develop quantitative scenarios once the basic features and driving forces of the narrative story-lines had been determined. There is no indication – at least, in the published reports – that there was any feedback from the quantitative analysis to the story-lines. In the WWV process, on the other hand, there were three formal rounds of iteration between the qualitative scenarios and the modelling efforts (along with commentary from regional and sectoral forums). In fact, the initial round of feedback led to an overall revision of the scenario story-lines (see Box 2.2). Nevertheless, the strong emphasis on the narrativeswas maintained, as described by Gallopín and Rijsberman (2000, p. 17):

> *The approach followed deliberately focused on the development of qualitative scenarios initially, to allow incorporation of the many social, economic, environmental and cultural factors that play a major role in shaping the water future, but may not be modelled quantitatively. The development and discussion of qualitative scenarios served as a platform for consultation among many stakeholders from different disciplinary backgrounds and a variety of stakeholder perspectives. Mathematical simulation models were used subsequently to analyse the consistency and coherence of the qualitative scenarios, explore some of the consequences and help fill in some of the gaps.*

For much of the time, the quantitative efforts in the GEO-3 process centred on reproducing information from scenarios that were already available and had a similarity with the GEO-3 scenarios in order to illustrate the types of environmental consequences that might be expected in each scenario. This was not so surprising, as it had been agreed at the Planning Meeting in July 2000 that there was neither the time nor sufficient resources to develop new data. Although some efforts were made to modify existing scenario data to take into account some aspects of the GEO-3 narratives, concerns were increasingly raised – internally and externally – about the remaining inconsistencies.

It was only after the Scenarios Expert Meeting in November 2001 that a major effort was made to better integrate the quantitative material and narrative stories. The possibilities for doing this were limited by the rapidly approaching deadline for the full report, which precluded, among other things, further extensive consultations with the regional teams. It was also difficult to link the initial quantification, which was partly based on previous work by the Global Scenario Group and partly on impressions from regional consultations, to the impact estimates generated by the deterministic models. The net result was that the scenario development process provided for less than ideal integration between the narrative and quantitative elements.

8.1.5 Interpretation of narrative story-lines

Because of their different structures, different tools may generate different estimates for the environmental consequences of the same scenario. Of more concern are the input assumptions made by the teams and embedded in the tools. Any given scenario narrative leaves room for interpretation when it comes to setting of specific quantitative representations. In addition, what may be exogenous inputs for some tools may be endogenous for others, e.g. energy efficiency can be a direct input or can be calculated from other factors such as relative prices and rates of investment. It may also be the case that, even if they are not formally linked in the tool itself, the users of the tool may have good reasons for maintaining certain relationships between various input assumptions. The key conditions that should be fulfilled are that the quantitative assumptions themselves ought to be consistent with the narratives and that the way they are used remains consistent with the narratives[14]. Within these constraints there is typically a range of options.

In deriving the assumptions for quantitative input into the GEO-3 scenarios, the choice was made to ensure that the different teams respected the narratives as constraints, but to accept the use of different numbers. Furthermore, we closely scrutinized the process of harmonising the assumptions for population and GDP per capita, as these are the key underlying drivers in all of the analytical tools. This harmonization was undertaken by SEI and RIVM, with all of the teams except SEI eventually using the input assumptions and intermediate projections, e.g. for land use, that were provided by RIVM (see Sections 2.2, 2.3 and 2.4 for details of these efforts).

---

[14] For example, the presumed development of regional GDP per capita in a *Sustainability First* scenario can be cast in very different numbers, depending on whether the related analysis of impacts operates on the assumption that many economic transactions will continue to be reflected in the GDP or not. The two approaches may be fully consistent in their outcomes even when the numerical assumptions look different at first sight.

In the IPCC-SRES process, a similar approach was taken, but more flexibility was allowed because of the number of quantitative scenarios produced. Within each of the four SRES scenario families, one of the quantitative scenarios was defined as the representative, or ‘marker’, scenario. Further scenarios within the family were classified as either ‘harmonized’ or ‘other’ scenarios. For a scenario to be considered harmonized, the input assumptions for specific key drivers – population, gross domestic product, and final energy – were required to fall within a certain range around those in the marker scenario, at both the global level and that of the four SRES regions. In the case of WWV, the different modelling teams worked together to produce a consistent set of scenario assumptions. PoleStar quantified the driving forces affecting population, economic growth, electricity production, equity, and food security. Furthermore, in some cases output from one model was used as input in another model to ensure consistency.

8.1.6 Multiple model exercise

Different modelling frameworks have different strengths and none can fully capture all of the richness of a narrative story. From that perspective, it is valuable to use a variety of models to address the various aspects of the narrative stories. At the same time, if the modelling frameworks can provide overlapping data, this makes it possible to explore the uncertainties arising from the differences among the quantitative frameworks, as well as those arising from different underlying assumptions. For this, however, the different models must be able to provide quantitative data at the same spatial, temporal, and structural aggregations.

The approach taken in the main GEO-3 report was to present separate variables (e.g. water stress) as quantified by one specific model (e.g. WaterGAP). This meant that the effects of differences in model structure would not be revealed in the results, but a wider range of variables could be considered. However, the estimates produced with the various tools do in some cases comprise comparable variables, so it was possible to make some comparison within scenarios across the models. See 8.2 for the results of these comparisons.

In contrast, in the SRES process each modelling group provided a complete set of results for each quantitative scenario it produced. As noted in Box 2.1, however, most comparisons required the models to provide data at a high level of aggregation, specifically at the level of four major regions: OECD90, Africa & Latin America, Asia, and countries engaged in economic and institutional reform. Given the emphasis in the GEO process on regional and sub-regional detail, this would have been an unattractive option for the GEO-3 scenarios. Furthermore, even with this level of aggregation, problems remain in relation to determining whether the source of the differences found is a direct result of the model structure vis à vis input assumptions (Van Vuuren, 2002).

In the WWV process (see Box 2.2), the different modelling teams and models provided both overlapping and complementary information. Through a series of three meetings and further interaction, the teams worked to provide a consistent, coherent set of results. This was done by discussing driving forces, defining shared assumptions, and exchanging data and information, including cases where output from one model was used as input for another. In the end, each group presented its own output separately .

8.2 Comparison of findings between teams

The variables calculated in GEO-3 were based on specific modelling frameworks (see Table 8.1). These frameworks allow calculation of more variables than those actually used in GEO-3, however, and there is some overlap in the variables quantified (see Table 8.2). This makes it possible to compare the frameworks using overlapping outcomes. The comparison is based on scatter plots (Figures 8.1 and 8.2) in which outcomes for the one model can be read on the x-axis, and for the other on the y-axis. The left hand sides of Figure 8.1 and 8.2 relate to the 2032 *levels*; the right hand sides relate to the *changes* between 2002 and 2032. The scatter plots are supplemented by two statistical measures that test how significant the similarity is between two data sets (see Box 8.1 for details).

This section evaluates whether there is consistency between modelling teams in the assumptions they made for the quantitative interpretation of story-lines on the basis of overlapping outcomes. Differences in overlapping outcomes between two analytical frameworks may be attributable to differences between the modelling teams (Potting and others, 2002), for example in the:

- definition of the variables
- model structure (see also sub-Section 8.1.2 on the nature of the tools)
- regional classification
- input data for the base year for scenario calculations
- interpretation of story-lines (and/or specific assumptions).

Below we evaluate the differences in overlapping outcomes between the frameworks in the light of the issues discussed above.

Table 8.2: Variables that are compared between PoleStar, AIM, and IMAGE 2.2

	PoleStar	**AIM**	**IMAGE 2.2**
Energy-related emissions of carbon dioxide in GEO-3 regions	X		X
Energy-related emissions of carbon dioxide in GEO-3 sub-regions in Asia and the Pacific		X	X
Energy-related emissions of nitrogen dioxide in GEO-3 sub-regions in Asia and the Pacific		X	X
Energy-related emissions of sulphur dioxide in GEO-3 sub-regions in Asia and the Pacific		X	X
Cropland in GEO-3 regions	X		X
Pasture in GEO-3 regions	X		X

BOX 8.1 Statistical tests used to compare sets of findings between teams

Scatter plots as in Figures 8.1 to 8.2 are an obvious way to visualize differences and similarities between data from two modelling frameworks. Provided that x-axis and y-axis have the same scale (as is the case here), the scattering of data around the mirror line gives a first indication of how well the two modelling teams compare.

The estimate by team x for scenario i applied to region j (in brief: x_{ij}) will always differ somewhat from the corresponding estimate by team y. We may want to know if the differences between the teams' sets of estimates for the various scenarios and regions_i are statistically significant. To answer this question, we should first define what we mean with 'differences'. We could test if the overall means (μ_x and μ_y) of the two groups differ, but may also look at the median or other percentile values. We could look if the variances (σ_x^2 and σ_y^2) differ between the two sets, focus on skewness or kurtosis, or test if the cumulative distribution functions of the estimates of the two groups (denoted as F_x and F_y) differ significantly.

In this Chapter we have chosen two statistical non-parametric tests: the *Wilcoxon signed ranks test* and the *Kolmogorov-Smirnov two-sample test*. Both tests are non-parametric, meaning that we do not depend on assumptions on distributions of the data x_{ij} and y_{ij}. The Wilcoxon signed ranks test utilizes information about the relative magnitude and the direction of the differences within pairs (x_{ij},y_{ij}) The test gives an answer to the question if the differences can be considered to be insignificant (H_0 hypothesis) as opposed to the hypothesis of significant differences (H_1 hypothesis).

The Kolmogorov-Smirnov two-sample test is a test of whether two independent samples have been drawn from the same population (or from populations with the same distribution function). In other words, we test if there are significant differences between F_x and F_y. The test is sensitive to any kind of differences in the distribution from which the two samples were drawn – differences in location (central tendency), in dispersion, in skewness, etc. The H_0 hypothesis is that $F_x = F_y$, while the H_1 hypothesis is $F_x \neq F_y$.

In both tests we accept the H_0 hypothesis of no differences if the probability value of the test is more than 0.05, i.e. we want to be 95% certain before rejecting this hypothesis. Otherwise, we accept H_1. The probability values are the numbers quoted next to the scatter plots.

Because the size and direction of change of environmental pressures, compared between the four scenarios, is key information for the messages of GEO-3, we have compared the teams' estimates of changes in addition to the levels (of, for example, carbon dioxide emissions). The scatter plots on the right-hand side relate to changes 2002-2032.

8.2.1 AIM and IMAGE 2.2

For a number of variables, results derived from NIES were incorporated in the GEO-3 Outlook, using the AIM model for the Asia and Pacific region and its sub-regions (see Table 8.1). However, RIVM results for the Asia and Pacific sub-regions are available as well, based on IMAGE 2.2. This makes it possible to compare the two teams' interpretations.

Figure 8.1 compares the teams' quantifications of future energy-related emissions of carbon dioxide, nitrogen oxides and sulphur dioxide. In these plots, an ideal similarity between the teams'

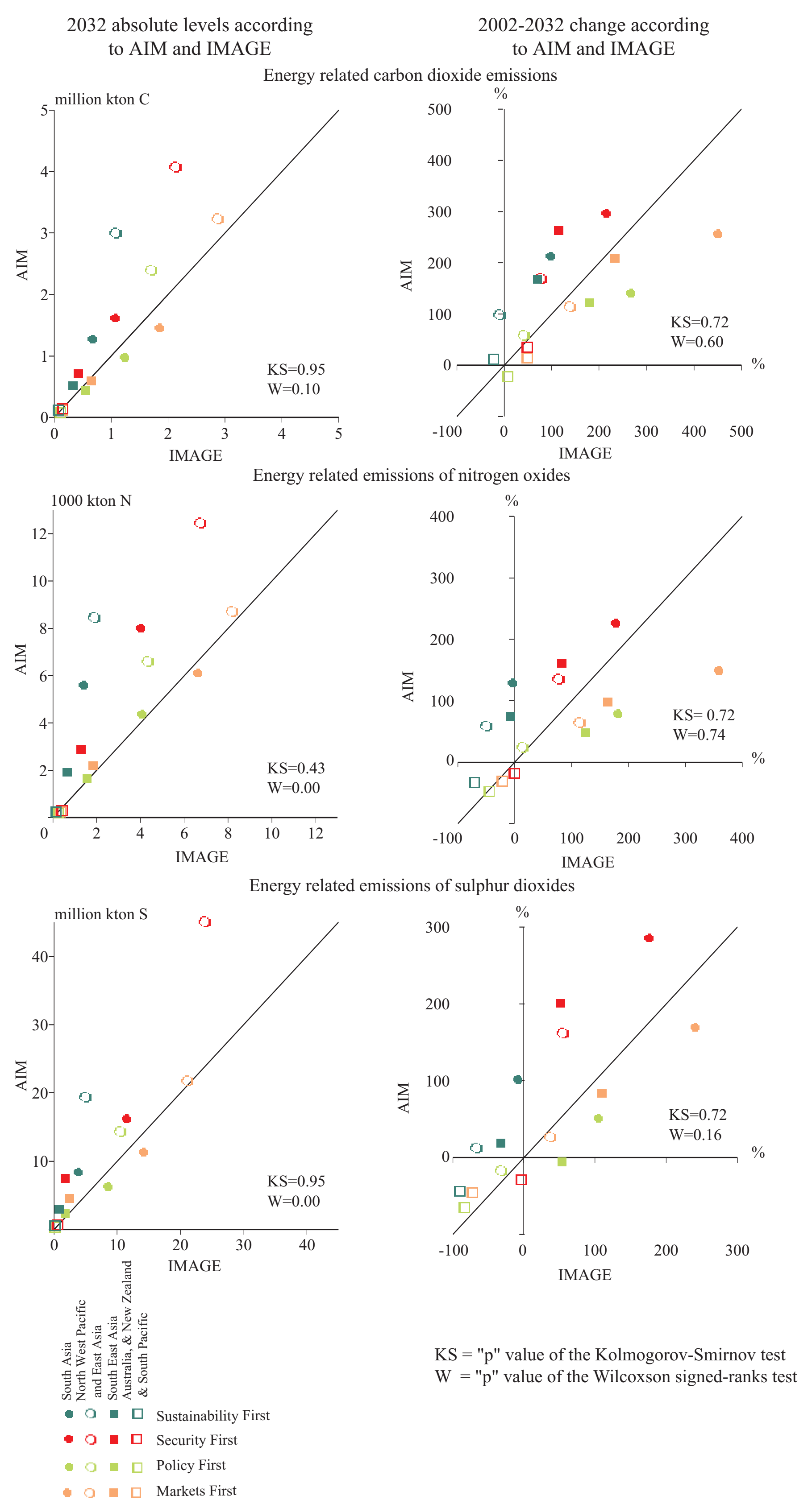


Figure 8.1: AIM and IMAGE 2.2 scenario results for selected variables in Asia and the Pacific

projections would show as scatter in the form of a narrow ellipse around the mirror line. Box 8.1 explains the statistical tests that were used in addition to this graphical comparison.

At first sight, the pattern displayed in Figure 8.1 may seem less than ideal. However, the largest differences between the results from the AIM and IMAGE teams relate to East Asia alone. As will be explained, these are due to a difference in estimates of developments in the energy sector in that sub-region between 1995 and 2002, i.e. before the start of the scenario period. In fact, most of the remaining pattern shows a reasonable similarity.

The fact that the Asia and the Pacific region in IMAGE does not include Iran will have contributed to the difference seen in the base year for the South Asia sub-region. This discrepancy makes the sub-region in IMAGE 15% smaller in terms of population and 40% smaller in terms of land area. Central Asia – another area causing a large discrepancy in the definition of this region – is not included in the comparison in this chapter because it is in a completely different region in IMAGE. However, these discrepancies in regional definition are not responsible for all of the base year differences in the Asia and the Pacific region.

More importantly, it could be asked if the regional definitions influence the comparison of projections between the teams. This seems to be the case, but again only for South Asia. The reasoning is as follows. Although no separate story-lines have been prepared for individual countries within South Asia, it can be presumed that the worlds of *Markets First* and *Security First* will be more dissimilar for Iran than for India, the other large country in the sub-region. Thus, we would expect *Markets First* and *Security First* to be further apart in the South Asia impact projections carried out by the IMAGE team than in those done by the AIM team. Indeed, for carbon dioxide emissions – the impact variable that is the easiest to compare – this is the case in IMAGE (Figure 8.1, top right-hand graph, South Asia).

Having discussed the potential effect of differences in base year data and regional definitions, four observations can be made about the teams' apparent consistency of interpretation. These are discussed below.

Table 8.3: AIM and IMAGE 2.2 data for energy-related emissions in 2002

	Carbon dioxide		Nitrogen oxides		Sulphur dioxide	
	AIM	IMAGE 2.2	AIM	IMAGE 2.2	AIM	IMAGE 2.2
	mln kton C		1000 kton N		1000 kton S	
South Asia*	0.41	0.34	2.45	1.44	4.20	4.14
North West Pacific and East Asia	1.51	1.21	5.31	3.82	17.19	15.45
South East Asia	0.20	0.20	1.10	0.69	2.48	1.14
Australia & New Zealand & South Pacific	0.11	0.10	0.35	0.41	0.97	0.52

* Without Iran for IMAGE 2.2

Firstly, viewing all scenario results together, the similarity between the teams looks better for the changes between 2002 and 2032 (the scatter lies symmetrically around the mirror line) than for the absolute emissions (the scatter lies on the AIM side of the mirror line). However, the difference for absolute emission estimates can largely be traced back to the 2002 data of the two teams (see Table 8.3). For carbon dioxide, for instance, emission projections for most of Asia and the Pacific correspond reasonably well among the models.

Only for East Asia (China, mostly) did the two teams produce different projections. In East Asia emissions grew relatively fast between 1980 and 1995, while since 1995 emissions in the sub-region have probably declined due to a decline in the use of coal. As a result, the emission trends since 1995 are more uncertain in East Asia than in the rest of the region. Reflecting this, the two models, calibrated against different datasets and different years, show different trends over the 1995-2002 period. For 1990, their emission data are in fact similar.

In addition, AIM emission estimates for nitrogen oxides and sulphur dioxide for the whole region in 2002 are larger than those produced by IMAGE[15]. There is no obvious explanation for this difference. But it relates to the base year, not to the developments over the scenario period.

Notwithstanding the differences for the base year, the statistical tests applied to all AIM and IMAGE scenario results together do confirm similarity. That is to say: most of the results indicate a similarity. Only the Wilcoxson test for the absolute numbers for emissions of nitrogen and sulphur oxides shows a lack of similarity, reflecting the fact that too many of the data points lie on one side of the mirror line rather than around it.

Secondly, considering the interrelationships among the outcomes of the four scenarios, the AIM and IMAGE results are consistent. For example, see the quadrangular constellation formed by the carbon dioxide plots for NW Pacific and East Asia. The scenario results show *Security First* in the upper right corner, *Markets First* in the lower right corner, *Policy First* in the lower left corner and *Sustainability First* in the upper left corner. The pattern for other regions is similar.

Thirdly, the teams are consistent regarding the ranking of the sub-regional emissions in absolute terms. Roughly speaking, the North West Pacific and East Asian emissions are larger than South Asian emissions, which in turn are larger than South East Asian emissions, which are larger again than the emissions in Australia, New Zealand and the South Pacific.

Fourthly, the *Security First* and *Sustainability First* scenarios feature higher levels of emissions in AIM than in IMAGE 2.2. Regarding *Security First*, IMAGE 2.2 contains a built-in response mechanism that starts to include policies as soon as emissions of nitrogen and sulphur oxides become so large that policy-makers will presumably have to take action, simply to maintain acceptable living conditions in their cities. Since AIM does not contain such a mechanism for

---

[15] AIM emission data is based on country data from the Asian and Pacific region. The primary source for the IMAGE 2.2 data is the EDGAR database. Different from AIM, the EDGAR database is not based on self-reported country data, but calculated from activity factors and emission factors from international sources. There may therefore be some variations between AIM and the EDGAR database for Asian and the Pacific data. IMAGE 2.2 is calibrated using the EDGAR database, but does not necessarily reproduce the EDGAR data for every single year.

Security First, this may explain why the AIM projection exceeds that of IMAGE 2.2 for this scenario.

The differences between the *Sustainability First* results in AIM and IMAGE 2.2 seem to be largely attributable to assumptions about whether strict environmental policies are introduced. In this scenario, IMAGE 2.2 presumes that stringent environmental policies are combined with ambitious climate policies all around the world. AIM does not take such policies into consideration, but its environmental Kuznets effect[16] sets in relatively early under the *Sustainability First* scenario. This explains why AIM emissions of energy-related nitrogen oxides and sulphur dioxide for *Sustainability First* and *Policy First* are always lower than for *Markets First* and *Security First*, but not why these emissions for *Sustainability First* are clearly larger in AIM than those in IMAGE 2.2. Apparently stringent environmental policies in combination with ambitious climate policies as presumed in the IMAGE 2.2 interpretation of *Sustainability First* lead to larger emission reductions than the Kuznets effect in AIM.

In all, the quantitative interpretations of the GEO-3 story-line for the changes in energy-related emissions up to 2032 seem consistent between the two teams. This good overall consistency may be partly due to the harmonization process in SRES-IPCC (see Box 2.1) and post-SRES in the IPCC Third Assessment Report-Working III (IPCC, 2002), in which both teams took part. In addition, the general model structures of AIM and IMAGE 2.2 have important similarities. However, the teams' interpretations differ regarding the stringency of environmental and climate policies in a *Sustainability First* world and regarding responses to very large air polluting emissions in a *Security First* world. But these differences in interpretation and subsequent quantification are relatively specific.

8.2.2 PoleStar and IMAGE 2.2

The introduction to this chapter highlighted the differences between PoleStar and IMAGE 2.2. The main emphasis in PoleStar is on flexibility (in order to be able to consider a wide range of assumptions in scenarios). This approach is different from that taken in a more deterministic model such as IMAGE 2.2 in which the description of the environment system is detailed and defined by initial conditions and where the future unfolds in a continuous, incremental way. Another feature of IMAGE 2.2 is the high spatial resolution for issues related to land use. This – together with the clear difference in focus between the two tools – makes it particularly interesting to compare scenario outcomes for energy-related carbon dioxide emissions, pasture and cropland between PoleStar and IMAGE 2.2. As this section shows, the results from PoleStar and IMAGE 2.2 seem at times to conflict and at others to reinforce each other, with the two approaches coming together at a broad level.

The GEO-3 Outlook shows the results from IMAGE 2.2 for energy-related emissions of carbon dioxide, but PoleStar estimates for this variable are available as well. This makes it possible to compare PoleStar and IMAGE 2.2. Comparison is also possible for cropland and pasture areas.

---

[16] The environmental Kuznets curve hypothesis postulates an inverse U relationship between income level and pollution (see Chapter 6 for details).

Estimates of changes in these areas were not included in the GEO-3 Outlook, but they underpin, for example, the projections with IMAGE that relate to terrestrial biodiversity and the risk of water erosion of soils. Figure 8.2 shows the scatter plots and the results of the statistical tests, Box 8.1 explains the statistical tests, and Table 8.4 presents data for the base year.

Differences in regional definition introduce some distortion into the comparison, but this is only significant for West Asia. For the other regions, the relative differences at the regional level are not that large, even though some rather big countries (Iran, Turkey, Kazakhstan and the other republics in Central Asia) are classified in the 'wrong' region. But West Asia is much smaller and therefore the difference between its GEO-3 definition and its IMAGE definition is significant. (The IMAGE region includes a land area that is two-thirds larger and in the base year it has more than double the number of people and double the GDP.) Presumably, including Turkey and Iran in the IMAGE definition of West Asia creates a bias towards stronger growth. Indeed, the changes for carbon dioxide emissions between 2002 and 2032 – the impact that is easiest to compare – suggest that this is the case.

First, the projections for energy-related carbon dioxide emissions are compared (see the top row in Figure 8.2).

In terms of the 2032 *levels* of carbon dioxide emissions, the overall picture is that the PoleStar and IMAGE estimates are rather similar, especially for the regions with large emissions in 2032 (Asia and the Pacific, North America and Europe). However, the projected *changes* between 2002 and 2032 are scattered roughly along a line below the mirror line. In other words, the PoleStar emission increases are consistently smaller than those derived from IMAGE. But because the PoleStar

Table 8.4: PoleStar and IMAGE 2.2 data for selected variables, 2002

	Energy-related emissions of carbon dioxide		Cropland area		Pasture area	
	PoleStar	IMAGE 2.2	PoleStar	IMAGE 2.2	PoleStar	IMAGE 2.2
	mln kton C		mln km^2		mln km^2	
North America	1.88	1.75	2.32	2.12	2.67	2.47
Latin America and the Caribbean	0.48	0.36	1.62	1.59	6.75	6.24
Africa	0.29	0.23	2.12	1.83	8.90	9.11
Europe*	2.07	1.69	3.56	3.06	1.96	3.84
West Asia**	0.22	0.34	0.17	0.52	1.51	2.08
Asia and the Pacific***	3.09	1.84	5.69	4.90	13.03	10.72

* With Central Asia and without Turkey for IMAGE 2.2

** With Iran and Turkey for IMAGE 2.2

*** Without Central Asia and Iran for IMAGE 2.2

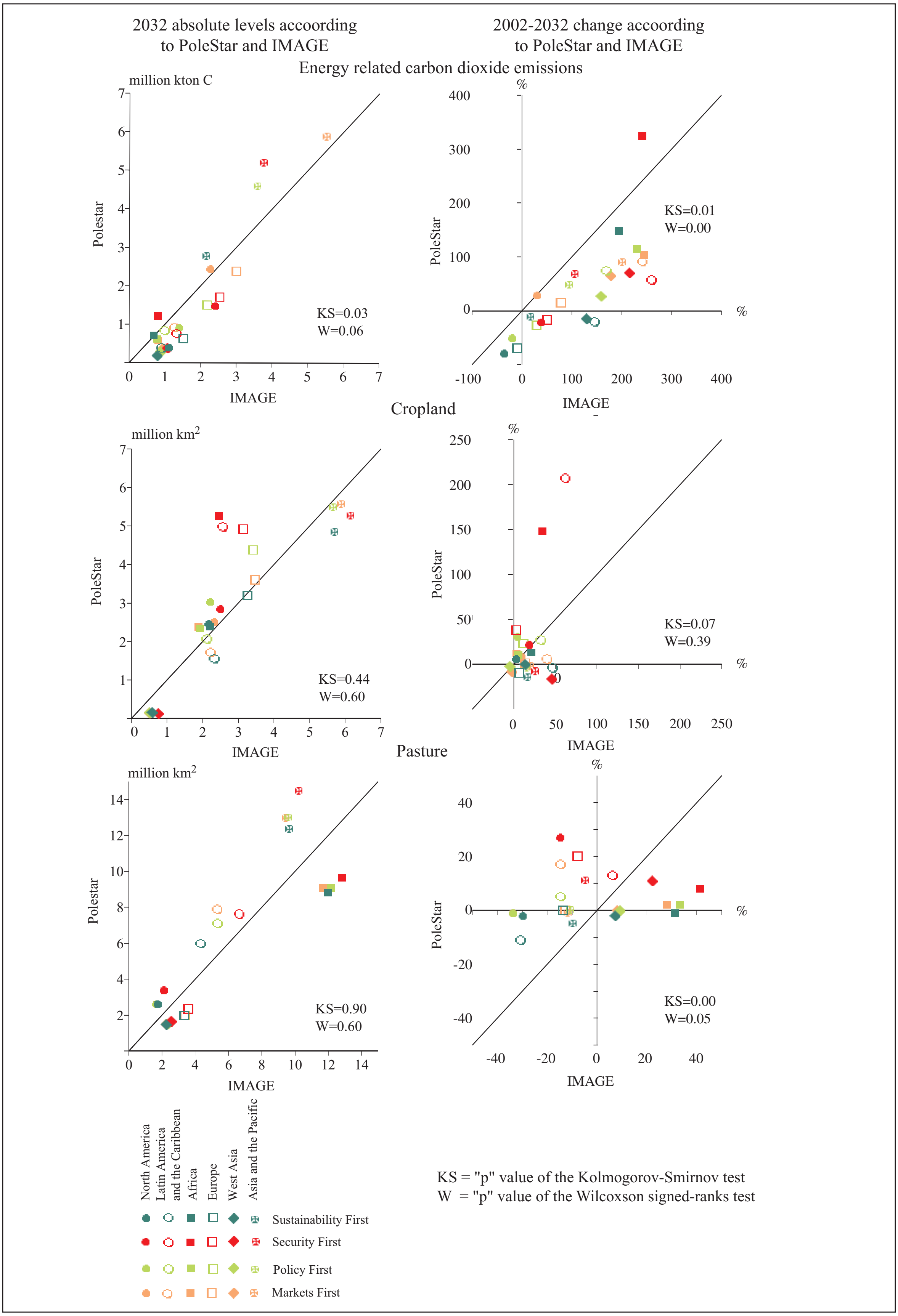


Figure 8.2: PoleStar and IMAGE 2.2 scenario results for selected variables

calculation starts with larger emissions in the base year, the resulting 2032 levels are not that different.

Second, the projections related to land use are compared (middle and bottom row in Figure 8.2). Briefly, the background to the cropland and pasture estimates with PoleStar and IMAGE 2.2 is as follows. Estimates of the demand for agricultural products in the two models take into account similar factors, such as changes in disposable income, diet and import/export – all at the sub-regional level. Demand for biofuels is factored in by IMAGE (as a sizeable component in some scenarios and some regions), but not in PoleStar. On the supply side, both teams have presumed changes in livestock practices due to modernization and development, in particular changes from grazing to feedlots. These changes increase the demand for cropland and reduce that for pasture, since feedlots rely heavily on crop production for animal fodder as opposed to pasture. A key difference, especially for land-related projections, is that IMAGE projections are spatially explicit – projected onto and checked against the map at a relatively detailed resolution. It is these spatially explicit land use projections that were used in GEO-3 as a basis for estimating impacts on for example biodiversity, erosion risk and water stress.

In Figure 8.2, the projections for total cropland area in 2032 in *absolute* terms lie mostly scattered along the PoleStar/IMAGE mirror line (middle row, left-hand graph). In other words, with the exception of some region-scenario combinations, the two teams produced estimates for the 2032 cropland areas that are not so dissimilar.

However, the comparison of the *changes* between 2002 and 2032 (right-hand graph) reveals a picture that is almost random. In fact, it suggests that the 2032 areas estimated by the two teams are similar mainly because the total cropland areas are very large and the changes are a mixture of relatively small losses and gains – very different from the development of the carbon dioxide emissions.

In two specific cases the teams estimated very different changes in cropland area: *Security First* in Africa and *Markets First* in Latin America and the Caribbean. Presumably, the *Security First* projection by the PoleStar team can be attributed to differing assumptions about the development of GDP per capita in Africa under this scenario (cf. Figure 2.1). In combination with substantial increases in population and slow growth in agricultural productivity, this would indeed lead to increases in agricultural land that are much larger than in the other scenarios.

The trebling of cropland area in the LAC region reflects a quantitatively different scenario interpretation: the PoleStar team calculates on the basis of a much larger expansion of cropland as a result of the changes in livestock farming (from grazing to feedlots) mentioned earlier in this section.

For regional pasture area, too, the total areas projected by the two teams for 2032 are similar when absolute numbers are considered (Figure 8.2, bottom left), while the projected changes are anything but similar (bottom right). Most significant in the scatter plot for changes in pasture is the fact that the IMAGE 2.2 increases and decreases are very large compared to those estimated with PoleStar. In fact, there is almost no change for total pasture area in PoleStar in most regions. Conversely, in *Security First* the PoleStar team estimated relatively large increases in North America, Europe, and Asia and the Pacific, while the IMAGE team projected decreases.

Not surprisingly, the background to the generally larger changes projected by the IMAGE team for Africa and West Asia is a difference in model structure. The IMAGE 2.2 model assumes a traditional pastoral system – with ruminants such as goats and sheep – throughout the scenario period, rather than assuming that such ruminants will in future be managed increasingly under livestock systems such as zero grazing. This assumption leads to exaggerated estimates for pasture in Africa and West Asia, where the increase in demand for meat and milk is partly met by an increase in the number of small ruminants. In contrast, for cattle, IMAGE 2.2 does model a transition from pasture to feedlots. (This is an important factor in the increased risk of water erosion of soils in South America, as discussed in section 7.7.3.) However, on this basis the IMAGE team projects a larger decrease in pasture land than PoleStar for regions such as Europe and the Americas.

Taken together, the PoleStar and IMAGE 2.2 interpretations of the story-lines seem qualitatively consistent at this point. But the structure of the tools, possibly together with differences in interpretation at the parameter level, as well as the incongruent interpretation of *Security First* by the PoleStar team lead to very different projections of the size of changes in pasture land. In effect, all the large increases – both those shown by the IMAGE team and those from the PoleStar team – seem exaggerated, but for different reasons.

In summary, the scatter plots show more similarity between PoleStar and IMAGE 2.2 for energy-related carbon dioxide emissions than for pasture and cropland. This is as expected. Modellers are known to share a conceptual understanding of the energy system, but it is widely acknowledged that issues related to land use are far less well understood and difficult to model. For example, land use is to a large extent affected by legal and other institutions, domestic and foreign food demand, changes in diet, as well as farmers' decisions about changing production systems. PoleStar does not model these issues explicitly and IMAGE 2.2 does so only partially. Nevertheless, both tools are to some extent geared to capturing the resulting changes in cropland and pasture areas. The same pattern was visible in SRES-IPCC (IPCC, 2000), where the results from the modelling teams are also better matched for energy-related issues than for land-related issues.

Thus, the overall conclusion is that the PoleStar and IMAGE 2.2 quantifications of the GEO-3 story-lines compare reasonably well for energy-related carbon dioxide, while the differences among the teams for cropland and pasture areas are rather large. These are mostly attributable to differences in modelling; yet the best explanation is the fact that the modelling of land-related issues is still in its infancy.

8.3 Discussion

This chapter reviews the role that the quantitative assessment undertaken by three modelling teams played in the development of the GEO-3 scenarios. It addresses questions concerning different types of scenarios, different types of modelling frameworks, and different ways in which quantitative models can and have been used in scenario development. Finally it has compared specific model outcomes across models where possible.

What has been the net result of this and what lessons can we draw from this assessment? Here, we attempt to provide an answer to this by addressing the three questions posed in the introduction to

this chapter:
- Was the GEO-3 multiple modelling approach useful, given the priorities of the overall GEO-3 process?
- How well do the overlapping outcomes of the analytical tools compare, and what does this say about the consistency of the teams' interpretation of the GEO-3 narratives?
- Did the process of quantifying the GEO-3 Outlook measure up to UNEP's goal of strengthening its regionally distributed assessment network?

The multiple modelling approach was tailored to meet the priorities of GEO-3, i.e. to provide regional and sub-regional information on key environmental indicators in the future. More information was made available than would have been possible from any single model.Furthermore, where possible, a regional model was used to provide specific information for the largest region – Asia and the Pacific.

At the same time, it must be pointed out that even using multiple models, estimates for the future values of a number of important other indicators could not be produced. Among these are the numbers of individuals without access to clean water, levels of biodiversity loss, and impacts from water stress. Estimates for some of these indicators may be available from other models, either existing or under development, but some may be beyond the capabilities of conventional modelling. In addition, the process of assessment undertaken in GEO-3 – especially the linkages between the models and between the models and the narratives – leaves open a number of questions related to consistency that need to be addressed in future exercises.

From the comparison of overlapping outcomes, the interpretation of the scenarios by the teams at SEI, NIES and RIVM appears to be largely consistent. On the inconsistencies, the main points of interest are as follows.

On the one hand, there are the regional GDP projections. A harmonisation exercise on these was carried out (see more details in Section 2.4). The pattern of similarities and remaining differences after harmonization can be summarized as follows:
- For most regions results from the teams engaged in this exercise converged. For initial GDP assumptions that in some cases were quite different among the teams, averages could eventually be decided that were agreeable to all teams and applicable in all tools.
- There was a lack of understanding only with regard to the economy in Africa vis à vis the rest of the world (the extent to which Africa will share in growth in a globalizing world). A compromise was chosen for this scenario exercise.
- Some differences in regional GDP projections remained for *Security First* in Asia and the Pacific. These differences are the result of imperfections in the GEO process – mainly a lack of time to communicate in more depth – rather than due to differences in interpretation.
- There are only symbolic GDP differences for *Sustainability First*, related to the future role of GDP as a key indicator in a world of *Sustainability First* rather than to a different interpretation of the scenario.

On the other hand, there are the findings related to the impacts that the scenarios have on the environment, resources and the incidence of hunger (direction of change, relative effect of the scenarios, regional differentiation). On this, the projections by the various teams generally go in the same direction and support the narratives. There seems to be greater-than-average uncertainty with regard to:

- the magnitude of the changes in regional pasture and cropland areas (although the teams seem to agree on the types of changes under the various scenarios)
- whether anti-pollution measures will become politically inevitable when certain levels of threats to health are reached including dangerous pollution in megacities, even in times when environment generally speaking is not a priority.

Energy-related estimates seem to be more consistent among the teams than land-related estimates. This is in line with the current state of science and therefore somewhat reassuring. (However, energy-related policy issues have in turn advanced to a stage where more precise answers are required, such as: can an atmospheric stabilization of 450 ppm of carbon dioxide be attained under this scenario?)

The answer to the final question follows to some extent from the answer to the first. The timing of the quantitative analysis, most of which occurred toward the end of the scenario development, did not allow for extensive feedback from the regional partners, who were able to contribute much more to the development of the scenario narratives. In the next round of the GEO, this needs to be handled much more carefully. A comparison with similar studies, such as WWV, shows that this is not impossible, given sufficient commitment from the participants. Finally, it must be admitted that no a-priori, concrete policy issues were identified for the scenarios to address. This meant that, at times, the regional and global partners were not clear as to the purpose of the scenarios, which made it more difficult for them to provide detailed comments.

References

Alcamo, J., et al., 2003. *Will climate change affect food and water security in Russia? Summary report of the International Project on Global Environmental Change and its Threat to Food and Water Security in Russia.* Kassel: Kassel University; Moscow: Moscow University and Russian Academy of Sciences.

Gallopín, G.C. and F. Rijsberman, 2000. Three global water scenarios. *International Journal of Water*, 1(1), pp. 16-40.

IPCC, 2000. *Special Report on emissions scenarios*. Cambridge: Cambridge University Press.

Potting, J., et al., 2002. *Outline of Research*. In: J. van der Sluijs et al., *Uncertainty Assessment of the IMAGE/TIMER B1 CO_2 emissions scenario using the NUSAP method.* (NOP Report no. 410 200 104). Bilthoven: Dutch National Research Programme on Global Air Pollution and Climate Change.

United Nations Environment Programme (UNEP), 2002. *Global Environment Outlook 3*. London: Earthscan.

Van Vuuren, D.P., et al., 2002. *Model Structure*. In: J. van der Sluijs et al., *Uncertainty Assessment of the IMAGE/TIMER B1 CO_2 emissions scenario using the NUSAP method*. (NOP Report no. 410 200 104). Bilthoven: Dutch National Research Programme on Global Air Pollution and Climate Change.

Summary and concluding observations

Six specialized centres have collaborated with UNEP in the production of the GEO-3 Outlook chapter. This took place in cooperation with a large group of experts who participated in regional and global consultations, and in the review of interim outputs to ensure a regional perspective. During this participatory Outlook production process a wealth of material was produced for the GEO-3 scenarios and their impacts on the environmental situation. In fact, the GEO-3 scenario material provided richer stories and data than could be presented in the GEO-3 main report.

This technical report provides a more detailed description of the methods used by the teams who carried out the GEO-3 scenario analysis. It also describes the regional significance and background of the impacts for all the GEO themes in more detail than would have been possible in the limited space of GEO-3. Since the authors are part of the GEO process itself, the report is not meant to be an independent external evaluation, but rather a look behind the scenes.

The focus is on quantifying impacts, and critically analysing model-based findings vis-à-vis the story-lines. Chapters 3 to 7 describe the analytical tools used by the different teams and present the quantitative results for a number of environmental implications of the four GEO scenarios.

Before and after this, Chapters 2 and 8 touch upon a number of cross-cutting issues. These are, for example, consistency between the analytical teams, involvement of regional specialists, and the development of the Outlook project over time.

An innovative approach was used for the GEO-3 Outlook chapter, in which multiple, contrasting scenarios were considered to evoke visions of how the world might develop, and what such a development would mean for the environment in the various regions. The Outlook was also meant to sketch the importance of a broad-based drive for the kind of society and environment we desire in preference to à la carte and piecemeal measures.

The following four contrasting scenarios were developed in the GEO-3 process:

Markets First – a world in which market-driven developments converge on the prevalent values and expectations in industrialized countries.

Policy First – a world in which concerted action on environmental and social issues occurs through ambitious but incremental policy adjustments. This world is aimed at maximizing the benefits offered by better management and technology.

Security First – a world of fragmentation, where inequality and conflict, brought about by social, economic and environmental stresses, prevail.

Sustainability First – a world in which a new development paradigm emerges in response to the challenge of sustainable development, and supported by new values and institutions.

A mixture of analytical tools and participatory approaches was used for the quantification of the story-lines and analysis of their impacts on the environment. Specifically, the analysis has dealt with the differences in impacts between the scenarios, globally as well as regionally. Table S.1 summarizes the variables analyzed and the tools used.

Table S.1: Variables analysed and tools used to produce the GEO-3 Outlook Chapter

Theme	Variables	Tools	Analysis characteristics
Hunger	People living with hunger	PoleStar	Income inequality
Land resources	Cropland degraded Changes in built environment	PoleStar	Scenario-dependent changes in regional trends
	Soils at risk from water erosion	IMAGE	Deterministic & spatially explicit modelling
Forests	Changes in mature natural	IMAGE	Differences in shrinkage/expansion for 1972-2032; spatially explicit. Re-growth within this period is left out of the comparison because of its small contribution to biodiversity during the first decades.
Biodiversity	Ecosystems impacted by infrastructure expansion	GLOBIO	Scenario-dependent, spatially explicit changes in regional trends
	Terrestrial biodiversity	IMAGE	Change in natural areas and key pressures on remaining natural areas; spatially explicit.
Freshwater resources	People living in areas with water stress	WaterGAP	Change in water balance and population, by drainage basin
Coastal marine ecosystems	Loading with nitrogen compounds	IMAGE	Effective loading from 6000 drainage basins from all sources, man-made and natural, via all routes. Semi-quantitative estimates of change potential per sub-region under each scenario
Atmosphere	Energy-related sulphur dioxide emissions	AIM and IMAGE	Emission coefficients
Urban areas	Energy-related nitrogen dioxide emissions	AIM and IMAGE	Emission coefficients Includes emissions from transport
	Municipal solid waste generation in Asia and the Pacific	AIM	Related to GDP/cap and projected to follow similar trends as Japan during the past two decades
Climate	Energy-related carbon dioxide emissions	AIM and IMAGE	Emission coefficients
	Carbon dioxide concentrations	IMAGE	Emissions from all sources and uptake of carbon dioxide
	Changes in regional and global a verage temperature and in regional annual precipitation	IMAGE	Concentrations of all major greenhouse gases; cooling effect of aerosols. Uncertainty in regional projections shown by applying four global circulation models

Note: The order of themes in this table corresponds with the order in the GEO-3 main report. AIM estimates relate to Asia and the Pacific only.

This summary concludes by asking what can be learned from the scenario exercise as a whole. Rather than repeating the conclusions of GEO-3, we provide suggestions in the 'learning by doing' spirit that has characterized the GEO process since its inception. The focus is on insights into scenario impacts, contributions to capacity-building and preparations for future outlooks, in particular:

- additional insights, which are more comprehensive and regionalized than could be reported in GEO-3 itself, are incorporated into environmental developments over the coming decades and the potential for change.
- approaches to the preparation of *future GEO-style Outlooks* in terms of overall set-up and implementation, analytical methods and the way the work on the GEO-3 Outlook contributes to capacity-building for integrated environment assessment. Capacity-building is an objective of the GEO process that is every bit as important as the GEO reports proper.

Potential for environmental change in the next half-century

Table S.2 below provides a synopsis of the regional environmental developments under the four scenarios as analysed in this report. This 'traffic lights' table is founded, as much as possible, on model-based outcomes for major environmental themes in the light of the GEO-3 scenario story-lines and on objectives of environmentally sustainable development as expressed in multilateral agreements, the Plan of Implementation of the World Summit on Sustainable Development and the Millennium Development Goals.

Box S.1 briefly describes how the synopsis was derived. Annex 4 lists the information inputs used for each issue. The broad issues listed in the first column of Table S.2 correspond with the environmental themes described in the retrospective of the 1972-2002 period in GEO-3. The second column in the table lists the specific variables analysed.

An important reason for compiling this synopsis was to compare regions. But in order to reduce the overview to manageable proportions, it had to be limited to the regional level, as opposed to the sub-regional level applied elsewhere in this technical report. Therefore, significant differences within the regions themselves may be obscured in this synopsis, in particular in the case of the large and diverse region of Asia and the Pacific.

If the synopsis in Table S.2 is viewed simply as if the themes were independent and of equal weight and as if the regions were of equal weight, a number of developments can be noted as described below.

Continuation of the environmental divide

The distribution of red signals across the regions strongly suggests a continuation of the 'environmental divide' throughout the coming decades between high-income and low-income regions. This divide characterized the 1972-2002 trend, as highlighted in GEO-3.

The number of red signals for Africa, Asia and the Pacific, Latin America & the Caribbean and West Asia is strikingly larger than for Europe and North America. Moreover, only for North America do green signals outnumber red signals. Obviously, the continued momentum of population growth in the South plays a major role. Connected to this is the double challenge of reducing poverty among a growing population in these regions, and at the same time reducing pressures on the environment.

Table S.2: Synopsis of scenario impact estimates

Theme	Operationalized by	Scenario	Afr	A&P	Eur	LAC	Nam	WA	World
Hunger	Percentage of Population remaining hungry; based on income distribution	Markets First	🔴	🟡	🟡	🟡	🟡	🟡	🟡
		Policy First	🟡	🟢	🟢	🟢	🟢	🟢	🟢
		Security First	🔴	🟡	🟡	🔴	🟡	🟡	🔴
		Sustainability First	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Land Use	Built Environment & Agricultural Land	Markets First	🔴	🔴	🟡	🔴	🟡	🟡	🔴
		Policy First	🔴	🔴	🟢	🟡	🟡	🟡	🔴
		Security First	🔴	🔴	🟡	🔴	🔴	🟡	🔴
		Sustainability First	🔴	🟡	🟡	🔴	🟡	🔴	🔴
Biodiversity	Impact of infrastructure & Natural Capital Index	Markets First	🔴	🔴	🟡	🔴	🟡	🔴	🔴
		Policy First	🔴	🟡	🟡	🟡	🟡	🔴	🔴
		Security First	🔴	🔴	🟡	🔴	🟡	🔴	🔴
		Sustainability First	🟡	🟡	🟢	🟡	🟢	🔴	🟡
Land Degradation	Cropland degraded & Area with high risk of water-induced soil degradation	Markets First	🔴	🔴	🔴	🔴	🟡	🔴	🔴
		Policy First	🔴	🔴	🔴	🔴	🟡	🟡	🔴
		Security First	🔴	🔴	🟡	🔴	🟡	🔴	🔴
		Sustainability First	🟡	🔴	🟡	🟡	🟡	🟡	🟡
Fresh Water (Quantity aspects)	Percentage of Population living in areas with severe water stress	Markets First	🔴	🔴	🔴	🔴	🟡	🔴	🔴
		Policy First	🟡	🔴	🟢	🔴	🟢	🔴	🔴
		Security First	🔴	🔴	🟡	🟡	🟡	🔴	🔴
		Sustainability First	🟡	🟡	🟢	🟡	🟢	🔴	🟡
Coastal Zones	Nitrogen loading at river mouths	Markets First	🔴	🔴	🔴	🔴	🟡	🔴	🔴
		Policy First	🟡	🔴	🟡	🟡	🟡	🔴	🟡
		Security First	🔴	🔴	🔴	🔴	🟡	🔴	🔴
		Sustainability First	🟡	🔴	🟡	🟡	🟡	🔴	🟡
Forests	Change in natural forest area (regrowth excluded)	Markets First	🔴	🔴	🟡	🟡	🟡	🟡	🔴
		Policy First	🔴	🔴	🟡	🟡	🟡	🟡	🔴
		Security First	🔴	🔴	🟡	🔴	🟡	🔴	🔴
		Sustainability First	🔴	🔴	🟡	🟢	🟡	🟡	🔴
Urban Areas	Change in energy-related nitrogen oxide emissions from all sources	Markets First	🔴	🔴	🔴	🔴	🟢	🔴	🔴
		Policy First	🔴	🔴	🟡	🔴	🟢	🔴	🔴
		Security First	🔴	🔴	🟡	🔴	🟡	🔴	🔴
		Sustainability First	🟡	🟢	🟢	🟡	🟢	🟡	🟢
Atmosphere	Change in energy-related SO2 and NOx emissions from all sources	Markets First	🟡	🔴	🟡	🔴	🟢	🟡	🔴
		Policy First	🟡	🔴	🟢	🔴	🟢	🟡	🔴
		Security First	🟡	🔴	🟡	🔴	🟡	🔴	🔴
		Sustainability First	🟡	🟡	🟡	🟡	🟢	🟡	🟡
Climate	Rate of temperature change	Markets First	🔴	🔴	🔴	🔴	🔴	🔴	🔴
		Policy First	🔴	🟡	🟡	🟡	🔴	🔴	🟡
		Security First	🔴	🔴	⚪	🔴	🔴	🔴	🔴
		Sustainability First	🟡	🟢	🟡	🟢	🟡	🟡	🟢

Key:

🔴	Increase in problem and/or persistant large problem
🟡	Some improvement or deterioration
🟢	Decrease in problem
⚪	Inconsistent results from global circulation models

Source: RIVM, based on information in this technical report and the GEO-3 main report

Box S.1 Process of deriving the 'traffic lights' table in Table S.2

The 'traffic lights' table presents a simplified synopsis of the impacts of the four GEO-3 scenarios on a number of environmental variables in the GEO regions (excluding the Polar Areas). The table aims to compare different developments, whicht might well arise in the future. It is not meant to provide a concrete predication of a specific scenario.

The traffic lights table is the product of a judgmental process, i.e.:

- Themes were operationalized by narrowing them down to specific issues. For example, the theme of Land Use is assessed using the information on 'built environment per capita' and on 'agricultural land use'. Operationalization was carried out using both information presented in this technical report and that found in the main GEO-3 report.
- Estimates for the issues dealth with were collected from the tables, charts and figures presented in the previous chapters of this report.
- The outlooks for the next thirty years were compared with the current trend of an issue in question so as to see the degree of change across different themes and scenarios. For themes that feature particularly large delays between changes in driving forces and environmental impacts such as climate, developments for the next 50 rather than 30 years have been considered.
- We are aware of interdependencies between the themes or issues, for example between land-use change and developments in biodiversity. At a more general level too, the driving forces and impact variables interact and form a complex and, often, a region-specific array of linkages. However, it was a conscious decision to juxtapose the issues here, keeping to the breakdown in the main GEO-3 report.
- The comparison was done in the light of the text provided on the various themes covered in this report and the story-lines that were developed for each GEO-3 scenario. For example, data on the changing risk of water-induced degradation of soils were interpreted in the light of the possibility of management to counteract these risks described under the various scenarios, for example through soil conservation.
- The table highlights differences and similarities between regional impacts. In addition, a 'world' column has been included to provide an overview of the impacts on global scale. For some issues, such as climate change, the impact for the world as a whole is a pertinent outcome directly from model-based analysis. For other issues, such as the population living in areas with water stress, the signal in the 'world' column is a weighted average of the regional signals.
- Climate signals for the world as a whole were assigned on the basis of the trend in rate of change in annual average atmospheric temperature in the final years of the scenario period (direction of the curve towards 2052, Figure 7.9). Climate signals for the regions were assigned on the same basis but adjusted with a view to the cumulative change in temperature that the region would incur under a particular scenario. For example, the global rate of change in average temperature by the end of the *Sustainability First* scenario does warrant a green signal. But over the whole scenario period Northern Africa will run up increases of 2 degrees Celsius in average temperature according to three of the four climate models used. (Figure 7.10) Thus, a 'yellow' signal is allocated for Africa.
- Estimates for emissions of nitrogen oxides in 2032 by sub-region, as considered for the theme Urban Areas, were added to this Technical Report as Annex 3. These estimates were neither reported in the GEO-3 main report nor in the previous chapters of the Technical Report.
- Generally, a red signal shows an increase of a large problem in the context of internationally articulated objectives. A yellow signal shows either improvement or deterioration in the problem, and a green signal reveals a significant decrease in the problem.

In most cases our analysis did not consider the differences between regions in terms of their capacity to cope with environmental change (amounting to differences in *vulnerability*). This would probably have shown the disadvantage of Africa even more strongly. In fact, the limited macro-economic modelling that was carried out for GEO-3 left questions. One of these concerned the degree to which Africa will share in the global growth of prosperity in a globalizing world (see Section 2.4).

Broad bifurcation in the impacts

The distribution of red and green signals over the scenarios (i.e. over the four rows corresponding with each theme) reflects the broad bifurcation that characterized the set of scenarios from the outset. On the one hand, a strengthening of currently dominant trends – either perceived as a market utopia in *Markets First* or as a world of strong tensions between cultures in *Security First* – leads to the highest counts of strongly increasing or persistent problems.

On the other hand, there are scenarios favouring different trends, i.e. featuring an ambitious change in priorities. These scenarios either remain within the limits of better management and technology in *Policy First* or move on to a new development paradigm in *Sustainability First*. Both run up a much lower score of red signals. Thus, in a very broad fashion, the divergent political, cultural, economic and demographic paths into the future (as told in the scenario story-lines) are revealed through differential impacts on biophysical systems from our largely model-based analysis.

Furthermore, even though our analysis only projects one or two future human generations, *Sustainability First* already distinguishes itself as the only scenario for which the number of green signals begins to approach the number of red ones.

For at least one theme, this report brings an insight that would have deserved mentioning in the main GEO-3 report. The insight is that almost the only possibility to slow the growth of pressures on marine coastal ecosystems in the next decades will be to ensure that wherever there is any investment in expanding the sanitation for growing cities, sewage treatment expands at the same time.

Dillemmas surrounding land use

Land-use changes as evaluated in Table S.1 show a counter-intuitive pattern, with most red signals appearing for the *Sustainability First* world, indicating dilemmas surrounding land use.

To begin with, there is the production of modern biofuels in the future as a measure to decrease carbon dioxide emissions, which competes with land requirements for food production and nature.

The second point relates to the need to cater for populations that are generally more affluent and therefore change their diets accordingly. Productivity increases in farming that would help reduce the need for converting nature into agricultural land often lead to more pressures on the surrounding ecosystems, for example, through accumulation and transfer of nitrogen and pesticides.

And thirdly, while the story-lines of some scenarios describe an increase in conservation of ‘undomesticated’ areas, such as the Siberian and Alaska tundra or the cerrado in South America, these efforts will be partly cancelled out by climate change caused by emissions from the past. Avoiding this might require much larger buffer zones around protected areas to accommodate climatic shifts, which in turn will involve land issues.

Finally, the only red signal for North America relates to land use. It flags urban sprawl, ever-increasing in all scenarios, but in particular under the conditions of *Security First*.

Delays in effect of policy action
Last, but by no means least, when comparing the gist of the story-lines with the quantified impact estimates on the bar charts and maps, it is inescapable that changes in the biophysical environment generally trail behind changes in attitudes and political atmosphere as sketched in the story-lines. This tells us that improvements in the world of *Policy First* and *Sustainability First* may not be harvested fully within the 30-year time horizon used for GEO-3.

The delay is caused by a multitude of factors, not all of them biophysical, ranging from demographic momentum to the time needed in education, replacement of capital stock and year-on-year improvements in resource efficiencies, to the longevity of some human-induced changes in the climate system.

This is not to say that all improvements under these scenarios are trivial or invisible. Rather, it is a reminder that timely action is required because of the sluggish ‘super tanker’ nature of many processes involved.

Analytical approach and organization of the assessment

The vision of a truly integrated assessment process is one of the reasons why GEO is so appealing. For example, the GEO process aims at delivering an integrated view of the various environmental themes, in which interlinkages are considered. In addition, it aims at applying global as well as regional perspectives. Another aim of integration in the GEO process is to report on the environment in the context of sustainable development.

Furthermore, GEO aims at capacity-building while at the same time delivering meaningful assessments. In fact, the development - over time - of GEO’s methods of analysis and reporting in terms of content is closely connected with the development of the GEO process and partnership network.

Consequently, when trying to formulate suggestions for those preparing future Outlooks, it makes sense to focus on aspects where the process this time round was not as integrated as it might have been. Thus, the observations have been grouped as far as possible into six categories showing the most apparent aspects hampering such a process but which could be improved.

Planning and coordination
Although learning-by-doing is an important and useful strategy of the GEO process, GEO-3 has shown that Outlook activities in a single edition of the report (GEO-1, GEO-2000, GEO-3, etc.) need to be more explicitly planned and carried out in an integrated manner from beginning to end. This should encompass both the analytical work and the participatory process. While sacrificing some flexibility, explicit planning in terms of effective use of the capacity within the GEO network at both global and regional levels would deliver considerable gains.

In this respect it is recommended that early on in the preparation of future GEO outlooks a distinct phase of *policy scoping* is included. The purpose of the scoping would be to identify and agree well in advance on the particular policy questions to be answered in the Outlook. What is more, given the growing number of people and centres involved in the GEO process, a common leading question becomes increasingly necessary to move from scenario formulation and analysis to an assessment of political significance. Thus, determining the policy questions as an explicit step would be a natural evolution from the explorative approach adopted in compiling the first three GEO Outlooks.

Such an approach would also make GEO more effective in capacity-building by requiring the collaborating centres to increasingly link the science-oriented and the policy-oriented aspects of their analyses.

The role of forward-looking analysis within the GEO assessment framework has clearly grown during the GEO-3 production. However, in the future the overall assessment capacity could gain in strength if retrospective (in GEO-3, the 1972-2002 period) and prospective analyses (in GEO-3, the 2002-2032 period) are carried out hand in hand. This would provide valuable experience to the GEO network in combining the best of empirical analysis with creative investigation of driving forces and alternative futures. Given the complexity of the process, cross-linkages and the usual time constraints, the challenge will be to synchronize the work on scenarios and state-of-the-environment and current policy.

Another recommendation in relation to organizing the Outlook as a whole is to incorporate into the planning one or more iterations between the development of the story-lines and model-based quantification along the lines of the process used for the recent World Water Vision (see Box 2.2).

An explicit project phase for reviewing the story-lines on the basis of early model results would also enable developers of the story-lines to make revisions such as dropping, adding or merging scenarios. This would help to improve the link between the two paths of research (qualitative story-lines and quantitative models), resulting ideally in 'computer-aided storytelling' (see also *'Nature of tools'* and *'Harmonization'* below).

Enhancing capacity

An important objective of the GEO process is to further develop the capacity to carry out integrated and policy-oriented assessments. This relates to expertise and skills, both at the global level (UNEP headquarters and collaborating centres with a global focus) and the regional level (regional UNEP offices and collaborating centres with a regional focus). As pointed out in Chapter 2 of this report, GEO-3 made much progress here by involving the full network of collaborating centres in the Outlook chapter.

Key characteristics of the process for the producing the GEO-3 Outlook chapter comprised providing a basis in pre-existing stories and data sets accessible through the GEO network, stepwise interpretation by regional experts and broad consultations within the GEO network, and a finalisation phase by six expert centres from the GEO network, with emphasis on the worldwide analysis.

However, more progress is possible in strengthening the capabilities of the GEO network. This applies, in particular, to cooperation between regionally and globally focused centres. In order to use the possibilities of future GEO studies more fully, its managers should among other things realistically plan for involvement of regional experts in draft worldwide analyses. In this respect, the compilation of GEO-3 has taught us that stricter and more comprehensive project phasing from beginning to end would pay off, especially in the later stages of the quantification and analysis of the environmental impacts of the scenarios by allowing sufficient time for consultation and follow-up.

Overall, it can be concluded that more institutional cooperation and collaboration may be required to further enhance assessment capacities of the network as a whole. One possibility in this direction would be to set up a system of secondment between the centres, in particular between centres specializing in global analysis and those focusing on a particular region.

Regional grouping

A hallmark of the GEO process has been the differentiation of global analyses by region. Although a challenge, it makes the GEO assessment more meaningful in many respects. In particular, regional differentiation allows the inclusion of regional dynamics and closer representation of the sustainable development context. In addition, as more GEO assessments are being carried out, differences between the regions prove to be an important part of the story.

GEO-3 has further strenghthened the regional dimension, both through involvement of regional experts in defining and elaborating the scenario story-lines, as mentioned in the previous section, as well as by specifying the regional differences in the scenario impacts, as elaborated in this report.

Ever since the GEO process began, one complication – for quantitative modelling in particular – has been the modification of country groupings into sub-regions and ultimately regions. UNEP and GEO try to keep in step with shifting requirements for the country groupings in UN work in general, and in UNEP's regional work in particular, especially as the relation between GEO and the latter has greatly intensified over the past years. As a result of these factors, the GEO-1 regional and sub-regional classification was modified for GEO-2000, and again before the work on GEO-3 started.

This modification was particularly difficult to accommodate in the model-based quantification in the Outlook chapter, because the larger models used for many of the impact estimates in GEO-3 do not simply build up their outcomes on the basis of independent country statistics. Instead, modelling involves various scale levels and flows between countries, e.g. goods or water. The models simulate situations at regional and sub-regional levels, with complicated routines to localize impacts on a map.

Thus, changing the regional breakdown of such models is a major, time-consuming operation requiring extensive model recalibration, preceded by an exhaustive collection of material to calibrate against, usually going back 100 years. Obviously, care and restraint should be exercised in changing any statistical classification.

For example, the IMAGE model used for many impact estimates in the GEO-3 Outlook had been changed to the GEO-2000 regional breakdown only just before GEO-3; this breakdown was subsequently maintained for GEO-3. The estimations of water stress with the WaterGAP model also complied with the older, GEO-2000 regional breakdown.

As regional differentiation is essential to GEO, regionalized impact estimates for GEO-3 were still provided even if some countries were grouped differently. Discrepancies in regional grouping between modelled results and the GEO-3 breakdown have been flagged in the graph labels. However, this method is less than perfect since, depending on the size of the country in the 'wrong' region, the connection between story-lines (following the 'official' GEO-3 regional breakdown) and impact estimates is hindered.

Nature of the scenarios

One conspicuous discontinuity in the Outlook process concerned the nature of the scenarios : explorative (what if....) or backcast (how can we....). Chapter 2 describes how the various GEO-3 scenarios evolved as the initial scenarios were adapted to the GEO process. In fact, analysts had different notions, and that remained a source of confusion. In terms of recommendations to the makers of future GEO Outlooks, this underlines the obvious need to articulate the leading policy question or questions at the start of the assessment process.

Another recommendation at this point is not only to be conscious of, and explicit about, the scenario set-up applied to the current outlook, but also to be explicity about how this may differ from the scenario approaches applied in previous GEO reports.

GEO-3 used a set of four contrasting scenarios, while GEO-2000 included a different analysis aimed at questions of regional policy optimization with a closer time horizon, thus applying a scenario scheme of baseline-with-variant. GEO-1, opening the GEO series in an agenda-setting mode, kept the analysis almost completely restricted to a business-as-usual scenario. This scenario illustrated what would happen if current trends prevailed and the world gradually started to adopt Western lifestyles and the related pattern of resource use.

These approaches serve different purposes and are equally valid. Explaining this may help readers and GEO centres to see the change as broadening the range of tools and approaches rather than contradicting previous work.

For GEO-3, a basic question to be asked in retrospect is what the added value has been of four scenarios over a simpler scheme consisting of a baseline and a policy variant (as applied in GEO 2000). The answer to this question must be that a thirty-year time horizon is thought to be too far away to safely assume a baseline (i.e. a highly probable development of the key driving forces worldwide). Therefore, given the time horizon, there is not much choice other than using a set of contrasting scenarios.

However, for many impacts the thirty-year horizon is too close to fully appreciate the changes in environmental trends set in motion. For future analyses *of this kind* it is recommended to include some form of further outlook (perhaps one additional human generation) to show the contrasting developments playing out. This would more clearly show the significance of current policies. The 2032 and 2052 biodiversity maps in Figure 7.20 illustrate this point. More generally, the recommendation is to be flexible in the application of any default time horizon.

Nature of the analytical tools

GEO-3 involved specialized tools used by different teams in different places. This multi-mode set-up broadened GEO's scientific and regional basis considerably. It also generated useful experiences for subsequent GEO Outlooks, and contributed to one of the important aims of UNEP’s entire GEO process, namely, to strengthen environmental assessment capacity in the regions through training and ‘learning by doing’.

From the start, the exercise was designed to involve two classes of tools. As explained in Chapter 8, one class is represented by PoleStar and GLOBIO – trend-based tools, which are particularly useful for supporting consultations on sharply different global ‘solutions’. This class of tools offers quick turn-around output on the basis of participants’ input; the possibility to employ these tools in an interactive process with a lay audience is very useful in scenario processes.

An example of the other class is IMAGE (with WaterGAP and AIM also belonging to this class). Its greatest strength is found in the delivery of a regionally interlinked, structurally continuous path from present to future using more robust economic models and land-use projections. This latter class is sometimes designated as containing ‘medium complexity models’ thought to be halfway between tools such as PoleStar and true earth system models.

In practice, GEO-3 has shown that connecting the approaches of the PoleStar and IMAGE types of tools is far from straightforward. Part of the problem is that the tools – and the teams applying them – report on a largely overlapping range of variables but with a different purpose and correspondingly different ‘weight’ of the underlying modelling. As explained in Chapter 8, an important point of debate between the two approaches is whether to focus on structural change or on structural continuity.

A focus on structural change involves tools that are designed in the first place to explore and advocate the necessity and potential for ‘transitions’ in society: quick and radical changes to the trends of the past in production, consumption, institutions or migration. In contrast, a focus on structural continuity involves tools that are geared towards the possibilities for, and constraints of, such changes; they can be used for a critical examination to see if a particular strategy is not merely wishing the problems away.

Furthermore, most of the ‘deterministic’ models involved in the GEO-3 scenario analysis produce spatially explicit results, for example for land-use changes. This is very useful for an assessment such as GEO – for critically investigating the plausibility of projected scenario impacts; for relating modelled impacts to sub-regional context; and for identifying shifts that disappear in regional averages.

However, the cross-comparison in this report between results from IMAGE and the PoleStar tool casts doubt on the sizes (although not on the direction) of some of the larger land-use changes projected with either tool. The differences identified in this case could be traced to differences in modelling structure, assumed rates of change, etc. However, the general impression is that modelling land-use change is far less mature than, for example, modelling energy issues.

Harmonization in multi-team and multi-tool scenario analyses

For GEO-3, the harmonization exercise between quantitative scenario interpretations described in Chapter 2 of this report came late in the process, requiring a good part of the model-based analysis to be redone, and so reducing the time left to involve regional experts. However, the harmonization did improve the consistency of the analysis using both classes of tools.

Nevertheless, a tantalizing idea for future outlooks has been left behind, i.e. to bring together the strengths of both approaches in a meaningful way, especially as both are available within the GEO network. In other words, it is recommended to devote some attention within, or annexed to, the GEO network to explore tools that cater for the analysis of radical, structural changes, while allowing critical analysis based on existing stocks and proven rates of change. As these novel tools have to support GEO analyses, they should also support regionally differentiated analysis, taking into account the linkages between regions.

Other global assessment processes, such as any follow-up work on the Millennium Ecosystem Assessment, are also likely to benefit from such novel tools. For a start, one could attempt to develop a common communication interface through which the results of several different tools can be displayed. This is not the same as an overarching integrated model, but it would help the process of interaction.

Another aspect of multi-team scenario analyses is the division of issues and scenarios over the teams. To date there has not been much experience with multi-team, multi-model worldwide assessments. The GEO-3 analysis was structured in such a way as to allow the teams to analyse specific impacts across all four scenarios, for example, the impact of the local balance of freshwater use and availability. This maximized the possibility of inter-scenario comparison. However, it did not ensure that teams would always interpret the scenarios in the same way.

Another aspect of multi-team scenario analyses is the division of issues and scenarios over the teams. To date there has not been much experience with multi-team, multi-model worldwide assessments. The GEO-3 analysis was structured in such a way as to allow the teams to analyse specific impacts across all four scenarios, for example, the impact of the local balance of freshwater use and availability. This maximized the possibility of inter-scenario comparison. However, it did not ensure that teams would always interpret the scenarios in the same way.

Chapter 8 of this report looked into this aspect after the GEO-3 main report had been completed and published. Except for one clear case, there was no sign found of inconsistent interpretation among the teams. For this reason, the GEO-3 set-up deserves to be recommended, albeit on two conditions: first, that a crosscheck as carried out in Chapter 8 is done during, not after, the preparation of the assessment; and second, that key intermediate results are exchanged between teams. An example of the latter is the exchange of maps of future land use among several centres during the GEO-3 Outlook preparations.

Annex 1. Energy-related and other assumptions related to the interpretation of the GEO-3 scenarios for analysis with IMAGE

	Markets First	Policy First	Security First	Sustainability First
Population	Stabilising population (8.2 billion in 2030; 9 billion in 2050)	Stabilising population (8.2 billion in 2030; 9 billion in 2050)	Growing population (9.2 billion in 2030); slowdown in fertility decline in lower income regions	Stabilising population (8.2 billion in 2030; 9 billion in 2050)
Characterisation of economy	Globalisation, high growth; high tech	Globalisation, high growth; high tech; stronger convergence of income	Focus on regional [cultural] identity; environment low-priority; world-wide economic growth low but on average still positive	Globalisation, high monetary growth; high tech; strong decoupling of physical flows and monetary growth
Steering	Market-based capital and labour allocation	Balanced government and market allocation		Balanced government and market allocation; but also strong social responsibility
	Orientation on profits and technological opportunities. Some convergence in regional income; rapid diffusion of technology. No trade barriers	Orientation on profits and technology opportunities – but within limits agreed upon by the larger community; rapid diffusion of technology; no trade barriers	No convergence in regional income and slow diffusion of technology; trade barriers. In some regions poorly functioning markets and institutions.	Orientation of non-material quality of life aspects. Convergence in income and rapid diffusion of resource-efficient technology.
		More investments in low-income countries and higher education spurs up economic growth.		Strong investment in low income countries, partly based on equity considerations spurs up economic growth in these regions.
Energy system				
Development of energy efficiency	Decline in energy intensity close to historic average (around 1% pa world-wide) as a result of fast energy efficiency improvement but spread of material intensive lifestyles	Decline in energy intensity faster than historic average (around 1-2% pa world-wide) as a very fast energy efficiency improvement but spread of material intensive lifestyles	Decline in energy intensity slower than historic average (0 – 0.5% pa world-wide) as result of slow energy efficiency improvement and relatively material intensive lifestyles	Decline in energy intensity much faster than historic average (around 2-3% pa world-wide) as a very fast energy efficiency improvement and a transition to less material intensive lifestyles
Energy/carbon tax levels	Energy end-use taxes for all sections converge towards 1995 USA levels.	A strong carbon tax is introduced as result of an international agreement on climate change reaching a level of around 200US$/tC in 2030.	Energy taxes very slowly converge to 1995 USA levels.	Normal energy taxes converge to Western European levels. In addition, a carbon tax is introduced reaching a level of around 200US$/tC in 2030.
Autonomous efficiency improvement	Between 2000 and 2040, low income regions strongly catch up in relation to high economic growth rates	Between 2000 and 2040, low income regions strongly catch up in relation to high economic growth rates	Only slow convergence in energy efficiency levels.	Between 2000 and 2040, low income regions strongly catch up as result of technology transfer and economic growth
Basic orientation towards fuel types (end-use)	Strong aversion from use of coal for health, convenience and environmental reasons	Strong aversion from use of coal for health, convenience and environmental reasons; carbon tax also reduces use of oil and promotes biofuels	Strong aversion from use of coal in some, not all regions	Very strong aversion from use of coal for environmental reasons; carbon tax also reduces use of oil and promotes biofuels
Basic orientation towards fuel types (electricity generation	Small aversion from use of coal (as a result of cost increase due to add-on technology)	Strong aversion from use of coal and oil. Non-fossil based electricity is promoted.	Regionally determined preference or aversion from coal, oil and natural gas.	Strong aversion from use of coal and oil. Non-fossil based electricity is promoted.

	Markets First	**Policy First**	**Security First**	**Sustainability First**
Carbon intensity of the energy system (result)	Carbon intensity remains more-or-less constant (declines in some regions; increases in several low income regions due to transition from traditional to fossil fuels)	Carbon intensity declines at a historically unprecedented rate, maximum 2% per year in 2030.	Carbon intensity remains more-or-less constant (declines in some regions; increases in several low income regions due to transition from traditional to fossil fuels)	Carbon intensity declines at a historically unprecedented rate, maximum 2% per year in 2030.
Technological learning	Default for fossil fuels; strong and very strong for biofuels and non-fossil based electricity	Default for fossil fuels; strong and very strong for biofuels and non-fossil based electricity	Slow or default for fossil fuels; slow for non-fossil based electricity.	Default for fossil fuels; very strong for biofuels and non-fossil based electricity
Trade constraints	All import and export constraints are removed	All import and export constraints are removed	New regional blocks introduced	All import and export constraints are removed
Emissions				
Emissions coefficients	Strong technology development means that, in general, emission coefficients decrease. Rapid decreases in low income countries result in slow convergence.	Strong technology development means that, in general, emission coefficients decrease but sometimes more integrated measures are taken (using less energy for instance)	Decrease of emission coefficient is more slowly.	Strong technology development and a strong environmental focus imply rapidly decreasing emission coefficients.
Food system				
General consumption patterns	Fast increase in the food consumption. Convergence to Western consumption patterns, resulting in very fast increase in consumption of livestock products	Fast increase in the food consumption. Convergence to Western consumption patterns, resulting in very fast increase in consumption of livestock products	Slower increase in per capita income in low-income countries implies that the convergence in food patterns is also much slower.	Per capita consumption of livestock products is 10% lower than in the MF/PF scenario in 2050.
Trade	Food is traded globally; volume increase fast	Food is traded globally; volume increase fast	Moderate increase in the volume of trade in food and feed	Food is traded globally; volume increase fast
Productivity	Fast increase in food and livestock productivity	Fast increase in food and livestock productivity	Slow increase in crop and livestock productivity	Fast increase in food and livestock productivity

Annex 2. Changes in agricultural land use following from the interpretation of the GEO-3 scenarios for analysis with IMAGE

	Markets First	Policy First	Security First	Sustainability First
Canada (output merged with USA to the GEO-3 region 'North America')	Total agricultural area decreases. Increasing demand for concentrates leads to less grassland and fodder crops; efficiency in crop production increases fast with decreasing crop area; biofuels cover 6% of total agricultural area in 2030	Comparable to MF, but biofuels much more important (20% in 2030)	Comparable to MF, but with slower technological growth.	Comparable to MF, but lower consumption of livestock products leading to less production, with major reduction of the use of both grassland and concentrates, and thus reduction of food crop areas
USA (output merged with USA to the North America GEO-3 region)	USA will continue to be the major exporting country for cereals. The total agricultural area is stable. Increasing demand for concentrates leads to less grassland and fodder crops and more cropland; biofuels make up 10% or agricultural area in 2030	Comparable to MF, but biofuels much more important (14% in 2030)	Slightly increasing total agricultural area with shift from grazing to crops, and slower technological growth than in MF. Biofuel areas comparable to MF.	Decreasing total agricultural area with shift from grazing to crops. Major difference with other scenarios is the lower consumption of livestock products, leading to reduced demand for both grazing land and crop land (because smaller use of concentrates). Biofuel areas comparable to MF.
Meso-America and the Caribbean	Slight increase in total agricultural area. Expansion of livestock production (cattle) leads to increasing demand for grassland, fodder crops and concentrates. Increasing human demand + shift in diet causes higher demand for crops which is not balanced by higher efficiency. Biofuels are becoming increasingly important with 7% of total agricultural area in 2030	Comparable to MF	Much faster increase in areas used for the production of crops and for grazing than in MF, mainly due to faster growth of demand due to faster population growth, and slower technological improvement.	Comparable to MF.
South America	The total agricultural area is stable. Intensification in livestock production leads to a shift from grassland to crops. Biofuel crops cover 4% of total agricultural area in 2030.	Biofuel crops cover ~10% of total agricultural area in 2030. Further comparable to MF	Faster population growth than in MF leads to increasing demand for food, but technological improvement is less fast (slower economic growth).	Faster economic growth leads to both shifts in consumption patterns (more meat at the expense of cereals and starchy roots) and technological development. This results in intensification in livestock production, and less grassland required than in MF, but more concentrates (food crops). Biofuels somewhat less important than in PF.
Northern Africa (without Sudan)	Slight increase in total agricultural area. In parts of this region, extensive livestock production (goats, sheep) is	Comparable to MF	Comparable to MF, but area for crop production increases, as a result of increasing human demand and slower	Comparable to MF

	Markets First	Policy First	Security First	Sustainability First
	an important pressure causing a moderate increasing area for grazing and production of fodder crops. Area of crops decreases somewhat due to intensification. Total agricultural area therefore increases by 16% from 2000 to 2030. Biofuels are of no importance.		economic growth and technological improvement than in the other scenarios.	
Western Africa and central Africa	This region has a slow economic growth in all scenarios, coupled with fast population growth. This leads to rapidly increasing food demand, while technological improvement is generally slow. Strong increase in total agricultural area results from expansion of more or less extensive livestock production (milk and meat). Iincreasing demand for human food and concentrates is balanced by increasing crop yields. Biofuels are of no importance.	Comparable to MF, with more grazing and biofuel production (for the region as a whole biofuel production remain unimportant at <1%)	Comparable to MF, but crop production and grazing increasing more rapidly due to faster growth of the food demand (high population growth) and slower technological improvement than in MF.	Comparable to MF, but faster economic growth leads to a shift towards higher consumption of livestock products and thus overall agricultural expansion which is somewhat faster than in MF.
Western Indian Ocean & Eastern Africa (with Sudan)	Slight increase in total agricultural areas as result of slight increases in both cropland and grazing areas. Biofuels are of no importance.	Comparable to MF, but expansion of grazing areas is somewhat faster	Comparable to MF, but expansion of croplands and grazing areas is faster due to faster growth of the food demand (high population growth) and slower technological improvement (slow economic growth) than in MF.	Comparable to PF, but faster economic growth leads to higher human consumption of livestock products and thus overall agricultural expansion which is somewhat faster than in MF.
Southern Africa	Southern Africa experiences high population growth and stagnating economic growth. This results in a sharp increase in food demand, while technological development lags behind. This scenario shows a strong increase in total agricultural area as a result of increases in both cropland and grazing areas. Extensive livestock production remains important, and land claims from such systems remain important in the coming decades. Biofuels are of no importance.	Comparable to MF, but expansion of biofuel crop areas is faster (although the area used for biofuel production remains unimportant).	Comparable to MF, but expansion of cropland and grazing areas is somewhat faster due to faster growth of the food demand (high population growth) and slower technological improvement than in MF.	Comparable to MF, but faster economic growth leads to a higher human consumption of livestock products and thus overall agricultural expansion which is somewhat faster than in MF.
Western Europe	This region remains a major exporter of primarily temperate cereals (wheat), which is one of the reasons for the large area required for food crop production. The increase in agricultural area in 2030, however, is mainly caused by increasing	Comparable to MF, but area used for biofuel production increases faster.	In SecF, total agricultural area increases less rapid than in MF, as a result of slower increase in crop and biofuel areas than in MF, and similar decline of grazing areas.	In the SustF scenario the per capita consumption of meat and milk is lower than in the other scenarios. In itself, this leads to a smaller area required for grazing and for the production of concentrates. On the other hand, there is a tendency

	Markets First	**Policy First**	**Security First**	**Sustainability First**
	production of biofuels of which an important part is made up by woody biofuels. This is relatively important in this sub-region because of its large energy use. The decrease in grazing is balanced by an increase in crops as a result of increasing dependence on concentrates.			towards extensification of grazing. On balance, the total agricultural area increases but somewhat les than in MF.
Central Europe (without Turkey)	Slowly decreasing agricultural area, caused by both decreasing areas of crops and grazing. Biofuels become more important, covering 8% of the agricultural area in 2030	Stable agricultural area, because decreasing crop and grazing areas are balanced by increasing areas for biofuel production.	Comparable to MF, but with less production of biofuels.	Comparable to MF, but with faster decrease of the area used for grazing. One of the reasons is the smaller share of livestock products in the human diet, leading to a reduced demand for both land for grazing and food crops.
Eastern Europe and Central Asia	Demand for food products collapsed in 1990-2000, leading to extensive abandoned productive areas. Agricultural area after 2000 is stable, with a further slow shift from grazing-dependent livestock to reliance on concentrates, which leads to slowly increasing crop areas and decreasing (extensive) grazing. Biofuels cover an important 4% of total agricultural area in 2030.	Difference with MF is caused primarily by faster increase in area used for biofuel production.	Somewhat less rapid increase in crop and biofuel production than in MF	Somewhat less rapid increase in crop and biofuel production than in MF, and faster decrease of grazing area due to technological development and less consumption of meat and milk.
West Asia (with Iran and Turkey)	Changes in Middle East are limited, due to limited possibilities for expansion and shifts between production systems. Livestock production is largely extensive and remains essentially dependent on grazing. Biofuels are not important.	Similar to MF, but with small decrease of the cropland area.	Much faster increase of total agricultural area than in MF, as a result of fast population growth (food demand), slow economic development (technology). This leads to more rapid expansion of areas required for crop and livestock production than in MF.	Comparable to MF.
South Asia (without Iran)	Strong increase in agricultural area, caused mainly by increasing production of crops. Grasslands are much less important and remain so, although the % increase is strong. Biofuels grow in importance to 5% of the total agricultural area	Faster increase of area used for biofuel production than in MF, slower increase of grazing areas	Comparable to MF, but with slower increase of biofuels.	Comparable to MF, but with faster increase of biofuels.
East Asia (output merged with North ***W***est Pacific to GEO-3 region 'North ***W***est Pacific	The agricultural area in East Asia is strongly dominated by extensive and marginal grasslands. Part of these is semi-natural, with very low population and animal densities. A	Comparable to MF. Biofuels are 6% of total agricultural area in 2030.	The decrease of the grazing area is less rapid than in MF. Further comparable to MF.	Comparable to MF.

	Markets First	Policy First	Security First	Sustainability First
	increase in biodiversity. Decrease in agricultural area results from slightly decreasing crop area and strongly decreasing grazing areas. This transition is accompanied by a gradual shift from extensive livestock production heavily dependent on grazing to increasing use of concentrates, i.e. increasing production of mainly white meat (poultry, pork), and relatively fewer sheep. Biofuels grow strongly to 3% of the total agricultural area.			
South East Asia	The agricultural area strongly increases, as a result of fast expansion of the area of crops and biofuels. Grasslands also increase but they cover about 20% of the agricultural area in 2000. Biofuels cover about 6% of the agricultural area in 2030.	Faster increase of the area used for biofuel production than in MF.	Comparable to MF.	Somewhat faster increase of the area used for biofuel production than in MF.
South Pacific and Australia and New Zealand	This region is a major exporter of cereals throughout the scenario period. The total agricultural area slightly decreases, primarily as a result of decreasing grazing areas. Biofuel crops are increasing, but their importance remains limited.	Comparable to MF.	Smaller total agricultural area in 2030 as a result of rapid decrease of the grazing area and smaller absolute increase of the food crop and biofuel area. Relative proportion of crops in total agricultural area gradually increases.	Comparable to MF, but with less consumption of meat and milk and thus faster decrease of the agricultural area.
North *W*est Pacific (output merged with East Asia to GEO-3 region 'North *W*est Pacific and East Asia'*)*	Scale problems. Change of one grid cell causes drastic changes in Japan's land use.	Idem	Idem	Idem

Annex 3. Energy-related emission of nitrogen oxides

		2032			
	2002	**Markets First**	**Policy First**	**Security First**	**Sustainability First**
	1000 ktN				
North America	8.38	5.95	3.96	8.55	2.49
Meso-America & the Caribbean	0.52	1.08	0.89	1.26	0.53
South America	0.91	2.50	1.98	2.74	1.16
Northern Africa (without Sudan)	0.27	0.91	1.06	1.00	0.56
Western & Central Africa	0.12	0.42	0.52	0.36	0.26
Eastern Africa, Western Indian Ocean (with Sudan)	0.04	0.17	0.23	0.15	0.12
Southern Africa	0.47	1.17	0.90	1.16	0.46
Western Europe	3.13	2.39	1.79	2.56	0.89
Central Europe	0.56	1.13	0.81	0.92	0.41
Eastern Europe	1.48	2.33	1.84	1.98	0.84
West Asia	1.03	2.11	2.00	2.38	1.28
South Asia	1.44	6.59	4.05	3.98	1.37
North West Pacific	3.82	8.14	4.31	6.71	1.87
South East Asia	0.69	1.82	1.55	1.26	0.64
Australia, New Zealand and South Pacific	0.41	0.31	0.22	0.40	0.11
World	23.24	37.03	26.12	35.41	12.97

Source: RIVM

Annex 4. Data sources for the 'traffic lights' table (Table S.2)

Theme	Operationalised by	Data derived from
Hunger	Percentage of population that remains hungry	Figure 3.12 Section 3.5
Land Use	Extent of built environment	Table 3.1 Section 3.4
	Agricultural Land	Annex 2
Biodiversity	Impact of Infrastructure	Map 4.1 Section 4.3
	Natural Capital Index	Figures 7.20 and 7.21 Section 7. 9
Land use degradation	Cropland degraded	Figure 3.3 Section 3.3
	Area with high risk of water-induced soil degradation	Figure 7.15 Section 7.7
Freshwater (quantity aspects)	Percentage of population living in areas with severe water stress	Figures 5.3, 5.4, and 5.5 Section 5.3
Coastal Zones	Nitrogen loading at river mouths	Table 7.2 Map 7.1 Section 7.3
Forests	Change in natural forest area (re-growth excluded)	Figure 7.17 Section 7.8
Urban Areas	Energy-related nitrogen oxide emissions from all sources	Annex 3 GEO 3 main report, Chapter 2
Atmosphere	Energy-related emissions of sulphur dioxide	Figure 7.4 Section 7.4
	Energy-related emissions of nitrogen oxides from all sources	Annex 3 GEO 3 main report, Chapter 2
Climate	World: Global rate of temperature change	Section 7.6
	Regions: Change in regional annual temperatures 2002-2052; change in average temperature in the Polar regions (both based on four global circulation models)	Section 7.6