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FAIR 1.0 (Framework to Assess International Regimes for differentiation of commitments):

- An interactive model to explore options for differentiation of future commitments in international climate policy making

USER DOCUMENTATION

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FOREWORD

One of the most contentious issues in international climate policy development is the issue of (international) burden sharing, or as we prefer to name it, *differentiation of (future) commitments*: who should contribute when and how much to mitigate global climate change? It is an issue related to both technical capabilities, economic costs, as well as normative aspects such as responsibility and equity.

This report presents a *new decision-support tool*, developed with the aim of assisting policy makers in evaluating different options for differentiation of future commitments. It is called FAIR (Framework to Asses International Regimes for differentiation of commitments) and was developed at the National Institute of Public Health and the Environment (RIVM), in The Netherlands. FAIR is an interactive - scanner-type - computer model that can be used to explore a range of alternative options for international differentiation of commitments in a quantitative way and link these to targets for global climate protection.

The first results of the FAIR model, focussing on an evaluation of the so-called Brazilian proposal were presented at the UNFCCC/COP-4 conference in Buenos Aires (Argentina, November 1998), and have been reported before (den Elzen *et al.*, 1999). Since then we have presented FAIR model results at various occasions, such as (inter-) national conferences and workshops. The FAIR model has also been used in the science-policy dialogue setting as part of the COOL (Climate OptiOns for the Long term). Over time, we have received very useful comments and suggestions that have enhanced the usefulness of the model. Now, we feel we should make the present version model available to a wider audience via the Internet. This requires the availability of proper model documentation and user instructions, which is the main purpose this report intends to serve. This report also forms the basis of our website: http://www.rivm.nl/fair/, where you can download the free FAIR software. Since we plan to continue with the development of the FAIR model, we would be very happy to also receive your comments and suggestions for improvements on the FAIR model as well as this report and our website. In this way we hope the FAIR model can play a constructive role in the many discussions to come on a fair differentiation of future commitments under the United Nations Framework Convention on Climate Change (UNFCCC).

The Authors
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The FAIR model was presented at the Seventh International Dialogue Workshop in Kassel (Germany, September 1998), the National Research Programme Climate conference in Garderen (The Netherlands, October 1998), the UNFCCC/COP-4 conference in Buenos Aires (Argentina, November 1998), the EFIEA policy workshop in Milan (Italy, March 1999) and the Expert meeting on the Brazilian Proposal in Cachoeira (Brazil, May, 1999) and other (inter-) national conferences and informal presentations. In 2000, the FAIR model was also presented at the World Resource Institute (WRI) (Washington) and the International Energy Agency (IEA) (Paris). Presently, the model is especially used in the context of the COOL (Climate OptiOns for the Long-term) Global Dialogue project, an integrated assessment project of the Dutch National Research Programme on Climate Change.

We owe a vote of thanks to the participants of these meetings and presentations for their participation in fruitful scientific discussions on this study and the FAIR model, and for their suggestions for improvements and/or alternative approaches. In particular, we would like to thank Ian Enting and Chris Mitchel (Australia), Luiz Gylvan Meira Filho, Jose Domingos Gonzales Miquez, Jose Goldemberg and Luiz Rosa (Brazil), Atiq Rahman (Bangkadesh), Art Jacques, John Drexhage and Henry Hengeveld (Canada), Liu Deshun, Xuedu Lu, Ye Ruquui and Shuguang Zhou (China), Jesper Gunderman, Lasse Ringius, Arild Underdal(Denmark), Jean-Jacques Becker and Jonathan Pershing (France), Bill Hare, Dennis Tirpak and Rolf Sartorius (Germany), Tibor Farago (Hungary), Anial Agarwal and P. Shukla (India), Yvo de Boer, Joyeeta Gupta, Jaap Jansen, Marcel Kok, Leo Meyer, Maressa Oosterman, Dian Phylipsen, Jos Sijm, Remco Ybema and Zhong Xiang Zhang (the Netherlands), Asbjorn Torvanger and Harold Dovland (Norway), Igor Bashmakov (Russian Federation), Geoff Jenkins, Michael Jefferson, Benito Muller, Aidan Murphy and David Warrilow (United Kingdom), Patricia Itturregui (Peru), Clare Breidenisch, Eileen Claussen, Abraham Haspel, Nancy Keete, Daniel Lashof, Bill Moomaw, Raymond Prince, Daniel Reifsnyder and Adam Rose (USA) and many others for their contributions.

Invaluable contributions, as well as on-line assistance, came from the developers of the simulation language ‘M’, Pascal de Vink and Arthur Beusen. This simulation language, developed at the RIVM, allows for easy visualisation in the development and presentations of simulation models, representing the secret of the RIVM interactive scanners’ success, e.g. the FAIR model and others.

Finally, we are grateful to the whole IMAGE team and other colleagues at the RIVM, in particular, Kees Klein-Goldewijk, Erik Kreileman, Rik Leemans, Bert Metz, Jelle van Minnen, Jos Olivier, Michiel Schaeffer, Bert de Vries and Detlef van Vuuren.

ABSTRACT

This report describes the model documentation and user instructions of the FAIR model (Framework to Assess International Regimes for differentiation of commitments). FAIR is an interactive - scanner-type - computer model to quantitatively explore a range of alternative climate policy options for international differentiation of future commitments in interbational climate policy making and link these to targets for global climate protection.
The model includes three different approaches for evaluating international commitment regimes:

1. *Increasing participation*: the number of Parties involved in this mode and their level of commitment gradually increase according to participation and differentiation rules, such as per-capita income, per capita emissions, or contribution to global warming.
2. *Convergence:* in this mode all Parties participate in the regime, with emission allowances converging to equal per capita levels over time. There are three types of convergence methodologies: (i) non-linear convergence towards equal emission allowances, according to the Contraction & Convergence approach; (ii) linear convergence towards equal emission allowances. (iii) CSE convergence approach in which convergence is combined with the distribution of basic sustainable emission rights.
3. *Triptych*: different differentiation of future commitments rules are applied to different sectors (e.g. convergence of per capita emissions in the domestic sector, efficiency and de-carbonisation targets for the industrial and the power generation sector)

The first two modes are representatives of top-down methodologies, starting from global emission ceilings and translating these to regional emission budgets, whereas the triptych approach is more bottom-up in character, not starting from a specified global emission ceiling. In order to construct and evaluate global emission profiles, the FAIR model also has the mode:

4. *Scenario construction.* In this mode the impacts in terms of the main climate indicators can be scanned of a constructed or well-defined global emissions profile.

Keywords: Climate change, Burden sharing, FAIR model, Differentiation of future commitments, Convergence, Triptych approach, *Brazilian proposal*

SAMENVATTING

Dit rapport bevat de model documentatie en gebruikershandleiding van het FAIR model (Framework to Assess International Regimes for differentiation of commitments). FAIR is een interactief computer model voor het (kwantitatief) verkennen van verschillende beleidsopties voor internationale lastenverdeling voor het internationale klimaatbeleid, gekoppeld aan doelstellingen voor bescherming van het klimaat. De huidige versie van FAIR bevat drie verschillende benaderingen voor internationale lastenverdeling-regimes:

1. *Increasing participation (toenemende participatie)*: in deze benadering neemt het aantal landen en hun inspanningsniveau geleidelijk toe op basis van regels en criteria voor zowel deelname als bijdrage (bijvoorbeeld op basis van hoofdelijk inkomen, hoofdelijke emissies of bijdrage aan temperatuurstijging (Braziliaans voorstel);
2. *Convergentie:* in deze benadering nemen alle partijen direct deel aan een emissierechtenregime, waarbij de toegestane emissieruimte in de tijd convergeert van het bestaande naar een gelijk hoofdelijk niveau;
3. *Triptych (triptiek)*: De methode is gebaseerd op gedifferentieerde doelstellingen voor verschillene sectoren: energie-efficiëntie en de-carbonisatiedoelstellingen voor de electriciteits- en internationaal georienteerde zware industriële sectoren en internationale convergentie in per capita emissieruimte voor de binnenlandse sectoren.

De eerste twee modes zijn top-down methodologen, ende triptych methode is een bottom-up methode. FAIR bevat ook een optie om eigen emissie scenario's te ontwikkelen, alsmede de klimaatseffecten hiervan te evalueren (scenario constructie).

Trefwoorden: Klimaatveanderingen, FAIR model, internationale lastenverdeling, convergentie, triptych benadering en Braziliaans voorstel

CONTENTS

1 INTRODUCTION

Introduction

Over the years, many approaches for burden sharing / differentiation of (future) commitments in international climate policy making have been proposed, both in academic and policy circles. The FAIR model presented in this report does not intend to promote any particular approach to international burden sharing. Instead it aims at providing some menu for choice to support policy makers in evaluating options for differentiation of (future) commitments (den Elzen *et al.*, 1999).
FAIR is a decision-support tool (a so-called 'scanner'), which allows the user to interactively evaluate the implications of different approaches and criteria for international burden sharing, in terms of the allocations of allowed emissions (emission permits). Allowed emissions are calculated on a regional basis for 2 (Annex I and non-Annex I), 4 (OECD Annex I, non-OECD Annex I, Asia and other developing regions), or 13 world regions, as well as a number of selected countries[1]. By including a simple climate model, called meta-IMAGE 2.1 (den Elzen, 1998), based on the integrated climate change assessment model IMAGE 2.1 (Alcamo *et al.*, 1998), the FAIR model enables users to relate burden sharing schemes to global climate protection targets, such as global mean surface temperature change and sea-level rise.

Four basic modes of FAIR

FAIR consists of four basic model modes:

1. *Scenario construction*: in this mode the climate impacts of pre-defined or own-constructed global emissions profiles for greenhouse gases can be scanned.
2. *Increasing participation*: in this mode the number of parties involved and their level of commitment gradually increase according to participation and differentiation rules, such as per-capita income, per capita emissions, or contribution to global warming.
3. *Convergence:* in this mode all parties participate in the burden-sharing regime, with emission rights converging to equal per capita levels over time.
4. *Triptych*: different burden sharing rules are applied for different sectors (e.g. convergence of per capita emissions in the domestic sector, efficiency and de-carbonisation targets for the industry sector and the power generation sector).

Organisation of the report

This report is foremost meant as documentation on the FAIR model and a manual for users. It does not provide an extensive description and evaluation of the literature on international burden sharing /differentiation of commitments in the field of climate change. Nevertheless, in chapter 2 we will give a short overview over various dimensions of international burden sharing / differentiation of commitments that are relevant for understanding the approaches within the FAIR model and the models' limitations. Moreover, we will describe the background of the development of the model. Next, in Chapter 3 we will describe in more detail the methodology of the scenario-construction part of the model, as well as the three main regime approaches included in the model. Chapters 4 and 5 contain the core of the report: the model documentation and manual.
Chapter 4 provides detailed background information on the (climate) model, historical data and scenario assumptions used. Chapter 5 describes and explains the design and user options of the various basic and advanced views of the FAIR user interface. A paragraph of this Chapter also consists of a technical manual that describes how the FAIR model can be operated, and some

[1] IMAGE 2.1 regions consist of Canada, USA, Latin America, Africa, OECD-Europe, Eastern Europe, CIS, Middle East, India + South Asia, China + centrally planned Asia, West Asia, Oceania, and Japan; selected countries presently consist of Australia, Germany, Japan, The Netherlands, USA, Brazil, China, India, Mexico and South Africa.

special features of the M-modelling language used for construction of both the model and its interface. Finally, in Chapter 6, we present a “guided tour“ through the model to illustrate the some of its features and insights that can be gained from the model.

2 BACKGROUND

2.1 Introduction

One of the key policy issues in the evolution of the Framework Convention on Climate Change (FCCC) is the involvement of developing country parties (non-Annex-1). While their emissions presently constitute only a minor part of global green house gas (GHG) emissions, it is expected that within a number of decades their emissions will outgrow those of the industrialised countries (Annex-1). However, already during the negotiations on the FCCC developing countries stressed that given their historical emissions the industrialised countries bear the primary responsibility for the climate problem and should be the first to act. This was formally recognised in the FCCC (1992) which states that developed and developing countries have "common but differentiated responsibilities" (article 3.1).
It was again re-acknowledged in the so-called Berlin Mandate (UNFCCC, 1995), in which additional commitments were limited to developed countries only. Nevertheless, during the negotiations on the Kyoto Protocol the (future) involvement of developing countries in global emission control became an issue again, especially due to the USA demand for "meaningful participation of key developing countries". In 1997, during the third Conference of Parties (CoP-3) the industrialised countries agreed in Kyoto (Japan) to reduce their greenhouse gas emissions by on average 5.2 % by 2008-20012 from 1990 levels (UNFCCC, 1998). The protocol does not include new commitments for developing country parties, but the issue of developing country participation has gained attention ever since, because it is expected that the USA will not ratify the Protocol without the "meaningful participation by key developing countries". Moreover, the debate has been fuelled by the announcements of some developing countries to voluntarily take up the new commitments (notably Argentina and Kazakhstan during CoP-5 in Buenos Aires).

2.2 Dimensions of International regimes for differentiation of commitments

In the past, the issue of international burden sharing in global climate change policy has received much attention, especially in the run up to the signing of the Framework Convention on Climate Change in Rio de Janeiro in 1992 (see e.g. Grubb, 1989, Krause *et al.*, 1989, Agarwal, 1991, Grubb *et al.*, 1992, den Elzen *et al.*, 1992, Grübler and Nakicenovic, 1994, Rose, 1992). After the adoption of the Berlin Mandate during the first Conference of Parties in 1995 the focus of analysis shifted to burden sharing within the group of Annex-1 (see e.g. Torvanger *et al.*, 1996, Kawashima, 1996, Reiner and Jacoby, 1997, Blok *et al.*, 1997, Metz, 2000). With the adoption of the Kyoto Protocol, a renewed interest in global burden sharing can be expected. Although, in the literature burden sharing is a common concept, this debate is likely to be framed in terms of "differentiation of (future) commitments" given the language in the FCCC. Therefore, we prefer to use this term in stead of burden sharing.
A key issue in this debate on "differentiation of future commitments" will be equity or fairness. Equity usually relates to principles. However, as we will elaborate below, there are more dimensions of regimes for differentiation of future commitments than equity principles only. All these dimensions need attention in discussing possible regimes for differentiation of future commitments. Nevertheless, equity principles, either explicitly or implicitly, are at the heart of those regimes. Here, we will first give a short overview of various equity principles in the literature on international burden sharing in climate change policy making.

Equity Principles

There is no common accepted definition of equity. Equity principles refer to more general notions or concepts of distributive justice or fairness (Rose, 1992). Rose *et al.* (1997) distinguish three types of alternative equity criteria for global warming regimes:

1. **allocation based criteria**, defining equitable burden sharing in terms of principles for the distribution of emission rights or the allocation of emission burdens;
2. **outcome based criteria**, defining equitable burden sharing in terms of its outcomes, in particular the distribution of economic effects; and
3. **process based criteria**, defining equitable burden sharing in terms of the process for arriving at a distribution of emission burdens.

This distinction is important for understanding the approach adopted in the FAIR model, because the model only incorporates *allocation based* criteria for the differentiation of future commitments. Outcome based criteria usually refer to the distribution of costs (and benefits) (in terms of either investment costs or welfare effects) resulting from any distribution of commitments. The economic modelling framework needed for this is not part of the (present) FAIR model. A general problem with such an approach, though, is the dependence on complex economic models, the outcomes of which are usually little transparent to policy makers. However, since costs and economic impacts of options for differentiation of future commitments are important policy considerations, we plan to include at least cost functions in future versions of the model.

Ringius *et al.* (1998) use another typology based on the type of equity principles relevant in the context of climate change. They distinguish five equity principles:

1. **egalitarian**: people have equal rights to use the atmosphere;
2. **sovereignty**: current emissions constitute a status quo right now;
3. **horizontal**: actors under similar (economic) conditions have similar emission rights and burden sharing responsibilities;
4. **vertical**: the greater the capacity to act/ability to pay the greater the (economic) burden;
5. **polluter pays**: the greater the contribution to the problem the greater the burden.

They note that in practise proposals for burden sharing often use formulas that relate to different equity principles and use multiple criteria relating to both economic and environmental dimensions of climate change regimes (see e.g. Kawashima, 1996, Ringius *et al.*, 1998). In their view, the principle of horizontal equity has been dominant during the negotiations on the Kyoto protocol. In the FCCC as well as the Kyoto Protocol the relations between the developed and developing countries are much more described in terms that refer to vertical equity and the polluter pays principle.

In a more recent studies, focusing on the most relevant elements for a widely accepted approach to burden differentiation in future international climate negotiations, Ringius *et al.* (Ringius *et al.*, 2000, Torvanger *et al.*, 2000) simplify their typology of equity principles or “principles for distributive fairness” to three key principles:

1. **Guilt**: costs should be distributed in proportion to a party’s share of responsibility for causing the problem;
2. **Capacity**: costs should be distributed in proportion to ability to pay;
3. **Need**: all individuals have equal rights to pollution permits, with a minimum to secure basic human rights, including a decent standard of living.

The interesting aspect of the simplified typology is that it resembles notions on fairness in the FCCC itself, in particularly article 3.1, which states:

> "The parties should protect the climate system for the benefit of present and future generations, on the basis of *equity* and in accordance with their common but differentiated *responsibilities* and respective *capabilities, …"*.

For this reason, we will follow their terminology, with the exception that we will use the term responsibility instead of guilt, like in the FCCC.
Compared to their previous typology, the principle of sovereignty seems no longer covered. In their view it seems that this principle, which is behind the rule of equal obligations (e.g. flat rate reductions), and a default option in international negotiations, does no longer have sufficient legitimacy in a situation of large inequality amongst the parties involved. However, the principle seems to be still relevant, as illustrated in the case of the convergence approach (see below).

<u>Other regime dimensions</u>
Many discussions on international burden sharing in the field of climate change focus on principles for distributional fairness or equity. There are a number of other important dimensions of international regimes that can be distinguished (see e.g. Pershing, 1999):

1. **Sharing of costs or also benefits**. A first dimension is related to the question whether the burden-sharing regime should account for not only the distribution of costs, but also of the benefits of climate change. In a typical cost-benefit approach the distribution of emission reduction/control efforts should account for the distribution of benefits as well since some parties may be asked to limit their emissions, while they may actually benefit from climate change. At the same time, the distribution of emission reduction / control efforts should also account for the distribution of damage. The application of a cost-benefit approach to international burden sharing in the field of climate change is, however, very much hampered by the large uncertainties about the impacts of climate change and therefore not very practical. In fact, the present approach in the FCCC and the Kyoto Protocol seems to be to create separate collective mechanisms to help (vulnerable) countries adapt to the impacts of climate change (see the Kyoto Protocol, art. 12, sub 8).
2. **Problem definition.** A second dimension is related to the question whether the climate change problem is defined as a pollution problem or as a common good issue. In the first case, the question is one of finding an equitable distribution of the emission reduction burden; in the latter case, the question is to find a fair distribution of the sustainable use of the atmosphere. These different approaches have implications for the design of burden sharing regimes. In the first approach, the burden sharing will focus on defining who should reduce his pollution how much; in the second approach the burden sharing will focus on who has what emission rights. The acceptance of the flexible mechanisms like emission trading in international climate policy making has made burden sharing on the basis of the allocation of rights much more viable than before because actual emission levels no longer need to be the same as allowed emission levels. At the same time, the introduction of concepts such as "assigned amount" has given rise to discussion on emission rights. Many developing countries have the view that the introduction of emission trading and "assigned" amounts should not be separated from the discussion on an equitable distribution of welfare (statements of Indian delegation during Kyoto and Buenos Aires rights, Centre for Science and Environment (CSE), 1998).
3. **Emission limit.** A third dimension concerns the way the burden is defined. One can define the burden top-down by defining the globally allowed emissions and applying certain participation and burden sharing rules for allocating the overall reduction effort needed, or instead in a bottom-up way allocate emission control efforts among parties, without a predefined overall emission reduction effort.
4. **Participation**. A fourth dimension is that of participation: who should participate when? Discussions on burden sharing sometimes seem to assume that all parties participate. This is not necessarily the case, as illustrated by the Kyoto Protocol, which does not contain obligations for

the non-Annex-B countries.[2] Regimes for the differentiation of future commitments not only concern rules for burden sharing, but also for participation.

5. **Form of commitment.** A fifth dimension is that of the form of the burden or commitment. This needs not necessarily be the same for all parties. It is well conceivable that future commitments of non-Annex-1 countries may be of a different nature than the present ones for the Annex-1 (see e.g. Baumert *et al.*, 1999; Claussen *et al.*, 1998).

2.3 Dimensions of regimes and modes in FAIR

The FAIR model was designed to allow for the evaluation of the consequences of different approaches to the differentiation of future commitments. The three modes in FAIR combine both different principles of equity as well as most of the other dimensions of regimes discussed above[3] (see table 2.1) For selecting the modes and options to be included in the present version of FAIR there were both pragmatic and theoretical considerations. A major pragmatic consideration was to include approaches that have (already) gained serious policy attention, e.g. the Brazilian proposal[4] (den Elzen *et al.*, 1999). A more theoretical consideration relates to the possible evaluation of the international climate regime. For the evolution of the FCCC two concepts are thinkable:

1. a gradual extension of the group of Annex-B countries, taking up binding commitments under the Convention, or
2. the development of a comprehensive regime, defining the rights and duties of all parties.

The first kind of regime would mean a gradual extension of the present Protocol approach to differentiate the obligations of various parties under the Convention and involve discussions on both rules for participation and on burden sharing on the basis of predominantly incremental decision making. This type of regime we call **'Increasing participation'**. The second regime would be a major shift away from the protocol approach and have a long-term perspective with respect to the distribution of rights and duties and their evolution over time. A clear case of the latter is the so-called "contraction and convergence" of the Global Commons Institute[5] which defines emission permits on the basis of a convergence of per capita emissions under a contracting global emission profile. Since there are different variants possible, such as the one proposed by CSE to account for basic emission rights, we call this approach simply '**Convergence**'.

As an alternative development, there could be a shift in focus from the level of the nation state towards the level of sectoral policies, which could be applied to a limited set of parties to the FCCC, but also be fully international in nature, such as in the case of industries dominated by a limited number of key multinational companies (steel industry, car industry, petrochemical industry etc.). Such a shift would fit in with a more bottom-up approach for defining commitments. A simple example of a bottom up approach, would be the global application of the **Triptych approach**. The Triptych approach (Blok *et al.*, 1997) is included as a totally different alternative to the two other approaches in the model, with a bottom-up, sector oriented character. This approach was successfully used in the EU before Kyoto to help defining an internal burden sharing agreement, and is in the literature on burden sharing considered as an attractive approach to define future commitments (see Ringius, 1998 and 2000; Torvanger, 2000). In the FAIR model, a somewhat

[2] Annex B: Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, United States of America. Annex-I countries are almost identical to the Annex B countries from the Kyoto Protocol, excluding Croatia, Liechtenstein, Slovenia and Ukraine.

[3] As indicated before the present version of the FAIR model does not include an economic model. Thus, not only outcome based, but also a cost-benefit approach to burden sharing is not included in the model.

[4] During the negotiations on the Kyoto Protocol Brazil made a proposal for linking Annex-1 contributions to emission control to their relative contribution to global warming (UNFCCC, 1997).

[5] Their web site can be found on the Internet through: http://www.gci.org.uk.

simplified version of the original triptych approach has been included in order to be able to apply the approach on a global scale and consistent with the (scenario) data used in the other two modes. The three different modes are described in more detail in the next chapter.

The three different modes are described in more detail in the next chapter.

Table 2.1. The three modes of FAIR and different dimensions of international burden sharing

Dimensions	*Increasing Participation*	*Convergence*	*Triptych*
Equity principles			
- responsibility	X		
- capability	(X)	(X)	X
- need	X	X	(X)
Problem definition			
- pollution problem	X		X
- global commons issue		X	
Emissions limit			
- top down	X	X	
- bottom up			X
Participation			
- partial	X		
- all	X	X	X
Form of Commitment			
- equal		X	X
- differentiated	X		X

3 METHODOLOGY

3.1 Introduction

We developed the FAIR model to evaluate the implications of different initial allocations of emission rights. This model is designed in such a way that many different criteria for burden sharing can be used, so as to support policy makers in evaluating options for international burden sharing and can be used interactively. The model relates burden sharing schemes to global climate protection targets and calculates the respective regional emission permits. The climate calculations are done by the simple climate assessment model *meta-IMAGE*. The FAIR model can calculate the implications of various burden-sharing approaches under various global emission profiles for 2 (Annex I and non-Annex I), 4 (OECD Annex I, non-OECD Annex I, Asia and other developing regions), or 13 world regions (under IMAGE 2.0) and a number of selected countries[6].

Three different approaches of defining burden-sharing schemes are included in the model:
1. **Increasing participation**. In this mode the number of parties involved and their level of commitment gradually increase according to participation and differentiation rules, such as per-capita income, per capita emissions, or contribution to global warming.
2. **Convergence**. In this mode all parties participate in the burden-sharing regime, with emission rights converging to equal per capita levels over time.
3. **Triptych**. Different burden sharing rules are applied for different sectors (e.g. convergence of per capita emissions in the domestic sector, efficiency and de-carbonisation targets for the industry sector and the power generation sector).

The first two modes are representatives of top-down methodologies, so from global emission ceilings to regional emission budgets, whereas the triptych approach is more bottom-up in character, although it can be combined with specific emission targets (as illustrated in the case of the EU). In order to construct and evaluate global emission profiles, the FAIR model also has the mode:

4. **Scenario construction**. In this mode the impacts in terms of the main climate indicators can be scanned of a constructed or well-defined global emissions profile.

3.2 Scenario construction

The *Scenario-construction* mode of FAIR allows the user to interactively define own global emission scenarios, or to select one of the pre-defined global emission scenario, and evaluate the climate impacts of the scenario in terms of the global climate indicators: global-mean-surface temperature change, rate of global temperature change and global-mean sea level rise.

Methodology
For the evaluation of the emission scenarios we made use of the global integrated simple climate assessment model meta-IMAGE 2.1 (hereafter to be referred to as meta-IMAGE) (Elzen, 1998; Elzen *et al.*, 1997), which itself forms an integral part of the FAIR modelling framework. Meta-IMAGE is a simplified version of the more complex climate assessment model IMAGE 2. The latter aims at a more thorough description of the complex, long-term dynamics of the biosphere-

[6] IMAGE regions consist of Canada, USA, Latin America, Africa, OECD-Europe, Eastern Europe, CIS, Middle East, India + South-east Asia, China + centrally planned Asia, Western Asia (Middle East), Oceania, Japan; selected countries presently consist of Australia, Germany, Japan, the Netherlands, USA, Brazil, China, India, Mexico and South Africa.

climate system at a geographically explicit level (0.5° x 0.5° latitude-longitude grid) (Alcamo, 1994; Alcamo *et al.*, 1996; 1998). Meta-IMAGE is a so-called meta-model[7] with a short run-time, i.e. a more flexible, transparent and interactive simulation tool, that on a global scale adequately reproduces the IMAGE-2.1 projections of concentrations of greenhouse gases, the global-mean temperature increase and sea-level rise for the various IMAGE 2.1 emission scenarios. Meta-IMAGE consists of an integration of a global carbon cycle model (den Elzen *et al.*, 1997), an atmospheric chemistry model (Krol and van der Woerd, 1994), and a climate model (upwelling-diffusion energy balance box model of Wigley and Schlesinger (1985) and Wigley and Raper (1992)). Meta-IMAGE was recently complemented with the following new elements: (i) the revised Brazilian model (Filho and Miquez, 1998) and (ii) global temperature impulse response functions (IRFs, see e.g. Hasselmann, 1993) based on simulation experiments with various Atmosphere-Ocean General Circulation Models (AOGCMs) for alternative temperature increase calculations (den Elzen and Schaeffer, 2001). Its set-up also allows for assuming different climate sensitivities and global sulphur emissions (see paragraph 5.1).

3.3 Increasing participation

In the Increasing participation approach (mode) the number of parties involved and the level of involvement in the burden sharing gradually increases over time according to participation and burden sharing rules, such as per capita emissions, or the contribution to global warming (Brazilian Proposal) (UNFCC, 1998). In essence, the approach is based on the polluter pays principle, but adjusted for considerations of need (for development) and capacity to act. Berk and den Elzen (1998) and den Elzen *et al.* (1999) first introduced this approach at the fourth Conference of the Parties (COP-4). Later, the approach was extended by more stages of participation into what can be called a '*multi-stages*' approach (see below).

In its basic form the procedure is as follows. First, a long-term target emission scenario (a concentration stabilisation scenario, including or excluding the Kyoto Protocol) is selected. For each 5-year time step, the following participation rules determine who should participate and when. More specifically:

- All Annex-I countries participate immediately (2000), or after the Kyoto period (2013), depending on whether the target emission scenarios exclude or include the Kyoto Protocol.
- Non-participating parties (non-Annex-I) follow their baseline emission scenario (reference scenario) until they meet a participation threshold.
- Participation thresholds are based on income and/or emission levels, or on a selected starting year.

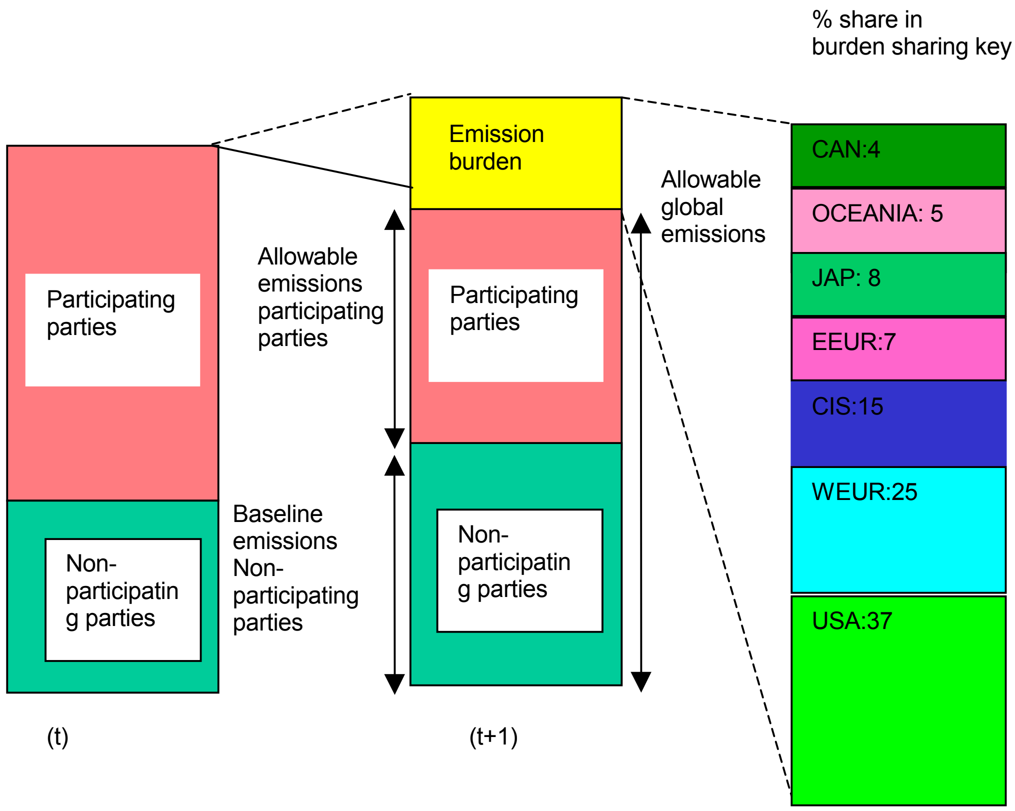
Next, the Burden sharing rules determine who gets what part of the burden. Various options of burden sharing rules are available in the FAIR model.

[7] A meta-model is a highly aggregated, simplified representation of an original model that is more detailed and referred to as the expert model. This means that it has to fulfill the following two requirements: (i) it should be a flexible, transparent and rapid simulation tool; (ii) its model structure and outcomes should be validated extensively against the original, expert model and empirical data.

Methodology

In the 'increasing participation' mode the FAIR model calculates allowed emissions (emission permits) for regions/countries as follows:

1. For each 5-year time step, the model evaluates if regions/countries satisfy any of the selected participation rules. When regions/countries satisfy one or more of these rules, they start sharing the emission reduction burden during the next time step. Other regions follow their Baseline emission scenario.
2. The required emission reduction effort (yellow block in Figure 3.1) is determined by subtracting the baseline emissions of non-participating regions/countries from the global emissions allowed in the next target year.
3. The share of each participating region/country in the burden-sharing key (e.g. contribution to CO_2 emissions or CO_2-induced temperature increase) then determines its share in the emission reduction effort. Over time, the share of regions/countries in the emission reduction efforts changes, both because of reductions in their emissions and because other regions/countries start participating in the burden sharing.



Example:

USA emissions (t)	= 1.7 GtC;
Emission burden (t+1)	= 0.5 GtC;
USA share in burden sharing key	= 37%
Allowable emissions USA at (t+1)	= 1.7 - (0.37 *0.5) = 1.52GtC

Figure 3.1 Calculating regional emission permits with FAIR in the "Increasing participation" mode

Multi-stage
The increasing participation approach can be refined by the introduction of two additional stages: stabilisation of emissions and de-carbonisation targets.

1. **Stabilisation of emissions**. In this case, a region/country that meets any of the selected participation thresholds first stabilises its absolute or per capita emissions for a user-defined number of years before it actually enters the burden-sharing regime.
2. **De-carbonisation targets**. In this case, an additional set of emission and/or income-based thresholds ('decarbonisation thresholds') is used which define when a region/country enters a stage in which its allowable emissions are controlled by de-carbonisation targets. These de-carbonisation targets define the rate of reduction in the carbon-intensity of the economy (CO_2 emissions per unit of Gross Domestic Product (GDP) or per unit of Purchasing Power Parity (PPP)). A region/country leaves this stage when it meets any of the selected participation thresholds for the stabilisation of emissions and/or burden sharing stages.

These two additional stages were introduced to prevent sharp changes in a region/country's allowable emissions when it meets any of the burden sharing thresholds. Ideally, the de-carbonisation stage results in a reduction of the increase in allowable emissions. The stabilisation stage, then, acts as an intermediate stage between an increase and subsequent decrease in allowable emissions. All together, the increasing participation mode offers a 4-stage regime to differentiate commitments among parties over time, which is summarised as follows:

- **Stage 1**: **Reference scenario**: Non-participating parties (non-Annex I) first follow their baseline emission scenario (reference scenario) until they meet a decarbonisation threshold
- **Stage 2: Decarbonisation targets**. Then, they enter a stage in which their allowable emissions are controlled by de-carbonisation targets, defined by the rate of reduction in the carbon-intensity of their economy. A region leaves this stage when it meets any of the selected participation thresholds.
- **Stage 3: Stabilisation of emissions:** Then, they enter an emissions stabilisation period, in which they stabilise their absolute or per capita emissions for a user-defined number of years before they actually enter the burden sharing regime.
- **Stage 4: Emission burden sharing regime:** Then, burden sharing rules determine the emission reductions for each of the participating regions.

Box 3.1 Purchase Power Parity (PPP)

The Purchase Power Parity (PPP) is an alternative indicator for GDP/capita, based on relative purchase power of individuals in various regions, that is the value of a dollar in any country, i.e. the amount of dollars needed to buy a set of goods, compared to the amount needed to buy the same set of goods in the United States.

More specifically, for international comparison it is also necessary to convert local currencies into some common denominator - mostly US$. However, in doing so several problems occur. One of the most important is that exchange rates (normally used to convert currencies into US$) are not a good representative of price levels of countries. A dollar can purchase more in some countries than in others. It is possible to adjust for such differences in purchasing power - although this requires a vast amount of data (and assumptions with regard to possibility to compare quality of different goods in different countries). Several organisations among which the ICP (International Comparison Programme) collect data on prices paid for a large set of comparable items in more than 100 countries. Purchasing Power Parities (PPP) computed from these data allow comparison of prices and real GDP estimates across countries. For the PPP-GDP data used within the IMAGE-framework and for FAIR data from the World Bank Development Indicators (1999) have been aggregated to regional levels - and used for historic trends. For future trends, we have assumed convergence in PPP-values based on regression analysis between PPP-values and GDP per capita.

3.4 Convergence

In the Convergence approach all parties immediately participate in the burden-sharing regime (after the first commitment period), with per capita emission rights/permits converging towards equal levels over time. The convergence approach is a combination of status quo rights and the egalitarian equity principle. It leaves aside differences in historical contributions to the problem. The Global Commons Institute (GCI) first introduced the approach as ‘Contraction and Convergence’. Early results of the approach were published to good effect at the Second Conference of the Parties (COP-2) and have been distributed widely since then.
The procedure is as follows. First ‘contraction’, a global atmospheric greenhouse gas concentration target (like the 450 ppmv CO_2 concentration target) is selected, which creates a long-term global emissions profile or global greenhouse gas emissions contraction budget (like the IPCC S450 ppmv stabilisation scenario). Then this budget is allocated by the regions/countries in a way that the per-capita emissions converge from their present diverse values to a global average world value, to be the same for each country in a convergence year (GCI, 1997).
The ‘Contraction and Convergence’ concept has been adopted by a global group of parliamentarians, called ‘Global Legislators for a Balanced environment’ (GLOBE). The idea of convergence of the per-capita emissions has also been included in a proposal by France and to a lesser explicitly defined extent by proposals of Switzerland and the European Community (Torvanger and Godal, 1999). The concept gained substantial support in developing countries. The Centre of Science and Environment in India also supports the convergence concept (CSE, 1998) but has suggested a variant in which the concept is combined with basic sustainable emission rights, related to both the idea of survival emissions as well as the idea of commons as natural sink for CO_2 (in particular the oceans). This variant has been included in FAIR as a separate option (see below).

Methodology

The present version of FAIR includes three types of convergence: 1) non-linear convergence towards equal emission rights, according to the ‘contraction and convergence’ approach of GCI; 2) linear convergence towards equal emission rights, and 3) the CSE convergence approach in which convergence is combined with the distribution of basic sustainable emission rights.

1. Non-linear convergence (GCI)

This non-linear convergence method of the GCI uses the following algorithm for the allocation of the shares of global emissions in terms of percentage:

1. It starts out with ‘actual’ shares, as derived by the methods described above;
2. It converges all shares from actual proportions in emissions to shares based on the distribution of global population in the convergence year;
3. The actual degree of convergence in per capita emission allocated in each year depends on the (potentially capped) population and the rate of convergence selected. The rate of convergence determines whether most of the per capita convergence takes place at the beginning or near the end of the convergence period.

The formula used for this convergence:

$$S_E(r,t) = S_E(r,t-1) - [S_E(r,t-1) - S_{pop}(r,t)] \cdot e^{(-a(1-t^*))} \tag{3.1}$$

$$t^* = \frac{(t - t_{start})}{(t_{conv} - t_{start})}$$

where $S_E(r,t)$ is the emissions share of a region r at time t, $S_{pop}(r,t)$ is its share of the global population at time t, t^* is the fractional time elapsed between 2000 and the target year (t=0 for 2000 and t=1 at the convergence year), and a is an arbitrary parameter that determines the rate of convergence.

2. Linear convergence

Another methodology assumes a linear convergence of an allocation based on shares in global emissions in the starting year to an allocation based on the share in global population in the convergence year. In formula:

$$S_E(r,t) = S_E(r,t_{start}).(1 - t^*) - S_{pop}(r,t).\ t^* \tag{3.2}$$

The actual total anthropogenic CO_2 emissions allocations are then made by multiplying the global total allowed emissions by each country's shares derived from the convergence process.

3. convergence with basic sustainable emissions (CSE)

The idea of convergence with Basic sustainable emissions was suggested by CSE (Agarwal *et al.*, 1991; CSE, 1998; Agarwal, 1999). Its starts from the concept of basic emission right per world citizen, which is linked to a so-called global ‘sustainable’ emission level. This level is determined by the amount of CO_2 that can be emitted into the atmosphere without resulting to an increase in the atmospheric concentration of CO_2 ; that is the ultimate level for stabilisation CO_2 concentrations, as referred to in article 2 of the UNFCC (1998).

This global ‘sustainable emission level’ (*GSEL* in GtC) is now allocated among the world population, as a common goal using the equity principle: *every human being in future has a basic emission quotum irrespective of the country he or she lives in.* Given a future population

development, this basic emission quotum changes in time, and is simply calculated as the global 'sustainable' emissions level divided by the population size. In formula: $GSEL / pop_{gl}(t)$.
Besides this basic emission quotum, each human being has a remaining emission quotum, which is calculated using the linear convergence methodology (as described above), but now using a "remaining" global emission profile. This remaining global emissions profile is determined by the global target emission profile minus the global 'sustainable' emission level (see also CSE, 1998).

Cap on population growth
In the methodology of the GCI, there is also an option to set a cap on population growth for the purposes of allocation of emissions rights. This was done by notional freezing populations for years beyond a 'population cut-off year' at the values for that year. Note there is no assumption being made about what populations will or should be beyond the cut-off year; merely that population growth after that year should not accrue additional emissions rights. The GCI recommends the year 2020. In their report they say: "One could make an ethical case for it being the year of the agreement, optimistically 1997, but it seems better to allow an adjustment period, as one could also make an ethical case for allowing rights based on family sizes - in effect allowing more rights to countries with an above-replacement proportion of females of reproductive age or below. It might be necessary to adopt some such cap criterion, as otherwise the system would give national governments a positive incentive to encourage their populations to grow to obtain an increasing share of emissions rights. Clearly this would be undesirable". This cap methodology is also implemented in the present version of FAIR (see below) for all three convergence methodologies.

3.5 Triptych

A quite different approach to international burden sharing is offered by the Triptych approach (Phylipsen *et al.*, 1998). This is a sector-oriented approach that has been used for supporting decision-making on burden sharing in the European Union (EU) prior to Kyoto (COP-3) (Blok *et al.*, 1997).
In contrast to the 'Increasing participation' mode, which follows a typical top-down approach (from global emission ceilings to regional emission budgets), the Triptych approach is more bottom-up in character, although it can be combined with specific emission targets (as illustrated in the case of the EU). The Triptych method is a sector approach to burden sharing, which allows for taking into account different national circumstances. The approach embraces considerations of fairness related to both equity, capability and need (Torvanger, 2000; see table 1, Chapter 2).

In the triptych approach three categories or sectors of emission sources are distinguished:
1. domestic sectors;
2. internationally-oriented energy-intensive industry;
3. power-producing sector.

Emission allowances are calculated by applying specific rules to each of these sectors. The triptych approach was developed for the EU-15, but has here been adapted for using it on world region level. A more extensive description of the (original) methodology and its background can be found in Phylipsen *et al.* (1998).

Three categories or sectors

The selection of the triptych categories is based on the main issues encountered in negotiations on international burden sharing in emission control: differences in standard of living, fuel mix, economic structure and the competitiveness of internationally-oriented industries. Different criteria are used for each of the categories to calculate the emission allowances. How stringent the absolute emission allowances are, depends on the overall ambition level. The sectors can be characterised as follows:

1. **Domestic sectors**: comprise the residential sector, the commercial sector, and sectors for transportation, light industry and agriculture. In these sectors emission reductions can be achieved by means of national measures; emissions here are assumed to be fairly, directly correlated with population size.
2. **Industrial sectors**: comprise internationally oriented industries, where competitiveness is determined by the costs of energy and of energy efficiency measures. These are heavy industry, which comprises the building materials industry, and the chemical, iron & steel industry, non-ferrous metals, and pulp & paper industries; also included are refineries, coke ovens, gasworks and other energy transformation industries (excluding electricity generation). Compared to other economic sectors, industry, especially heavy industry, generally has a relatively high energy value added and in most countries also high CO_2 per value added ratio. Countries and regions with a high share of heavy industry will therefore have relatively higher CO_2 emissions/units of GDP than countries that focus primarily on light industry and services. Setting CO_2 emission targets on a per capita basis would be to the disadvantage of the competitiveness of industries in countries with a high share of such industries. Specific rules for this sector could take these considerations into account.
3. **Electricity generation sectors**: show great differences between regions and countries in their share of power production techniques like nuclear power and renewables, and in the (fossil)-fuel mix. The potential for renewable energy is different for each region, just like the public acceptance of nuclear energy.

Methodology

The 1990 CO_2 emissions from the EDGAR-HYDE database (Olivier *et al.*, 1996; 1999) are used as starting and reference values. Projections for population growth, Industrial Added Value (IVA) rates and Gross Domestic Product (GDP) (describing the sectoral growth rates) are based on the assumptions in the reference scenarios (IMAGE 2.1 Baseline scenarios and the IMAGE 2.1 IPCC/SRES scenarios[8]).

Domestic sectors

The allowable CO_2 emissions in the domestic sectors are assumed to be primarily related to population size. Therefore a per capita approach seems appropriate here. Differences in development are taken into account by allowing convergence of per capita CO_2 emissions over time. Here, we assume that the regional domestic CO_2 emissions per capita converges linear (using a constant yearly reduction factor) between 1990 and the convergence year to the world-wide average allowed emissions per capita level. The latter is derived from the allowed total domestic CO_2 emissions and the total population in the convergence year. The dynamics of the convergence can be described in formulas as follows:

[8] The IMAGE 2.1 IPCC/SRES A1 and B1 emission scenarios are the IMAGE 2.1 implementation of the IPCC SRES A1 and B1 emission scenarios (Nakicenovic *et al.*, 2000). The IMAGE 2.1 implementattion of the IPCC SRES B1 emission scenario was also the marker of the family of IPCC SRES B1 emission scenarios (Nakicenovic *et al.*, 2000), and therefore corresponds with the IPCC SRES B1 emission scenario. This scenario is extensively described in de Vries *et al.* (2000).

$$E_{dom,pc}(r,t) = E_{dom,pc}(r,t-1).\left[\frac{E_{dom,pc}(gl,t_{conv})}{E_{dom,pc}(r,1990)}\right]^{1/(t_{conv}-1990)} \quad (3.3)$$

where $E_{dom,pc}(r,t)$ is the regional domestic CO_2 emissions per capita for region *r* and at time *t* (the 1990 values are based on EDGAR-HYDE data), and $E_{dom,pc}(gl,t)$ is the global domestic CO_2 emissions per capita at time *t*. The decision parameters are the convergence year t_{conv} and the global domestic CO_2 emissions reduction factor, i.e. the %-reduction of the total domestic CO_2 emissions in the convergence year. The latter describes the domestic CO_2 emissions per capita at are the convergence year ($E_{dom,pc}(gl, t_{con})$). From the convergence year to 2100 (end of the simulation period), the allowance of CO_2 emissions per capita remains equal which implies that the total domestic CO_2 emissions can increase after the convergence year due to an increasing population.

Industrial sectors
The development of the emissions in the industrial sectors from 1990 to 2100 depends on the industrial growth rate, the projected energy efficiency improvement and the de-carbonization improvements, using the so-called Kaya identity (Kaya, 1989)):

$$CO_2 = P * Y/P * E/Y * CO_2/E$$

where CO_2 represents the fossil CO_2 emissions, P the population of the region, Y the Gross Regional Product (such that Y/P represents the average income), E stands for (primary) energy use (such that E/Y represents energy intensity of Y) and CO_2/E is the carbon intensity of (primary) energy use.
Energy intensity of the economy (E/Y): this indicator represent two different dimensions of the energy demand side: (1) (the change in) the energy intensity of the industrial economy due to (a structural change in) its composition (e.g. from heavy to light industries) and (2) the (general tendency of an improvement of) technical efficiencies of processes (which is assumed to have an autonomous component, apart from any price-induced component). Note that energy intensity is here defined for primary energy use. Thus, also energy conversion efficiencies (e.g. to produce electricity from coal) are included in this parameter.
- C*arbon intensity of energy use (CO_2 /E):* this indicator represents two different dimensions of (a change in) the energy supply side: (1) (the shift in) the relative use of different fossil fuel types (coal, oil, natural gas), and (2) (the change in) the share of non-fossil fuels (nuclear, hydro-power, wind, solar, biomass).

For calculating the future emissions in the industrial sector (Em_{ind}) the Kaya identities of the industry sector based on EDGAR-HYDE data in 1990 are taken as a starting point. Industry Value Added (*IVA*) represents the share of industry in the economy (in 1990 dollars). Industrial energy intensity is than defined by En_{ind}/IVA, with En_{ind} the industrial primary energy use. The carbon intensity of the Industrial sector is defined by the carbon intensity of industrial primary energy use, i.e.
Em_{ind}/ En_{ind}.

The regional industrial CO_2 emissions for region *r* and at time *t* (*t* = 1990, …, 2100) ($Em_{ind}(r,t)$) can now be described as follows:

$$Em_{ind}(r,t) = IVA(r,t) \cdot \left[\frac{En_{ind}(r,t)}{IVA(r,t)} \cdot \frac{Em_{ind}(r,t)}{En_{ind}(r,t)}\right] \quad (3.4)$$

This can also be translated into growth trajectories of the industrial value added, energy efficiency of the industrial production and the de-carbonisation improvements of the industrial energy consumption:

$$Em_{ind}(r,t) = Em_{ind}(r,t-1)\left[1+gr_{ind}(r,t)\right]\left[1-ef_{ind}(r,t)\right]\left[1-dec_{ind}(r,t)\right] \tag{3.5}$$

The three last factors represent (i) the growth index of IVA in the reference scenario compared to the 1990 values ($gr_{ind}(r,t)$ in %/year); (ii) the index value of the energy intensity (based on the yearly rate of energy efficiency improvements ($ef_{ind}(r,t)$ in %/year)), and (iii) the index value of the carbon intensity (based on the yearly rate of decarbonisation ($dec_{ind}(r)$ in %/year)).

The growth of the IVA is described by the simulated pathway of the reference scenario. The yearly efficiency improvement of the industrial sector, and the de-carbonisation rate for the industrial sector are decision parameters in the FAIR model.

Electricity production sector
The CO_2 emissions from the Power sector can be defined as:

$$Em_{pow}(r,t) = ED_{pow}(r,t) \cdot \frac{En_{pow}(r,t)}{ED_{pow}(r,t)} \cdot \frac{Em_{pow}(r,t)}{En_{pow}(r,t)} \tag{3.6}$$

where $ED_{pow}(r,t)$ represent secondary energy (electricity) demand for region r and time t (t = 1990, …, 2100), $En_{pow}(r,t)$ is the primary energy use of the power sector, $En_{pow}(r,t)/ED_{pow}(r,t)$ represents the convergence efficiency of the power sector and $Em_{pow}(r,t)/ En_{pow}(r,t)$ the carbon intensity of the power sector. The calculations of the emissions in the power sector again start in 1990, using the EDGAR-HYDE emissions data in 1990 initial data.

The carbon intensity of the Power sector is defined by two factors: (1) the share of CO_2-free sources in the primary energy use (i.e. by use of renewables and nuclear) and (2) the carbon intensity of the fossil fuel based share in primary energy use, related to the fossil fuel mix. In formulas:

$$\frac{Em_{pow}(r,t)}{En_{pow}(r,t)} = \frac{EnFossil_{pow}(r,t)}{En_{pow}(r,t)} \frac{Em_{pow}(r,t)}{EnFossil_{pow}(r,t)} \tag{3.7}$$

with $EnFossil_{pow}(r,t)$ is the fossil fuel based primary energy use of the power sector.

Historical evidence shows that the growth of electricity consumption is highly related to the growth of GDP. Therefore, the growth in electricity demand is linked to the growth of GDP according to the reference scenario. This justifies a higher growth rate in electricity consumption in the countries that are entitled to a higher economic growth. The growth in electricity production is affected by the end-use energy efficiency improvement, improvements by de-carbonization and CO_2-free electricity, i.e.:

$$Em_{pow}(r,t) = GDP(r,t) \cdot \left[\frac{En_{pow}(r,t)}{GDP(r,t)} \cdot \frac{EnFossil_{pow}(r,t)}{En_{pow}(r,t)} \frac{Em_{pow}(r,t)}{EnFossil_{pow}(r,t)}\right] \tag{3.8}$$

with: $GDP(r,t)$ is total Gross Domestic Production.

This can also be translated into growth of the Gross Domestic Production, energy efficiency of the power sector (converge efficiency) and the de-carbonisation improvements of the primary energy use of the power sector, i.e. increasing share of CO_2-free sources in the primary energy use and de-carbonisation improvements of the fossil fuel-based share in primary energy use:

$$Em_{pow}(r,\ t+1) = Em_{pow}(r,\ t)\ \left[1 + gr_{pow}(r,t)\right]\ \left[1 - ef_{pow}(r)\right]\ \left[1 - co2free_{pow}(r)\right]\left[1 - dec_{pow}(r)\right] \quad (3.9)$$

The four factors represent (i) the growth index of the Gross Domestic Production in the reference scenario compared to the 1990 values ($gr_{pow}(r,t)$ in %/year); (ii) the change in the index value of the converge efficiency (based on the yearly rate of energy efficiency improvements ($ef_{pow}(r)$ in %/year)), and (iii) the change in index value of the CO_2-free share in electricity production ($CO_2\ free_{pow}(r)$ in %/year)), and (iv) the change in index value of the carbon intensity (based on the yearly rate of de-carbonisation of the fossil fuel-based share in primary energy use ($dec_{pow}(r)$ in %/year)).

4 MODELS & DATA

This Chapter briefly describes the climate model of FAIR, meta-IMAGE 2.1, and the IMAGE 2.1 model. As mentioned in Chapter 3, FAIR also uses the IMAGE Baseline emission scenarios, a part of IMAGE 2.1 historical datasets, and the 13 IMAGE 2.1 world regions, which are all described here.

4.1 Meta-IMAGE

The meta-IMAGE 2.1 model is an integrated climate assessment model which describes on a global scale the chain of causality for anthropogenic climate change, from emissions of greenhouse gases to the changes in temperature and sea level (den Elzen *et al.*, 1997; den Elzen, 1998). The model is a so-called meta-model[1] of the larger integrated climate assessment model, IMAGE 2.1 (Alcamo *et al.*, 1994; 1998). The IMAGE 2.1 model aims at a more thorough detailed description of the complex, long-term dynamics of the biosphere-climate system at a geographically explicit level (0.5^o x 0.5^o latitude-longitude grid). The model forms an integral part of the FAIR modelling framework.

The meta-IMAGE model is a more flexible, transparent and interactive simulation tool that on a global scale adequately reproduces the IMAGE-2.1 projections of the main climate indicators, i.e. the concentrations of greenhouse gases, the global mean temperature increase and sea level rise for the various IMAGE 2.1 Baseline emission scenarios. The meta-IMAGE 2.1 model itself is an adapted version of the biogeochemical cycles model CYCLES (den Elzen *et al.*, 1997). The feedbacks nutrient stress on CO_2 fertilisation and N fertilisation in the global carbon cycle as included in CYCLES were excluded in meta-IMAGE, because of meta-IMAGE's consistency with IMAGE 2. This implies that now in both models, a balanced past carbon budget is realised with only the CO_2 fertilisation feedback (dominant factor) and temperature feedbacks. Other adaptations are (i) other values of the main model parameters (i.e. those related to terrestrial carbon cycling and the climate sensitivity parameter), (ii) a replacement of the ocean submodel by a convolution integral representation. Also the land use classes were further aggregated to four major land cover types: forests, grasslands, agriculture and other land, for the developing and industrialised world.

Set-up

Meta-IMAGE 2.1 consists of a global carbon cycle model (den Elzen *et al.*, 1997), an atmospheric chemistry model (Krol and van der Woerd, 1994), and a climate model (upwelling-diffusion energy balance box model of Wigley and Schlesinger (1985) and Wigley and Raper (1992)) (see *Figure 4.1*). Other SCMs in the total model framework are: the revised Brazilian model (Filho and Miquez, 1998), the carbon cycle model of MAGICC (Wigley, 1991; 1993) and the Bern carbon cycle model (Joos *et al.*, 1996). The temperature increase calculations can also be performed using a set of climate response functions calibrated to mimic results of simulation experiments with a variety of Atmosphere-Ocean General Circulation Models (AOGCMs).

Attribution of climate change

A special module is developed, which calculates a region's / country's attribution of the main indicators of global anthropogenic climate change (anthropogenic emissions and concentrations of the major greenhouse gases, radiative forcing and mean surface temperature increase) (den Elzen *et al.*, 1999). The aggregation was done by linking attribution of concentrations, radiative forcing and temperature increase to the origin of emissions, using as input the regional anthropogenic emissions of the major greenhouse gases regulated in the Kyoto Protocol (i.e. CO_2, CH_4, N_2O). The other greenhouse gases included in the Kyoto Protocol i.e. HFCs, PFCs and SF_6, are not taken into account in the regional attribution since no regional emission data are available. The anthropogenic emissions of these gases, and the other halocarbons, i.e. CFCs, methyl chloroform, carbon tetrachloride, halons and HCFCs (Montreal Protocol), ozone precursors and SO_2 (Clean Air Protocols), as well as the natural emissions of all gases are considered as one category on a global level. The attribution calculation is described in more detail below:

- Attribution of concentrations: Modelling the attribution of the concentrations by origin of emissions can be done in a straightforward manner using the mass balance equation with regional anthropogenic emissions and a regional sink term, i.e. $\rho_{g,r}(t)/\tau_g(t)$, in which $\rho_{g,r}(t)$ is the regional atmospheric concentration of greenhouse gas g at time t and τ_g the atmospheric exponential decay time or lifetime (yr).
- Attribution of radiative forcing: Attribution of radiative forcing from a greenhouse gas is more complicated than attribution of concentration. Due to the saturation effect, the radiative forcing of each additional unit of concentration from the ”early emitters” (no saturation of CO_2 absorption) is larger than the radiative forcing of an additional unit from the ”later emitters” (partial saturation of CO_2 absorption). When more regions start to contribute, a decision will have to be made on how to divide the “benefit” of the overlap or saturation, otherwise the sum of the partial effects would exceed the whole radiative effect (Enting, 1998). The resulting regional radiative forcing depends on the methodology followed. There are two possibilities: the radiative forcing (Q_g in $W \cdot m^{-2}$) could be calculated in proportion to (i) the attribution of the concentration of greenhouse gas or (ii) the changes in the attributed concentrations. The methodology of (ii), the non-linear radiative forcing attribution approach, is described in Enting (1998). The first methodology ignores the partial saturation effect and considers equal radiative effects of the ”early emitters” and the ”late emitters”, whereas the second includes this partial saturation effect, implying a larger radiative effect of the “early emitters” (Annex I regions). The first methodology has been adopted for the further base calculations.
- Attribution of temperature increase: Global radiative forcing from a greenhouse gas (i.e. CO_2, CH_4 and N_2O) is the sum of radiative forcings caused by emissions of individual regions. The linkage between attribution of radiative forcing and attribution of global temperature increase is therefore straightforward. It is also important that in the regional attribution calculations the factor of climate sensitivity ΔT_{2x} cancels out when relative contributions are calculated by dividing individual regional terms by global temperature increase. This means that uncertainty in climate sensitivity does not matter any longer.

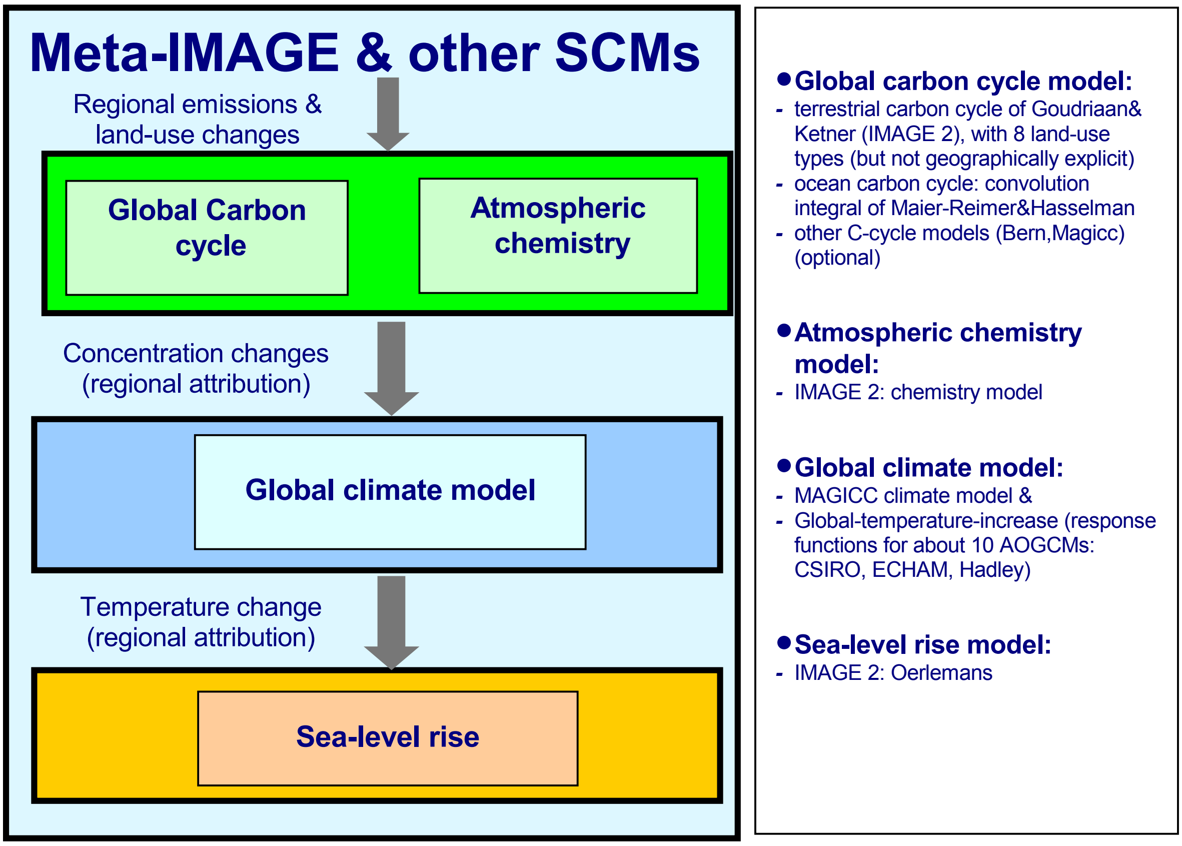


Figure 4.1 The meta-IMAGE 2.1 model

4.2 IMAGE 2.1

IMAGE 2 is an integrated model of global change, which provides an interdisciplinary and geographic overview of the society- biosphere-climate system. Calculations range from the grid (0.5° x 0.5° latitude-longitude) to world regional level, depending on the type of calculations, with a time horizon from 1970 to 2100. The model is organised into three systems of models: Energy-Industry, Terrestrial Environment, and Atmosphere-Ocean.

The Energy-Industry models are used to compute (for 13 world regions) the effect of economic and population scenarios on industrial production and regional and global energy use/fuel mix. Based on these calculations, the emissions of all important greenhouse gases, and near-term costs of CO_2 reduction are then computed.

The Terrestrial Environment models compute land use/cover changes on a grid scale as affected by changes in food, timber, and biomass production, and as influenced by climate change. This set of models produces scenarios relevant to biodiversity and similar land cover issues. Data from these models are then used to compute the land-related emissions of greenhouse gases, and the flux of carbon dioxide.

The Atmosphere-Ocean models are used to estimate large-scale changes in the atmosphere and ocean, with a spatial resolution ranging from tropospheric average for chemical calculations to zonal average for temperature and precipitation calculations. First the composition of several important tropospheric gases are computed as they are affected by anthropogenic and non-anthropogenic emissions. Next, the radiative forcing of these gases is computed, together with the heat balance of the atmosphere and ocean and the radiative forcing for the sulphate aerosols. It then calculates the changes in the climatic patterns, on the basis of a downscaling methodology using GCM results. As a result the change in sea level and changing patterns of precipitation are computed.

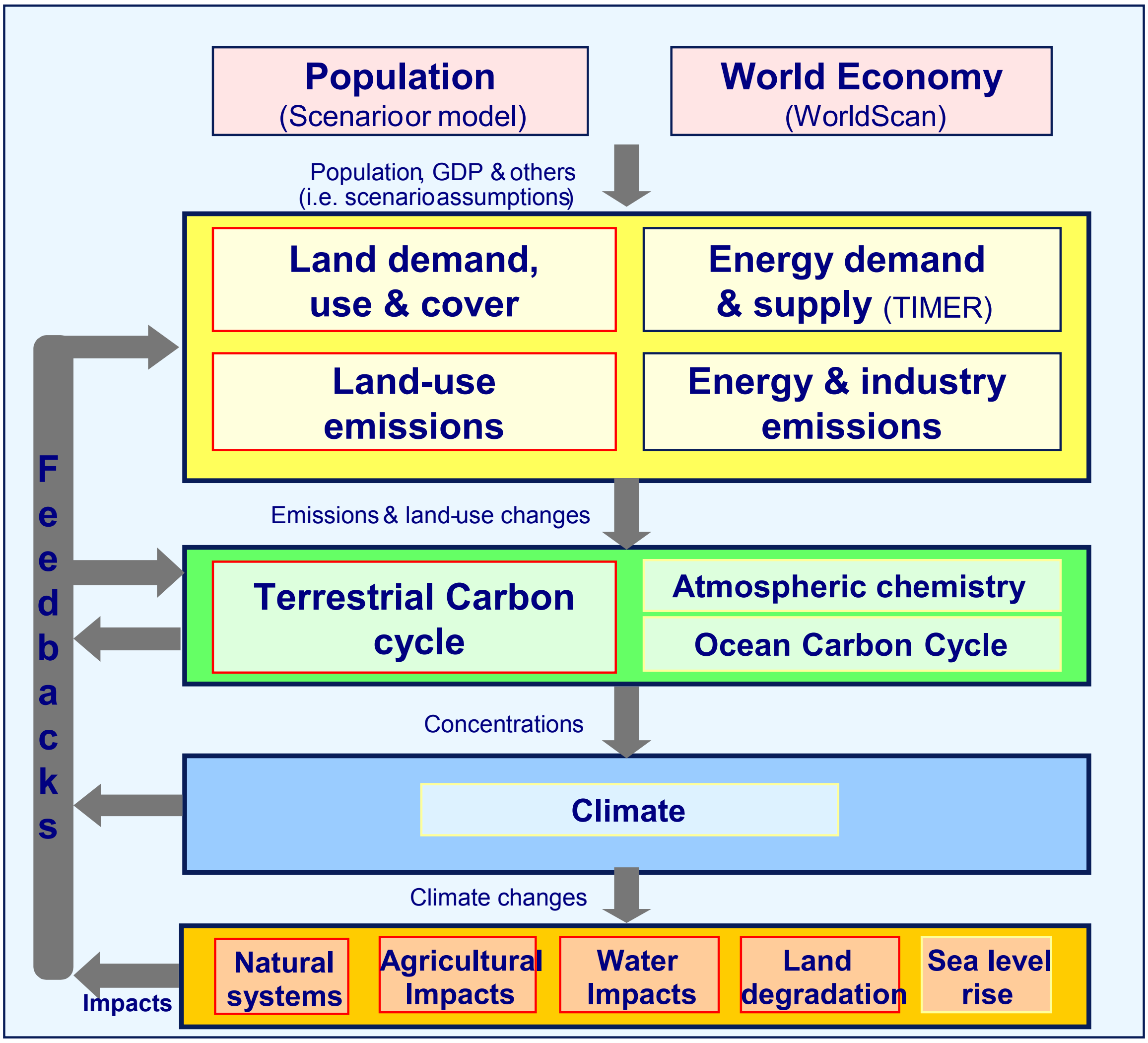


Figure 4.2 The IMAGE 2.1 model as used for the calculation of the IPCC SRES emission scenarios.

All components of IMAGE 2.1 have been tested against either current data sets or historical data, where available. As compared to the earlier version, IMAGE 2.1 provides more realism and detail in its simulation of various processes. For example, the process of fuel substitution has been added to calculations of energy use, and crop substitution has been added to the estimation of food production. Important new factors have been added to the simulation of land cover changes including global production of timber and biofuels, as well as the shift in vegetation zones following climate change. Calculations for the atmosphere have been extended to include the influence of regional sulphur emissions on regional atmospheric sulphate aerosol, and the effect of aerosol on climate. Also, calculations for the ocean now include climate-related sea level rise.

These extensions have made the model applicable to a wider range of global change policy and science questions.

Box 4.1 IPCC SRES scenarios

In 1996 the Intergovernmental Panel on Climate Change (IPCC) decided to develop new emissions scenarios. These scenarios are now described in a Special Report on Emissions Scenarios (SRES) (Nakicenovic *et al.*, 2000). Within SRES four scenario families are constructed, each with its own storyline and model-based quantification. They differ in assumptions about driving forces like population, economic activity and technology, but also in assumptions about specific measures and policies with regard to the North-South income gap, poverty and trade issues, and environmental problems such as acid rain. Policies and measures to slow global warming are excluded. The scenario families can be illustrated by two dimensions. One of them specifies whether dominant trends are towards more or less globalisation and the other whether dominant trends are towards more or less concern about environmental and equity issues.

<u>RIVM contribution to IPCC SRES</u>
RIVM contributes to SRES by an elaboration of the storylines for A1 and B1 using two simulation models: WorldScan and an adapted version of the IMAGE 2.1, both using exogeneously given trends for demographic developments. WorldScan is a multi-sector, multi-region, and dynamic applied general equilibrium model for the world economy. It provides consistent regional economic growth paths as input for the energy demand and land demand model of IMAGE 2. The following submodels of IMAGE were included: Energy demand & supply (TIMER), Energy & industry emissions, land demand, use & cover, Land-use emissions and the carbon cycle model.

IPCC SRES A1:'Golden Economic Age' – Present trends of globalisation and liberalisation continue. This and rapid technological innovations lead to high economic growth. Affluence converges among regions but the absolute difference between developed and less developed regions keeps growing. Increasing affluence supports a rapid decline in fertility levels and world population drops after 2050. Life expectancy increases and ageing becomes an important phenomenon.
IPCC SRES B1: 'Sustainable Development' – Present trends of globalisation and liberalisation continue, but there is a strong commitment towards sustainable development. Because business takes an active role, the pace of technological innovations is high. Increasing and more equally distributed affluence, supported by policies oriented towards education for women and community-based initiatives, cause a rapid decline in fertility levels: world population drops after 2050. Affluence converges among the world regions at a faster rate than in A1.

4.3 IMAGE 2.1 Baseline scenarios

4.3.1 Introduction

We consider five alternative scenarios. Each scenario examines the consequences on global environmental change of a different set of "not implausible" developments of population, economy, and other driving forces. The first three emission scenarios are the three IMAGE 2.1 Baseline emission scenarios (Alcamo *et al.*, 1998):

- **IMAGE 2.1 Baseline A** is an intermediate scenario with medium assumptions about population growth, economic growth, and economic activity.
- **IMAGE 2.1 Baseline B** has lower estimates of all driving forces compared to *A;*
- **IMAGE 2.1 Baseline C** has the same estimate for population growth as *A*, but higher estimates of economic growth, and economic activity.

Two other emission scenarios considered are the IMAGE 2.1 IPCC/SRES A1 and B1 emission scenarios. These two scenarios were developed as part of the IPCC SRES emission scenario exercises (see Box 4.1). Both scenarios represented a globalizing world, but with major differences in social and environmental awareness (Nakicenovic *et al.*, 2000):

- **IMAGE 2.1 IPCC/SRES A1 scenario** [9] describes a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality.
- **IMAGE 2.1 IPCC/SRES B1 scenario** describes a convergent world with a low population growth, with rapid change in economic structures, "dematerialization" and introduction of clean technologies. The emphasis is on global solutions to environmental and social sustainability, including concerted efforts for rapid technology development, dematerialization of the economy, and improving equity.

4.3.2 Primary Driving Forces: population and economic growth

Assumptions about population, economy, and economic activity are the driving forces of the IMAGE 2.1 emission scenarios.

Population growth

IMAGE 2.1 Baseline – A, B and C scenario **-** The regional population assumptions of intermediate and high baseline scenarios in of the IMAGE Baseline A and C scenarios use IPCC-1990's medium population estimates (Table 4.1), and are based on World Bank estimates. These estimates are close to medium population estimates of UN (1992) and of the International Institute of Applied Systems Analysis (IIASA) (Lutz *et al.* 1994). Hence there is some international agreement on these intermediate projections. According to this scenario world population will more than double by the year 2100, reaching 11.5 billion people. The low baseline scenario (Baseline-B) uses IPCC-1990's low population estimate which is lower than that used for any CO2 emission scenario found in the literature (Alcamo *et al.* 1994), and somewhat below the low IIASA estimate. Population is one of the main driving forces of the socio-economic components of the IMAGE 2 model.

[9] The IMAGE 2.1 IPCC/SRES A1 and B1 emission scenarios are the IMAGE 2.1 implementation of the IPCC SRES A1 and B1 emission scenarios (Nakicenovic *et al.*, 2000). The IMAGE 2.1 implementattion of the IPCC SRES B1 emission scenario was also the marker of the family of IPCC SRES B1 emission scenarios (Nakicenovic *et al.*, 2000), and therefore corresponds with the IPCC SRES B1 emission scenario. This scenario is extensively described in de Vries *et al.* (2000).

IMAGE 2.1 IPCC/SRES A1 and B1 scenario – assume the same population scenario. This assumes a continuing decline in fertility, which results in a stabilisation and then decline in world population by the middle of the next century (Lutz, 1996). Increasing and more equally distributed affluence, supported by policies oriented toward education for women and community-based initiatives, cause a rapid decline in fertility levels: World population drops from 8.7 billion people in 2050 to 7.0 billion in 2100.

Table 4.1: Assumptions for population for the IMAGE Baseline emission scenarios and the IMAGE 2.1 IPCC/SRES A1 and B1 scenario. Units: Millions

			Baseline A and C			Baseline B			IMAGE 2.1 IPCC/SRES A1 and B1		
	1970	1990	2010	2050	2100	2010	2050	2100	2010	2050	2100
Canada	21.3	26.6	30.2	31.8	31.5	27.2	22.8	15.4	31.4	39.9	47.7
USA	205.1	249.9	283.0	298.2	295.2	263.6	234.9	166.0	294.2	374.0	447.5
Latin America	283.8	445.8	603.2	819.6	872.8	587.7	770.9	772.9	605.1	775.4	627.8
Africa	359.8	639.3	1117.8	2198.3	2862.1	1022.2	1621.1	1611.4	1.030.0	1723.7	1584.1
OECD Europe	351.1	377.1	398.2	394.4	387.5	385.0	323.0	218.4	407.4	428.1	395.4
Eastern Europe	108.4	123.4	135.5	149.3	147.8	132.5	128.9	97.2	130.1	120.8	91.7
CIS	242.8	289.4	317.7	350.0	346.6	310.8	302.2	227.6	307.0	311.1	255.3
Middle East	114.9	202.1	364.3	726.2	931.7	325.0	439.4	345.3	319.4	555.8	571.3
India + S.Asia	739.4	1170.9	1635.1	2374.5	2643.5	1549.0	1896.9	1478.6	1651.8	2188.1	1594.0
China + C.P. Asia	898.9	1242.1	1553.5	1886.3	1953.3	1460.6	1390.0	949.7	1466.8	1419.9	844.8
East Asia	239.5	368.0	513.9	746.2	830.8	486.8	596.1	464.7	490.0	611.9	447.5
Oceania	16.2	21.4	23.0	22.8	22.5	22.2	17.4	11.9	23.4	23.5	20.8
Japan	104.3	123.5	132.7	131.5	129.9	128.1	100.7	68.9	135.0	135.8	120,3
World	3685.7	5279.5	7108.0	10129.1	11455.2	6700.7	7844.3	6427.7	6980.7	8707.7	7048.7

Economic growth

IMAGE 2.1 Baseline – A, B and C scenario - Economic growth assumptions of the IMAGE Baseline A scenario generally follow those of Scenario IS92a of IPCC (1992). Medium estimates from IPCC are used for Baseline-A, and are lower than historical trends for most regions. The IPCC (1992) reports that the GNP growth assumptions of this scenario are at the low end or even below the recent range of World Bank forecasts. Nevertheless these assumptions imply a substantial increase in GDP per capita. For example, GDP per capita in Latin America and East Asia will exceed current levels in OECD Europe in constant dollars (IPCC, 1994). Nevertheless, a large gap will remain in income between industrialised and developing regions. The low and high estimates used in Baselines-B and C are also based on the IPCC and are representative of the low and high range of estimates used by other researchers to estimate global CO2 emissions (Alcamo *et al.* 1996).

IMAGE 2.1 IPCC/SRES A1 and B1 scenario - The economic growth assumptions for the IMAGE 2.1 IPCC/SRES A1 and B1 scenario are much higher compared to the economic growth scenario of the IMAGE Baseline scenarios, especially for the non-Annex I regions. Economic output in monetary units grows at a somewhat lower rate than in the past 50 years: gross world product (GWP) increases by a factor of 5 till 6 between 2000 and 2050 for the IMAGE 2.1 IPCC/SRES B1 and A1 scenario, resp., as compared with the factor 6 increase between 1950 and 2000. Per capita Gross Regional Product (GRP) converges among the world regions at a faster rate than is the case with the "business as usual" expectations (as used in the IMAGE Baseline scenarios) of the 1990s.

Table 4.2: Assumptions for Gross Domestic Product for the IMAGE Baseline scenarios
Units: US$ per capita

			Baseline A			Baseline B			Baseline C		
	1970	1990	2010	2050	2100	2010	2050	2100	2010	2050	2100
Canada	13001	21273	33599	65523	115454	29752	46102	64815	37993	89622	201262
USA	15931	21866	38224	65531	114178	33884	48209	66522	43189	89709	199289
Latin America	2024	2569	3430	8425	25048	2840	5198	10762	4190	13626	59578
Africa	613	646	700	1956	6553	596	1205	2803	835	3087	14843
OECD Europe	12268	19065	30111	58722	103470	26664	41317	58088	34050	80320	180372
Eastern Europe	1213	1913	4194	9584	16768	3970	6047	7278	6054	15638	39408
CIS	1452	2476	3355	7666	13413	3136	4777	5749	4854	12540	31599
Middle East	2883	2823	3434	7018	19773	2912	4166	7893	4077	11306	46077
India + S.Asia	220	327	563	1907	7436	480	1185	3240	683	3056	17103
China + C.P. Asia	127	369	807	3481	15226	675	2117	6552	977	5541	35352
East Asia	569	1508	2597	8795	34293	2215	5465	14941	3151	14093	78871
Oceania	11670	15579	29800	58690	103093	26448	42862	59305	33684	82188	184012
Japan	12088	23734	45399	89411	157058	40293	65299	90349	51317	125210	280335
World	3073	3971	**5595**	**9473**	**21319**	**4968**	**6566**	**10453**	**6481**	**13894**	**44485**

Table 4.3:Assumptions for Gross Domestic Product for the IMAGE 2.1 IPCC/SRES A1 and B1 scenario
Units: US$ per capita

	IMAGE 2.1 IPCC/SRSES A1			IMAGE 2.1 IPCC/SRSES B1		
	2010	2050	2100	2010	2050	2100
Canada	29000	55605	101310	27808	45468	71683
USA	31369	60147	109585	30079	49181	77539
Latin America	5096	25651	69624	5137	21219	49556
Africa	882	7723	52929	964	8608	39409
OECD Europe	27739	63662	116226	26670	48302	82228
Eastern Europe	3409	25169	100771	3170	14700	48743
CIS	1942	19849	98328	1979	14178	53449
Middle East	4258	18951	72854	4533	18574	54831
India + S.Asia	800	11485	59713	783	7766	26763
China + C.P. Asia	1038	7699	87007	1107	7171	45865
East Asia	3737	19739	71550	3887	17509	48481
Oceania	25344	58765	122574	24319	42145	74602
Japan	35707	66348	101446	35397	58828	84048
World	**5502**	**18769**	**73603**	**5416**	**15566**	**46587**

4.4 Anthropogenic greenhouse gas emissions

Based on these assumptions, IMAGE 2 computes future changes in the consumption of energy, food, and timber. This consumption leads to gas emissions from energy and industry, shifts in land use and land cover, and changes in the fluxes of gases from the terrestrial environment.

4.4.1 Energy consumption

To calculate a scenario of energy consumption for each of 13 world regions, the energy model of IMAGE takes into account four main factors:

1. changes in the level of activity in each economic sector connected with changes in income and population;
2. "structural changes" of the economy that lead to changes in energy intensity of sectors;
3. "technological changes" that improved the performance of devices and appliances used to deliver energy services.

4. changes in fuel prices that stimulate energy conservation and shifts in fuel mix.

IMAGE Baseline A, B, and C scenario – Assumptions about these factors and the trends in the primary energy consumption, and the final CO_2 emissions from fossil fuel burning for the IMAGE Baseline scenarios are extensively described in De Vries *et al.* (1994) and Alcamo *et al.* (1998). The assumptions of the scenario and model lead to higher energy intensity of the economy for some regions, while leading to lower energy intensities for other regions (see Table 4.4). For the world as a whole, energy intensity decreases by a factor of 2.8 between 1990 and 2100, and for the different regions converge towards common energy intensity in the long run. For the IMAGE 2.1 Baseline A scenario, secondary energy use stabilises in the coming decades in the OECD regions. In other regions it continues to sharply increase until the end of the next century. Globally, the industry and transport sectors are more or less equally important. Generally, for all three baseline scenarios, the energy use in the OECD regions increases in the coming decades and decreases afterwards. In the other regions it steadily increases at the two highest scenarios, but stabilises in some regions under the lower scenario. For the two other scenarios energy use increases by a factor of 4 to 5 between 1990 and 2100.
The global emissions of CO_2 in Baseline A, the intermediate scenario, reach about 20 GtC/yr. in 2100, while Baseline B and -C reach 7 and 31 GtC/yr respectively. Results for Baseline A in 2100 are close to the intermediate IPCC emission scenario (IS92a), but baselines B and C are much less extreme than the minimum and maximum IPCC scenarios (IS92c and e). This is interesting, because Baselines B and C involve the same economic and population assumptions as the extreme IPCC scenarios. The difference is caused by the different models and input assumptions used to make these estimates. Although economic growth is substantially higher in Baseline C than in Baseline B, opposing trends reduce the differences between the scenarios. On one hand, the higher economic level leads to more economic activity, which will obviously tend to increase emissions. On the other hand, higher economic growth will lead to a variety of economic effects that will tend to lower emissions. For example, a high rate of structural change is assumed, and therefore a faster shift will occur from energy-intensive heavy industry to lighter industry. In addition, appliances and power plants with a higher rate of energy efficiency will be introduced at a faster rate into the economy. The net effect of these opposing tendencies is that the differences between Baseline A and Baseline C in energy use and emissions is smaller than the differences between the corresponding IPCC scenarios with the same economic and population assumptions. In the same way, the Baseline B scenario (the lowest of the three IMAGE baseline scenarios) does not give as low an estimate of CO_2 emissions as the lowest IPCC scenario (IS92c).

IMAGE 2.1 IPCC/SRES A1 and B1 scenario – The high economic growth in the IPCC SCRES scenarios leads to increases in energy use in the first half of the next century for A1 and B1, with higher growth rates in A1 due to higher growth rates for economic activity. After about 2050 energy intensity kept falling, especially in B1, due to decreasing population and ongoing materialisation and technology transfer, and high-tech innovations in energy use and supply. Renewable sources (wind, solar photovoltaics, biofuels, a.o.) become dominant in the second half of the next century. Almost all of the increase in primary fuel use takes place in the non-OECD regions. In the IMAGE 2.1 IPCC/SRES B1 scenario high penetration rates of non-fossil fuels eventually lead to levels of fossil fuels use that are comparable to current levels, and, as a result, to CO_2 emissions in 2100 just below 1990 levels. More specifically, the CO_2 emissions from fossil fuel burning peak at 9,5 GtC/yr around 2060 after which it declines to 1990 levels. The increase is largely happening in the ASIA- and ROW-regions, whereas the Annex-1 regions show a significant reduction (see for more details De Vries *et al.*, 2000).
In the IMAGE 2.1 IPCC/SRES A1 scenario non-fossil fuels penetrate at lower rates, which lead, in combination with higher energy use than in the B1 scenario, to high emission levels in 2100 of about twice the 1990 levels. The decline after 2050 is also a consequence of the decline in energy

demand. The CO_2 emissions from fossil fuel burning peak at about 18 GtC/yr around 2045 after which there is a 50 % decline between 2050 and 2100.

The primary energy intensity for the five scenarios is given in the following tables:

Table 4.4: Final energy intensity of GDP (MJ/US$) and the annual change rate (%/yr) between 1990 and 2100 in the IMAGE Baseline A, B and C scenario.

	Primary energy intensity IMAGE Baseline A				Primary energy intensity IMAGE Baseline B				Primary energy intensity IMAGE Baseline C			
Region	1990	2020	2050	2100	1990	2020	2050	2100	1990	2020	2050	2100
OECD-An	10.9	7.6	4.9	2.6	10.9	8.2	6.3	4.5	10.9	7.0	3.8	1.6
NOECD-An	71.7	46.9	34.6	21.9	71.7	47.4	38.1	30.7	71.7	44.8	29.8	14.0
ASIA	53.3	35.7	22.0	8.4	53.3	37.0	24.8	13.2	53.3	34.5	19.4	4.8
ALM	22.6	16.0	13.3	7.4	22.6	16.6	14.8	11.7	22.6	15.6	11.5	3.6
World	14.2	13.5	10.8	6.2	14.2	13.9	12.0	9.3	14.2	13.3	9.6	3.7

Table 4.5. Final energy intensity of GDP (MJ/US$) and the annual change rate (%/yr) between 1990 and 2100 in the IMAGE 2.1 IPCC/SRSESIMAGE 2.1 IPCC/SRES A1 and IMAGE 2.1 IPCC/SRES B1 scenario.

	Primary energy intensity IMAGE 2.1 IPCC/SRES A1				Primary energy intensity IMAGE 2.1 IPCC/SRES B1			
Region	1990	2020	2050	2100	1990	2020	2050	2100
OECD-An	9.1	6.7	3.9	2.0	9.1	6.1	3.3	1.5
NOECD-An	98.4	34.6	11.2	2.0	98.4	30.5	10.3	2.1
ASIA	55.8	26.9	9.3	1.5	55.8	22.5	7.2	1.5
ALM	21.0	18.8	9.8	2.3	21.0	16.3	7.5	1.6
World	17.5	13.0	7.5	1.9	17.5	11.5	6.0	1.6

4.4.2 Change in Agricultural Production and the land use related emissions

Land cover change is an essential aspect of global environmental change. For example, deforestation leads to releases of greenhouse and other gases, expansion of agricultural and urban land endangers natural ecosystem habitats, and forestation increases the uptake of CO_2 from the atmosphere. IMAGE 2 computes changes in land cover by taking into account the need for agricultural land (used here to mean pasture and cropland, and managed forests.) The model computes these changes in land use by computing the changing demand in 13 world regions for livestock, crops, and forest products and the amount of crop, pasture, and forestland required to provide these products. To calculate a scenario of agricultural production, IMAGE 2 takes into account a number of main factors, i.e. trade of agricultural products, animal husbandry, cropping intensity, technological improvements in crop yield, fertiliser application, agricultural demand and potential productivity of land due to climate.
The need for agricultural land will depend, first and foremost, on regional agricultural demands, which are computed as described below. However, for some regions, the amount of agricultural land will also depend on the amount of food traded with other regions, and this must also be specified for each scenario. In addition, there are a number of factors that are important to estimating requirements for agricultural land because they influence the amount of food that can be produced per hectare of land. One of these factors is the effect of climate on potential crop productivity, and this is computed internally by the model. The other three factors of this type must be specified for each scenario. They are animal husbandry, cropping intensity, and technological

improvements in crop yield. For more details about the calculation of these factors we refer to Alcamo *et al.* (1996).
IMAGE Baseline A, B and C scenario – On the global level the amount of agricultural land sharply increases up to 2030 due to the expansion of agricultural land in the developing regions. Afterwards, when a number of developing regions have used up all their suitable land for crops and livestock, the global trend is dominated by the trends in the developed regions as agricultural lands are abandoned. The impact of abandonment in the highest baseline scenario is even stronger than in Baseline A. In this scenario the faster improvements in animal productivity and crop yields in regions like Latin America and the CIS outweigh the increases in demand. The low scenario shows a much smaller amount of agricultural land, mainly due to the lower human population. One of the most important consequences of expanding or shrinking agricultural land is the changing extent of forestland. According to the baseline scenarios, agricultural land expands largely at the expense of forests, especially in the tropics (as it does in reality now as well). In the industrialised regions, where agricultural land shrinks according to the scenarios, then the IMAGE 2 model assumes that it will be replaced by naturally occurring vegetation. This means that much new forest land appears in these regions. Under baseline A, these factors alone lead to a shrinking of global forested area from around 4296 to 3170 million ha between 1990 and 2100. The corresponding rates of deforestation are 17.0 million ha per year in the first half of the next century, and 0.2 million ha per year in the second half. This all leads for the IMAGE Baseline scenarios to a decreasing trend in the CO_2 emissions of biomass burning due to deforestation till a peak value around 2010, then stabilising around 0.5 GtC / yr for the IMAGE Baseline A scenario.

IMAGE 2.1 IPCC / SRES A1 and B1 scenario – In the IPCC SRES scenarios the increasing demand for food, feed , timber and biofuels lead to an increasing productivity and increasing demand, and an expansion of the agricultural area in Africa and Asia (excl. FSU) up until 2050 and a decline afterwards. In other regions, total agricultural area shows a gradual decrease over the next century. Commitments towards sustainable development in B1 lead to lower deforestation rates and higher reforestation rates than in A1. As a result, emissions from land use in B1 are lower than in A1. More specifically, for the IMAGE 2.1 IPCC/SRSES B1 scenario the CO_2 emissions of biomass burning due to deforestation remain an important source of the CO_2 emissions, resulting in a CO_2 emission of about 1 GtC/yr up to 2030, and about 0.5 GtC/yr afterwards. For the IMAGE 2.1 IPCC/SRSES A scenario, the CO_2 emissions of biomass burning due to deforestation are somewhat higher till 2030, and then these emissions still increase till 2100.

4.4.3 Overall greenhouse gases emissions

The IMAGE 2 model computes regional emissions of all radiatively important gases as well as sulphur dioxide, which leads to the radiatively important sulphate aerosol.
IMAGE Baseline A, B, and C scenarios – The global emissions of CO_2, the most important greenhouse gas, reach 20.5 GtC/ yr in 2100 for the Baseline A scenario, the intermediate scenario. In baselines B and C peaks are at 7.5 and 32.2 GtC / yr respectively. For the SO_2 emissions, the IMAGE Baseline scenarios assume constant sulphur dioxide SO_2 emissions for the entire simulation period. The emission pathways of the other greenhouse gases are described in de Vries *et al.* (1994).
IMAGE 2.1 IPCC/SRES A1 and B1 scenarios – Global CO_2 emissions peak around 2050 in A1 and B1, but with a much higher peak in a1 (20 GtC/yr) than in B1 (13 GtC/yr), due to higher fossil fuel use and more use of land for agricultural practices. After 2050 emissions drop faster in B1 than in A1. Similar trends can be distinguished for other greenhouse gases (De Vries *et al.*, 2000). For the SO_2 emissions the IMAGE 2.1 IPCC/SRES A1 and B1 scenarios assume full implementation of the sulphur control policies in the near future.
These reflect the most recent developments in environmental legislation and deviate from the earlier IS92 scenarios. For OECD Europe, Eastern Europe, CIS, these controls are specified in the second

Sulphur Protocol of the Geneva Convention on Transboundary Air Pollution in Europe (ECE, 1994). For most of the other industrialised regions (Canada, USA, Japan) we take into account national plans for control of sulphur (e.g., Clean Air Act in the USA). After 2010, the emissions in the IMAGE 2.1 IPCC/SRES B1 scenario continue to fall as a result of reductions in energy use, fuel substitution and desulphurisation, and technologies in the electricity sector. In non-OECD regions, sulphur emissions in this scenario will also become increasingly controlled in order to avoid large local and regional negative impacts on human health, crop productivity, and ecosystems, particularly in Asia. For the IMAGE 2.1 IPCC/SRSES A1 scenario the energy-related SO_2 emissions follow moderate desulphurisation strategies after 2010. For the non-Annex I the present Annex I desulphurisation technologies will be implemented in the second of the next century.

4.5 Historical databases

4.5.1 Introduction

The main input data of meta-IMAGE (and FAIR) is composed of the following human-induced perturbations of the climate system: (1) anthropogenic (energy-, industrial and agricultural related) emissions of greenhouse gases, (2) land use changes and its associated CO_2 emissions. The historical data (time-period 1751-1995) is derived form historical datasets as described below, whereas the data for the time-period 1995-2100 is based on the IMAGE 2.1 Baseline scenarios (Alcamo *et al.*, 1996), or the IMAGE '99 B1 scenario (de Vries *et al.*, 2000).

4.5.2 Anthropogenic emissions of greenhouse gases

The regional fossil fuel CO_2 emissions for the period 1751-1996 (varies with country) are based on the CO_2 emissions database of USA Oak Ridge National Laboratory (ORNL) (also referred as ORNL-CDIAC (CO_2 Data and Information Assessment Center)) (Marland and Rotty, 1984; Marland *et al.*, 1999). The global, regional and national CO_2 emissions from fossil fuel combustion and cement production are based on the annually updated UN energy statistics on total domestic fuel consumption per country for coal, oil, and gas (Andres *et al.*, 1998). The global bunker emissions, the difference between the global and total sum of regional CDIAC emissions, are allocated to the regional CO_2 emissions, using the constant 1990 countries' contribution of the international marine and aviation bunker fuel emissions given by Olivier and Peters (1999).
The ORNL-CDIAC emission data are limited to CO_2 emissions from fossil fuels and cement production. The historical regional anthropogenic CH_4 and N_2O emissions (including the emissions due to land use changes) are therefore taken from the EDGAR (Emission Database for Global Atmospheric Research) data set. This emission data set is jointly developed by the Dutch Organization for Applied Scientific Research (TNO), and the RIVM (Olivier *et al.*, 1996, 1999; Klein-Goldewijk *et al.*, 1996), and is based on historical activity data by region and country compiled in the HYDE database for the period 1890-1970. The historical global anthropogenic emissions of the halocarbons, other greenhouse gases and ozone precursors are based on EDGAR (Olivier *et al.*, 1999; SO_2 is based on Smith *et al.* (1999)).

4.5.3 Land use changes and its associated CO_2 emissions

The historical regional CO_2 emissions from land use changes are based on Houghton and Hackler (1995) and Houghton *et al.* (1983; 1987), although further aggregated to the 13 IMAGE 2.1 regions according to regional past population trends. The global CO_2 emissions estimate for the period 1850 to 1980 (115 GtC) and the 1980-1990 average flux (1.4 GtC/yr) is almost identical to the estimate presented by the 1995 update of the IPCC scientific assessment (Schimel *et al.*, 1995). A recent revised analysis of Houghton (1999) shows a somewhat higher estimate for the 1980s (2.0 GtC/yr),

but an almost similar estimate for the 1850-1980 total flux. These revised emissions have not been adopted here, because we want to be consistence with the central estimates of the latest IPCC 1995 scientific assessment.
The land use changes itself important for the terrestrial carbon cycling processes in the meta-IMAGE model, are also based on Houghton and Hackler (1995), but further disaggregated in the four major land cover types: forests, grasslands, agriculture and other land, for the developing and industrialized world, as used in meta-IMAGE (den Elzen, 1998).

4.6 Regions

The description of the 13 IMAGE 2.1 regions is given in Alcamo *et al.* (1998). The IMAGE 2.1 regions consist of Canada, USA, Latin America, Africa, OECD-Europe, Eastern Europe, CIS, Middle East, India + South-east Asia, China + centrally planned Asia, Western Asia (Middle East), Oceania and Japan

5 MANUAL

This Chapter describes the technical manual of the FAIR model, which corresponds with the help-pages in the electronic documentation system of FAIR. These can be reached by selecting a box and then pressing the F1 button. This manual explains how to use the interface of the FAIR model and gives an in depth description of the various modes and views of FAIR.

5.1 Introduction

After starting up, FAIR opens 2 windows:

- The *M viewer* or Model Interface of FAIR.
- The Documentation system of FAIR (Netscape or Internet Explorer).

1. The **M-viewer interface of FAIR** supports the whole visualisation of the simulations within the FAIR model, and is developed with the M-software, like the FAIR program itself (de Bruin *et al.*, 1996; http://www.m.rivm.nl). This interface allows a flexible and interactive visualisation, analysis and comparison of the various FAIR output data. It thereby facilitates the display, the use and the graphical analysis of all complex data sets used and produced by FAIR, and provides access to FAIR simulations for both novice and experienced users.
   The graphical interface consists of a variety of different views. Many views basically consist of a construction or a manipulation menu on the left-hand side, and an evaluation part on the right hand side of the screen. The interface views of FAIR are organised around the four main modes within FAIR: Scenario construction, Increasing participation, Convergence and Triptych.
2. The **Documentation System of FAIR** is a html-browser, which supports the online help for the users and is available for all views, graphs and maps within the M-viewer interface. Selecting any box and pressing F1 will link you to the help texts on the item selected. Keywords in each help-screen are cross-referenced. The home page of this documentation system is depicted in Figure 5.1. The documentation system corresponds with the FAIR website: http://www.rivm.nl/FAIR.

How to bring the interface of FAIR to the front:

- Click the M Viewer button on the taskbar with the left mouse button, or
- Use the alt-tab key combination. You can select the M viewer by holding the alt key and repeatedly press the tab key.

How to bring the documentation system of FAIR to the front:

- Click the Netscape or Explorer button on the taskbar with the left mouse button, or
- Use the alt-tab key combination.

How to start the views of FAIR

After starting the FAIR program as described in the installation procedure, the first view will appear. From now on the program is most simply controlled by mouse-actions.

Figure 5.1 The home page of the documentation System of FAIR

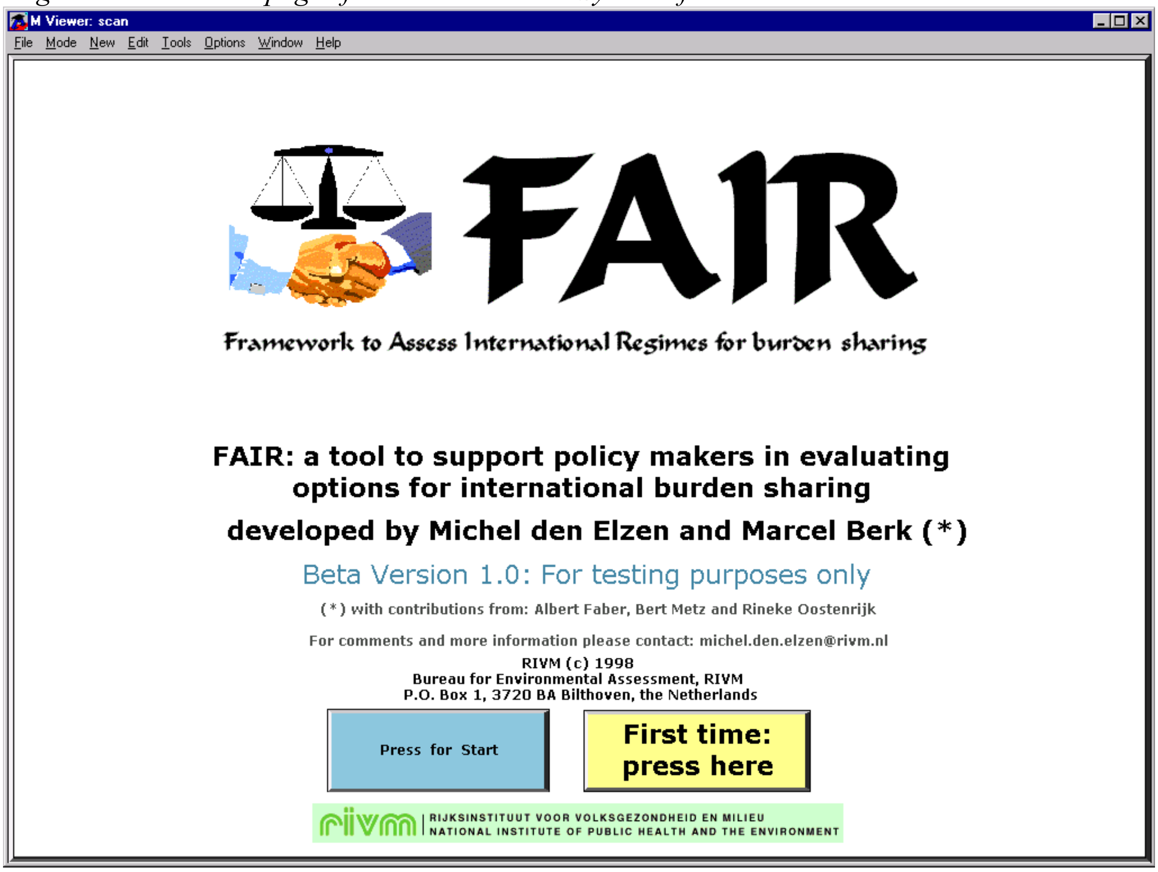


Figure 5.2 The 'Start'-view of FAIR

From the *Start-view*, you have two options to continue with. If you use the software for the first time click on the yellow button; otherwise use the blue button. After pressing on the yellow button you will get a First-use-view, which welcomes you and asks you to contact RIVM about the license agreement of FAIR. In that case, you will receive updates of the software as they come available.
If you click on the blue button (in the Start-view or in the First-use-view) you will get the Disclaimer-view. This view contains the necessary disclaimers for using the software. Click the next blue button, and the Scenario construction main view will appear. You can now start with your FAIR simulations.

You can zoom in and out on the various containers in the following way:

1. Move the mouse cursor to the container you want to zoom upon.
2. - Click the right mouse button to display an advanced menu with more options and select "zoom in". or:
   - Press Shift-key and right mouse button.

When you are finished and want to quit:

1. Use "Exit" under the "File" in the menu bar.
2. Confirm with "yes" Now the model closes.
3. Exit the HTML Browser.

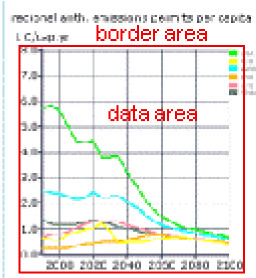
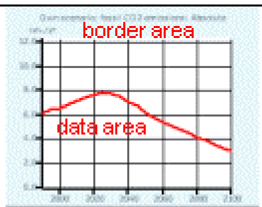
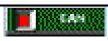
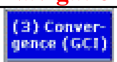
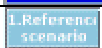
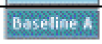
5.2 How to use the FAIR interface

User interface components and how to handle them

FAIR can be manipulated by mouse actions only. You can use the left mouse button for conventional actions, such as selection of buttons and sliders. The right mouse button provides an additional menu for purposes as zooming and opening and closing boxes. For a complete overview of all interface components see the table below.

Table 5.1: Use of mouse buttons for the different boxes, buttons and sliders.

Name	Symbol	How to use	Description/Actions
Options		Left mouse button click & select option	Displays an option-list. The active option is displayed beside the switch.
Slider		Use left mouse button to drag the slider	Move the slider to the desired value. The value is displayed on the left.
Disabled Optionlist		No action	Display function, shows the active scenario.
Graph box		Right mouse button click opens a menu; select *Zoom in*	Zooms in on a box containing one or more graphs of variables or parameters
		Right mouse button click in border; select *Open all*	Displays the graphs
		Right mouse button click in border; select *Close*	Closes the graphs & brings you back to the Main view

Graph		Right mouse button click in *border area* pop ups a menu with options for the box or data; Select *Open / Close* or *Zoom in / Zoom out*	Opens / closes the box or zooms in/ zooms out the graph The data options are not used in FAIR
		Right mouse button click in *data area* pop ups a menu with options for the graph	For edit options see *input graph*
		• Select *Show value*	Shows the x,y values at the position of the mouse
		• Select *Scale x*	Scales the x-axe
		• Select *Scale y*	Scales the y-axe
		• Select *Drag*	Repostions the origin by dragging it to the preferrred position
		• Select *Edit Table*	Pops up a window with the data of the graph
Input Graph		Has the same options as graph plus edit options. All edit options start with pointing the mouse cursor to the startpoint on the data area. Press and hold the left mouse button and move the cursor quietly to the desired end point. Release button	
		• Select *Edit free*	Changes the graph freely by dragging the line; result:line follows your cursormovement
		• Select *Edit line*	Changes (part of) the graph linearly; result: lineair line from startpoint to endpoint
		• Select *Edit expo*	Changes (part of) the graph exponentially; result: exponential line from startpoint to endpoint
Selector	 red = off	Left mouse button click	Line of this region (or other qualifier) is not displayed in the graph
	 bgcolor = on	Left mouse button click	Line of this region (or other qualifier) is displayed in the graph
	Navigation bar		
View		Left mouse button click	Opens one of the four main views
Subview		Left mouse button click	Opens a subview of the current view
Scenario		Left mouse button click	Changes the reference scenario (this is refelected in the disabled slider on the left)
Text		No action	Text box
Help		Select and press F1	Activates the Help system for technical Help

<u>Menu bar</u>
The menu bar of FAIR consists of several items, e.g. File, Edit, Tools. With the options in the menu bar you can perform actions like saving or loading scenarios, printing your results, or exit the program. Most items will speak for them selves. Here is a complete overview of all menu-options:

File
- <u>Print</u>: Prints the window currently on the screen without menu bar or window frame,
- <u>Exit</u>: Exits from the User Support System.

Edit
- <u>Domain</u>: Only available for variables. Changes the domain (X-axis) of the active item: minimum/maximum; number of decimals; and number of tick marks along the axis.
- <u>Dimension</u>: Only available for variables. Selects the dimensions of the active item. For each item and each dimension the active number of classes can be selected.
- <u>Range</u>: Only available for variables. Changes the range (Y-axis) of the active item: minimum/maximum; number of decimals; and number of tick marks along the axis.
- <u>Widget</u>: Selects type and subtype of the active item. Has no meaning for containers (nothing can be changed). For variables: changes the type (map, graph, etc.) and subtype (depending on type e.g. colour, line type, etc.).
- <u>Table</u>: Activates the table editor (do not use with maps!)

Tools
- <u>Scenario Manager</u>: Manages the scenarios: selects, loads, saves and unloads scenarios.

Window
- <u>Split Horizontal</u>: Splits the active view horizontally in half
- <u>Split Vertical</u>: Splits the active view vertically in

Help
- <u>About</u>:Information about the current M version

Notes:
- Disabled menu options are grey coloured and will not be described.
- A graph can be made active by pressing the *left mouse button* in the graph.
- When settings are changed they have to be confirmed by a <return> before they will be activated.

The Scenario manager in the Tools menu requires some more explanation. If you click with your *left mouse button* the scenario management menu will pop up. You will see five items which helps you to load scenario files, to save scenario files and to select loaded scenario files. If you save a scenario a new menu pops up. It allows you to give the scenario a name and a label and to mention the author and the date of the scenario construction. If you now press the *Save* button, the user inputs of the scenario scanner such as the climate change policy targets for the impact indicators, the climate sensitivity, land use change emissions etc.

The *View Options* in the same Tools menu is a helpful item because of the *Freeze* option. After activating *Freeze* you can change the inputs without directly rerunning of the model. You have to press the *Freeze* button again to rerun the model.

<u>Additional Features</u>
Additional features are available with the Right Mouse Button. This action calls a pop-up menu from which additional features can be chosen. Additional functionality is also added when clicking the Right Mouse Button in the data area of a graph.

Table 5.2 Use of right mouse button while positioned in a container

Menu item	Action
Open	opens container (same as middle mouse button)
Open all	opens all containers, variables and maps below current level
Close all	closes all containers, variables and maps below current level
Zoom in	Zoom in on container (same as shift plus right mouse button) and opens it.
Reset	resets variables and maps to initial scenario values
Set reference	Sets the line of all line-graphs as a reference which will remain visible when changing graph settings (e.g. loading a different scenario, choosing another region)
Unset reference	removes all references
Load ...	not relevant for FAIR
Save ...	to save data in ASCII format

Table 5.3: Use of right mouse button while positioned in a graph outside the data area

Menu item	Action
Open/Close	opens/closes the variable box
Zoom in/out	zooms in/out on the box
Reset	resets all values to loaded scenario values
Zoom in	Zoom in on container (same as shift plus right mouse button) and opens it.
Save ...	save an M data file (ASCII format, comma delimited)

Table 5.4: Use of right mouse button while positioned in a graph inside the data area

Menu item	Action
Show value	shows the value at the place of the mouse pointer
Drag	drag the line across the screen
Scale X	change the scale of the X-axis
Scale Y	change the scale of the Y-axis
Edit Free	Changes the graph freely by dragging the line; result: line follows your cursor-movement
Edit line	Changes (part of) the graph linearly; result: linear line from start-point to endpoint
Edit Expo	Changes (part of) the graph exponentially; result: exponential line from start-point to endpoint
Set reference	Sets the current line as a reference which will remain visible when changing graph settings (e.g. loading a different scenario, choosing another region)
Unset reference	removes the reference
Edit Table ...	invokes the table editor (make sure not to change from scenario while the table editor is open, the editor is **not** updated)

Table 5.5: Use of right mouse button (Point at the border of a view):

Menu item	Action
Zoom in	zooms in on view (only available in split views)
Split view	splits the view into two views, starting from the current zoom level, on the place of the mouse pointer.
Join views	Joins two views back to one.
Redraw	redraws the screen
...	

5.3 Scenario construction

All four modes consist of an advanced view as well as a basic view. These vary mainly in the number of settings you are able to manipulate, and hence in the complexity of views. The different views within the FAIR model are generally built-up as follows. On the left-hand, there are the decision support variables, which the user can change. In the middle the main output-variables are depicted, whereas on the right-hand the user can select one of the four modes (main-views), the sub-views belonging to this main-view, or choose the reference scenario (IMAGE Baseline A, B and C, IS98A1 and IS98B1 scenario).

5.3.1 Scenario construction basic mode main view

Having started the FAIR scenario construction main-view, you will find that you are working in the *scenario construction - basic mode*. The scenario construction main view (basic mode) consists of two main blocks labelled ‘scenario’ (left) and ‘scenario evaluation’ (right).

Scenario

Here you can select a reference scenario and a target scenario. The reference scenario describes the fossil fuel CO_2[10] emissions of the non-participating regions, i.e. the non-Annex I regions for the period 1995-2013 (for the target scenarios including Kyoto) and the global CO_2 emissions due to land-use changes (deforestation) for the period 1995-2100. The target emissions scenario describes the global anthropogenic CO_2 emissions for the period 1995-2100 (for the target scenarios including Kyoto starting from 2013), which could be an IPCC stabilisation emission profile aiming at a stabilisation of the atmospheric CO_2 concentrations at 450 ppmv by 2100.

- The **reference scenario** refers to a set of five pre-set emission scenarios, developed as part of IMAGE 2.1, i.e. the IMAGE 2.1 Baseline A, B and C scenario (Alcamo *et al.*, 1996) and the two new IPCC SRES scenarios, IMAGE 2.1 IPCC SRES A1 and B1 scenario (de Vries *et al.*, 2000) (see also Chapter 4)[11].
- Then you should select a **target scenario**, of which three main sets are available, which corresponds with:
    1. the reference scenario;
    2. your own constructed emission scenario (including or excluding Kyoto, i.e. the implementation of the Annex I emissions reductions as described in the Kyoto

[10] The emissions of the other greenhouse gases and SO_2 will be deescribed in the next paragraphs.

[11] The IMAGE 2.1 IPCC/SRES A1 and B1 emission scenarios are the IMAGE 2.1 implementation of the IPCC SRES A1 and B1 emission scenarios (Nakicenovic *et al.*, 2000). The IMAGE 2.1 implementattion of the IPCC SRES B1 emission scenario was also the marker of the family of IPCC SRES B1 emission scenarios (Nakicenovic *et al.*, 2000), and therefore corresponds with the IPCC SRES B1 emission scenario. This scenario is extensively described in de Vries *et al.* (2000).

Protocol for the period 2000-2013) and own triptych scenario (see Section 4.5) (*only available in the advanced mode*);

3. one of the pre-defined emission scenarios, i.e. one of the IMAGE stabilisation scenarios, IPCC emission scenarios, or FAIR pre-defined stabilization emission scenarios (including or excluding Kyoto).

Note: The global emission profile of the FAIR pre-defined stabilization 450 and 550 ppmv scenario including the Kyoto Protocol emissions requirements also depends on the assumed Baseline emissions (reference scenario). During the Kyoto period, the anthropogenic CO_2 emissions of the non-Annex I region follow their Baseline emissions, and the CO_2 emissions of the Annex I region follow the Kyoto Protocol emission reductions. This implies that the final global anthropogenic CO_2 emission level by 2010 differs for the various assumed reference scenarios. On the basis of this 2010 global emission level FAIR selects one emission scenario among a set of pre-defined stabilization emission scenarios, which lead to a stabilization of the atmospheric CO_2 concentration at the level of 450 and 550 ppmv.

Once you have chosen your scenarios, you will see the burden in the upper left graph indicated as the difference between the baseline and the target emission scenario. You can use the sliders to select climate targets and to evaluate your emission scenarios. To evaluate your emission scenarios, three parameters are elaborated:

- Change in **global mean average surface temperature increase** relative to 1900: default-value of 2 ^oC;
- Rate of global **temperature increase**: default-value of 0.15 ^oC/decade;
- **Sea level rise**: default-value of 30 cm.

The settings of the climate targets determine the colours of the graphs in the scenario evaluation block at the right-hand side.

Scenario evaluation

This part depicts the climate change evaluation impacts of the target emission scenario that was selected. The scenario is then evaluated on the basis of the values chosen for the global climate change target indicators, i.e. global mean temperature increase compared to the 1900 level, decadal rate of temperature change and the sea-level rise compared to the 1900 level. More specifically:

- The **anthropogenic CO_2-equivalent emissions**. The colour of the upper box is the result of the three individual global climate indicators, i.e. global mean temperature increase, rate of temperature increase and sea level rise. Changing the policy targets for climate change may change the colour of the indicators. Colouring the profiles shows this. The profile becomes:
  - Red: “critical”, if one or more of the global climate indicators exceeds its climate target by more than 20 %;
  - Yellow; “approximated”, if one or more climate indicators approximates its climate target within a 20% uncertainty range;
  - Green; “safe”, if all climate indicator values are below 80 % of their target level;
- **Global climate indicators**: concentration CO_2 (ppmv), global mean surface temperature increase (^oC), sea level rise (m) and rate of global mean surface temperature increase (^oC/decade). The colours are also marked for each climate indicator to see which one(s) determine(s) the colour of the overall evaluation profile at the top of the block.

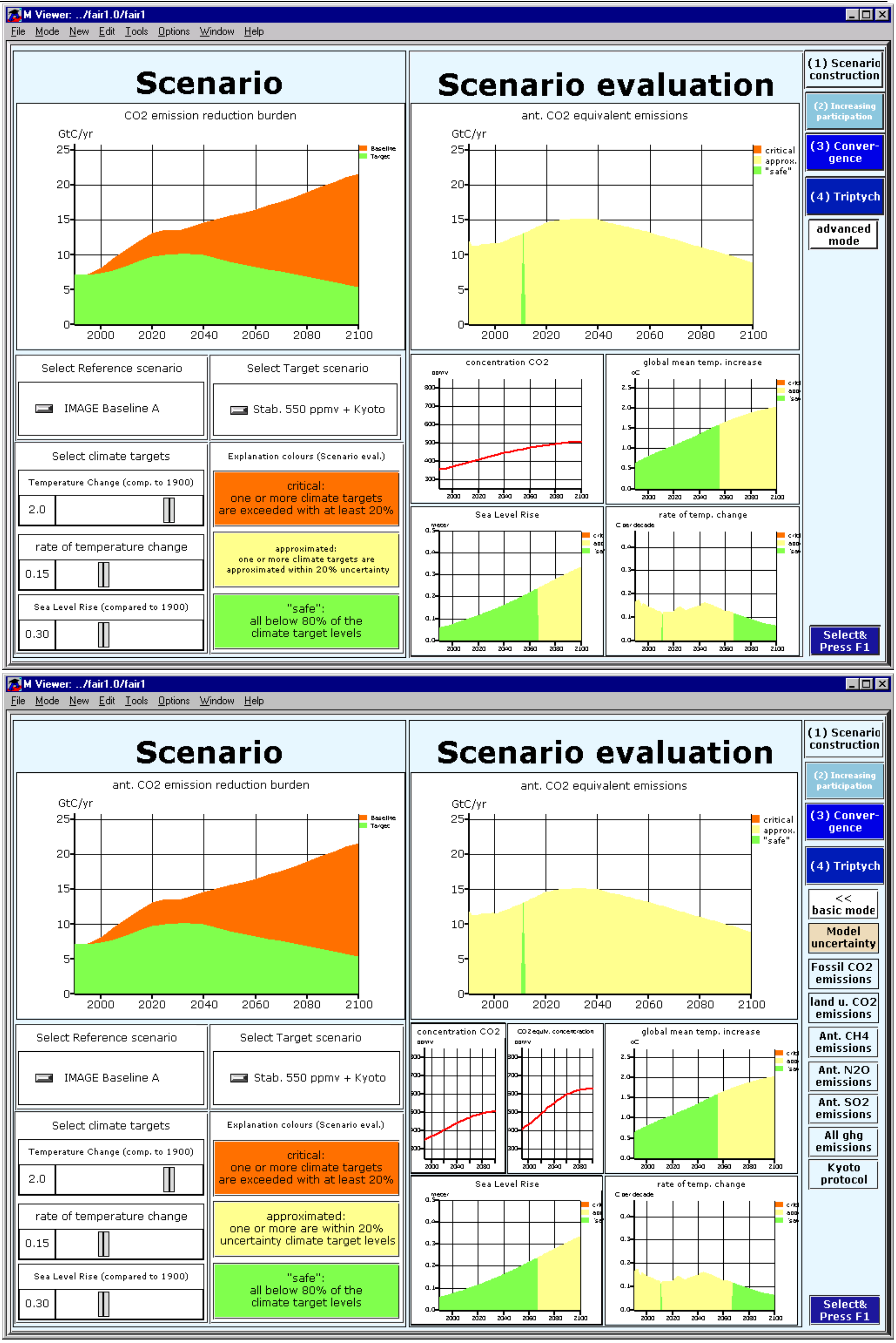


Figure 5.3: The 'Scenario construction' view of FAIR: basic mode (upper graph) and advanced mode (lower graph)

We also included the atmospheric CO_2 concentration in volume parts per million (ppmv). This allows for comparing present levels with pre-industrial levels (280 ppmv), and to evaluate whether its concentration stabilizes as defined as the ultimate objective of the UNFCCC. The level of stabilisation of CO_2 can be selected as target scenarios, and may then be evaluated in this box.

5.3.2 Scenario construction in the advanced mode

The more experienced user may want to have some more options for constructing an emission scenario, or to study in more detail the anthropogenic greenhouse gas emissions of the assumed target scenario. If you choose the 'advanced mode' box at the right, you will find several additional possibilities: extra items are available on land-use, other greenhouse gases, etc, not only for scenario construction, but also for evaluation of the scenarios. The set-up of the scenario construction advanced mode view is similar to the basic mode view: the left-hand block offers a scenario construction option, while this scenario is evaluated in the right hand block. Note that several evaluation options are available on the left-hand block as well, once they are more specific, e.g. the land-use emissions for various scenarios are evaluated here (Figure 5.3). The various sub-views of the scenario construction mode can be opened through the somewhat smaller boxes in the menu on the right.
One brownish box labelled 'model uncertainty' brings you to a view, which enables you to set the climate uncertainty parameters, while the white 'basic mode' box will bring you back to the basic mode of the scenario construction. Each of the other boxes is a link to a specific view, which will be explained in further details in the next few sub-paragraphs.
The 'scenario evaluation' in the right-hand block offers one additional climate indicator: the CO_2-equivalent concentration, which is also used as an important climate policy target. Such a stabilisation target is explicitly mentioned in the objective of FCCC.

5.3.3 Model uncertainty

The model uncertainty view consists of an uncertainty assessment part of meta-IMAGE 2.1, where the user can change settings of the main climate model parameters (left-hand block), and an evaluation part, where the user can assess the impact of the various parameter settings (right-hand block). The latter is the same as in the main scenario construction view.

In the uncertainty assessment part (left-side) you can assess the impact of uncertainties in the main model parameters on the model projections of the main global climate indicators (see right-hand block), a co-called sensitivity analysis. The main model parameters and its uncertainty range (based on the IPCC Second Assessment Report) (Houghton *et al.*, 1996) are the following:

- **climate sensitivity:** the long-term (equilibrium) change in global mean surface temperature due to a doubling of CO_2 levels, with a central IPCC value of 2.25 $^oC/Wm^{-2}$, with an IPCC range of [1.5;4.5] $^oC/Wm^{-2}$. Here a central value of 2.35 $^oC/Wm^{-2}$ is taken, a value similar to the one derived from equilibrium doubling CO_2 concentration experiments with the IMAGE 2.1 model (see also den Elzen, 1998).
- the **direct SO_2 forcing** parameter (scaling parameter): the central IPCC value of the direct radiative forcing by sulphate aerosols in 1990 is -0.5 W/m2, with a range of [-0.75;-0.25] Wm^{-2}. Here a central value of -0.57 Wm^{-2} is adopted, to be consistent with the IMAGE temperature increase projections.
- the **indirect SO_2 forcing** parameter (scaling parameter): a highly uncertain model parameter. The central IPCC value of the indirect radiative forcing by sulphate aerosols in 1990 is zero, whereas there is a range of [-2;0] Wm^{-2}. Here a central value of -0.3 Wm^{-2} is adopted, to be consistent with the IMAGE temperature increase projections.

- the **indirect radiative forcing by CFCs** due to stratospheric ozone depletion and the radiative forcing by smoke particles can be included or excluded in the model calculations. In the default calculations these forcings are excluded for reasons of consistency with IMAGE 2 climate modelling. Both are small components (less than 5%) of the overall radiative forcing in 1990.
- the **thermal sea level rise parameter**, with a central value of 0.24 m, and a range of [0.1;0.4]m.

The output variables are the main global climate indicators: the global mean temperature change compared to the 1900 level and the sea-level rise compared to the 1900 level.

Note: Various parameters can now be changed to assess the uncertainty in temperature change and sea level rise. However, the resulting outcome for the 2000 level should not differ too much from the reference value. It will be found that a high climate sensitivity implies a high negative forcing by aerosols in order to remain within the estimated observed temperature change (0.4 - 0.8 ºC late twentieth century). So, not all combinations of uncertainties are scientifically credible.

5.3.4 Fossil CO_2 emissions view

Fossil CO_2 emissions are the most important determinant of climate change. It relates to all anthropogenic emissions of CO_2 due to the burning of fossil fuels, by consumers, as well as in emissions of CO_2 by cement production, or whatever other source of CO_2 emissions, excluding emissions due to land-use changes. This view offers several policy variables to be set by the user in the scenario construction block on the left-hand side to generate your own fossil CO_2 emissions scenario, as well as to show the fossil CO_2 emissions for your target scenario/ your own scenario.

- Reference scenario and target scenario can be changed here. The reference scenario describes the non-Annex I fossil fuel CO_2 emissions for the period 1995-2013 (for target scenarios including Kyoto) and the global CO_2 emissions due to land-use changes for the period 1995-2100 (see section 5.3.5). The target emissions scenario describes the global anthropogenic CO_2 emissions for the period 1995-2100 (for the target scenarios including Kyoto starting from 2013). The fossil CO_2 emissions are now calculated as the anthropogenic CO_2 emissions minus the CO_2 emissions due to land-use changes.
- Own scenario: You can construct your own scenario in the block labelled ‘own scenario’, but not before you have selected the ‘own constr. scenario’/ ‘own constr. Scenario + Kyoto’ in the target scenario slider. Open the scenario construction block by using the right mouse button and zoom in. You can construct an own scenario of fossil CO_2 emissions, in either absolute emissions or relative to the 1990 emissions. First choose ‘relative’ or ‘absolute’ in the slider, to enable you to make changes in one of the graphs.
- Two graphs related to emissions on the target scenario can be distinguished:
  - Fossil CO_2 emissions (Target scenario) in GtC/yr: shows the fossil CO_2 emissions for the target scenario (red line), as well as for the three scenarios, i.e. IMAGE 2.1 IPCC/SRES A1 and B1 and IMAGE 2.1 Baseline A (see paragraph 4.2 for some more background on these scenarios).
  - Anthropogenic CO_2 emissions (target scenario) in GtC/yr: shows the *total* CO_2 emissions, divided into fossil CO_2 emissions (green) and CO_2 emissions due to land-use change (yellow). The former can be changed in the fossil CO_2 emissions here.
- the lower block shows the relation between the baseline scenario and the target scenario, indicating the global CO_2 emission reduction burden in red.

5.3.5 Land-use CO_2 emissions view

Land-use changes are exceptionally difficult to capture in simple modelling frameworks. To account for options to control land-use CO_2 emissions, we allow the user to change land-use CO_2 emissions directly. Land-use related CO_2 emissions may differ from their emissions pathway as described in the background baseline emission scenario (reference scenario). For example, you can choose the IMAGE 2.1 IPCC/SRES A1 scenario as a reference scenario, in combination with the land-use CO_2 emissions according to a different emission scenario.
This view offers several policy variables to generate your own land-use CO_2 emissions scenario, and to show the land-use CO_2 emissions for your target scenario/ your own scenario. The view is built up as follows:

- Reference scenario and target scenario can be changed here. The reference scenario describes the global CO_2 emissions due to land-use changes for the period 1995-2100 (default-case). The target emissions scenario only affect the land-use CO_2 emissions for the 'own constr. scenario' choices.
- Own scenario: There are two ways to change the land-use CO_2 emissions in the 'own scenario'-box (right mouse: 'open all'):
  (i) You can construct your own scenario for the land-use emissions in the block labelled 'own scenario', when you select the 'own constr. scenario'/ 'own constr. scenario + Kyoto' in the target scenario slider, and then dragging the graph line in the box ' Own scenario: land-use CO2 emissions'[12].
  (ii) You can select a land-use CO_2 emissions scenario. In the own scenario box, the default land-use reference scenario is given as 'use baseline emissions', which means that the land-use CO_2 emissions follow the emission pathway as described in the reference scenario. The slider now gives six options:
    1. use of **baseline emissions**: follows the baseline (reference) scenario;
    2. use of **IPCC IS92a scenario**: somewhat older IPCC scenario, based on earlier IPCC work and Worldbank. Intermediate scenario compared to the newer A1 and B1 scenarios;
    3. use of **IMAGE 2.1 IPCC/SRES A1 scenario**: this option uses the IMAGE 2.1 IPCC/SRES A1 scenario for land-use change emissions;
    4. use of **IMAGE 2.1 IPCC/SRES B1 scenario**: this option uses the IMAGE 2.1 IPCC/SRES B1 scenario for land-use change emissions;
    5. use of a '**no deforestation scenario'**: in this scenario no deforestation is halted before 2010, and the land-use emissions return to zero by 2010.
    6. use of an 'own **land-use scenario'**: you can construct your own scenario in the blue box, by dragging the graph line.

    The regional land-use emissions for the last two options are calculated using a time-dependent distribution function derived IMAGE 2.1 land-use change data.

- Two graphs related to emissions on the target scenario can be distinguished:
  - land-use CO_2 emissions (Target scenario) in GtC/yr: shows the land-use CO_2 emissions for the target scenario (red line), as well as for the three scenarios, i.e. IMAGE 2.1 IPCC/SRES A1 and B1 and IMAGE 2.1 Baseline A.
  - anthropogenic CO_2 emissions (target scenario) in GtC/yr: shows the *total* CO_2 emissions, divided into fossil CO_2 emissions (green) and CO_2 emissions due to land-use change (yellow). The latter can be changed in the land-use CO_2 emissions here.

[12] You can also include a net *sink* in your land-use CO_2 emission scenario by dragging the line to negative values.

- The lower block shows the relation between the baseline scenario and the target scenario, indicating the global CO_2 emission reduction burden in red.

The default scenario of land-use emissions follows the IMAGE 2 Baseline A projections (Alcamo *et al.*, 1996). The comparison with other scenarios may give you an impression of the order of magnitude, but cannot avoid that you possibly make inconsistent scenario assumptions. The impact of changes in land-use emissions can be directly evaluated in the right-hand part of the Land-use emissions-view.

Note: The actual land-use related CO_2 emissions in the future burden sharing calculation within FAIR can be lower by larger regional emissions reductions following from the assumed burden sharing regime, which allows somewhat higher fossil CO_2 emissions, since the total anthropogenic CO_2 emissions are restricted to the global anthropogenic CO_2 emission profile.

5.3.6 Anthropogenic CH_4 emissions view

- The anthropogenic methane (CH_4) emissions for the period 1995-2100 can be changed in this view. These emissions consists of:

1. **fossil CH_4 emissions**, i.e. CH_4 emissions related to fuel production and transportation/ distribution (coal, mining, oil and gas production and gas supply), such as CH_4 leakages from natural gas pipelines. The 1990 value for the IMAGE 2.1 emission scenarios[13] is 95-100 $TgCH_4$/yr (IPCC SAR-range: 70-120). Industry-related emissions are almost negligible.
2. **land-use CH_4 emissions**, the CH_4 emissions from enteric fermentation (1990: about 70 $TgCH_4$/yr), from rice paddies (about 30 $TgCH_4$/yr), from animal waste (about 15 $TgCH_4$/yr), from biomass burning (about 30 $TgCH_4$/yr), from landfills (about 35 $TgCH_4$/yr) and from domestic sewage (about 25 $TgCH_4$/yr). The 1990 value for the IMAGE emission scenarios[4] is 205-235 $TgCH_4$/yr (IPCC SAR-range: 200-350).

Besides these anthropogenic emissions, there also natural CH_4 emissions, i.e.:

3. **natural CH_4 emissions**. This category contains global emissions of CH_4 from termites, oceans/freshwater and methane hydrates and others. In the model these emissions are kept constant, and calculated based the difference between the 1990 IPCC global CH_4 emissions (500 $TgCH_4$/yr) and the total anthropogenic CH_4 emissions (IMAGE range: 300-335 $TgCH_4$/yr). This implies a range of the natural CH_4 emissions of 175-205 $TgCH_4$/yr (IPCC SAR-range: 110-210 Tg CH_4/yr).

The view is built up as follows:

- Reference scenario and target scenario can be changed here. The reference scenario describes the non-Annex I anthropogenic CH_4 emissions for the period 1995-2013 (for target scenarios including Kyoto). The target emissions scenario describes the global anthropogenic CH_4 emissions for the period 1995-2100 (for the target scenarios including Kyoto starting from 2013). The fossil CH_4 emissions for the target scenario are now calculated by scaling with the fossil fuel CO_2 emissions reductions efforts in the target scenario. The same holds for the land-use CH_4 emissions for Annex I, whereas for non-Annex I the land-use CH_4 emissions are assumed to decrease slightly compared to the baseline emission trends.
- Own scenario: You can construct your own scenario in the block labelled 'own scenario', but not before you have selected the 'own constr. scenario'/ 'own constr. Scenario + Kyoto' in the target scenario slider. If you choose 'own constr. scenario' in the upper 'Target scenario box', you are able to make changes in two ways:

[13] The lower value corresponds with the IS98 A1 and IS98 B1 scenario (simulated with IMAGE 2 model Version 2.1 IPCC SRES99), whereas the upper value corresponds with the IMAGE Baseline A, B and C scenario (Alcamo *et al.*, 1998) (simulated with IMAGE 2 model Version 2.1).

1. **Abatement factor CH_4 leakages**. These are leakages from pipelines, quantified through an index figure relative to 1990. You can drag the graph to change this figure. The abatement factor will be *in addition* to the fossil CO_2 emissions reductions achieved in the assumed target scenario.
2. **Land-use CH_4 emission.** You can construct your own scenario in the blue box 'Own scenario: land-use CH_4 emissions', by dragging the graph line.

- A comparison of your target CH_4 emission scenario with the Baseline emission scenarios is given in the next two graphs, one for fossil CH_4 emissions and one for land-use CH_4 emissions. There is also one graph for the calculated the atmospheric CH_4 concentration. A comparison of the contributions of CH_4 through land-use emissions and fossil emissions is shown in the *total* 'CH_4 emissions' graph.

5.3.7 Anthropogenic N_2O emissions view

The anthropogenic nitrous dioxide (N_2O) emissions for the period 1995-2100 can be changed in this view. These emissions consists of three parts:

1. **fossil N_2O emissions**, i.e. the N_2O emissions from fossil fuel combustion. The 1990 value for the IMAGE emission scenarios[14] is around 0.2-0.3 TgN/yr.
2. **land-use N_2O emissions**, the N_2O emissions from fertilized soils (1990: about 1.5 TgN/yr), from animal waste (about 3.2 TgN/yr), from biomass burning (about 0.1 TgN/yr), from land clearing (about 0.1 TgN/yr), from domestic sewage (about 0.2 TgN/yr). The 1990 value is around 5.1 TgN/yr.
3. **industry-related N_2O emissions** are emissions related to the nitric acid and adipic acid production, and are in 1990 around 0.7 TgN/yr.

In addition to the anthropogenic emissions, the category of natural emissions contains global emissions of N_2O from natural soils. The 1990 value is around 9.0 TgN/yr.

In the scenario construction of N_2O emissions, the anthropogenic emissions of nitrous oxide are summarized in two graphs: fossil & industrial N_2O emissions, and land-use N_2O emissions. In the own scenario block, these can be manipulated by dragging the curve. This view is built up similar as the view of the anthropogenic CH_4 emissions, except that here the industry-related N_2O emissions are explicitly included in the fossil related emissions. The calculation of the N_2O emissions is similar to the CH_4 emissions calculations, except that the fossil N_2O emissions in the own constructed scenarios are calculated based on a scaling with the fossil CO_2 emissions.

5.3.8 SO_2 emissions view

The SO_2 emissions result in sulphate aerosols that cause a (globally averaged) negative radiative forcing, which on a global level offset a part of the global radiative forcing due to increased concentrations of greenhouse gases. It is a too strong simplification just to conclude that the sulphate aerosol forcing simply offsets the greenhouse forcing, because of the strong regional variations in the negative radiative forcing by sulphate aerosols resulting from the differences in regional SO_2 emission levels and their relatively short lifetimes.

In the own scenario box, four baseline options are available:

1. **Baseline scenario**: the anthropogenic SO_2 emissions according to the selected reference scenario.

[14] The lower value corresponds with the IMAGE 2.1 IPCC/SRES A1 and IMAGE 2.1 IPCC/SRES B1 scenarios (simulated with IMAGE 2 model Version 2.1 IPCC/SRES 99), whereas the upper value corresponds with the IMAGE Baseline A, B and C scenario (Alcamo *et al.*, 1998) (simulated with IMAGE 2 model Version 2.1).

2. **1990 level**: the anthropogenic SO_2 emissions remain at their 1990 level.
3. **SO_2 related to CO_2**: the anthropogenic SO_2 emissions are scaled with the fossil fuel CO_2 emissions (following the fossil fuel CO_2 emissions reduction pathway), and multiplied by a desulphurisation factor. The latter is a final option to change the amount of SO_2 per unit of fossil CO_2 emissions, and reflecting international air pollution policies. This would be either a fuel-switch mix, from coal to gas, or desulphurisation by 'flue gas desulphurisation. With a desulphurisation factor of 1, the reduction of SO_2 emissions is in line with CO_2; when the factor is lower than 1 additional policy on SO_2 emission reduction is taking place, when the factor is higher than 1, reduction of SO_2 emissions is slower than reductions of CO_2 emissions (rather unrealistic, and only possible for fuel-switch mix towards an increasing coal use).
4. **SO_2 related to CO_2 by the B1 Sulphur protocol**; similar option as SO_2 related to CO_2, but now with the global desulphurisation factor as derived from the IMAGE 2.1 IPCC/SRES B1 emission scenario (de Vries *et al.*, 2000).

The final output variable, the global anthropogenic SO_2 emissions is depicted in the lower graph. The fossil CO_2 emissions are also given. Also the calculated anthropogenic SO_2: CO2 emission ratio (red line) is depicted here. This factor also indicates unrealistic assumptions about the anthropogenic SO_2 emissions (like for the options 1 and 2).
If the anthropogenic SO_2 emissions are reduced, also their cooling is reduced, and this results in an increasing global mean surface temperature increase, which is depicted on the right-hand side of this view, in the scenario evaluation.

5.3.9 All GHG emissions view

The 'All GHG emissions'-view provides an overview of the contributions of the various greenhouse gases and assumptions for a selected group of halocarbons included: the hydrofluorocarbons (HFCs) and the perfluorocarbons (PFCs, i.e. CF_4, C_2F_6 and sulphur hexafluoride (SF_6)). The emissions of these compounds are set exogenously, based on the IPCC SRES B1 emission scenarios developed by Fenhann (1999). The emissions of the halocarbons regulated in the Montreal Protocol, i.e. the CFCs, HCFCs, halons, carbon tetra-chloride and methyl chloroform follow the Montreal Protocol scenario (A3) of WMO (1999), similar as in the IPCC SRES emission scenarios.
In the own scenario view, the emissions of HFCs and PFCs can be manipulated in three ways:

1. **baseline scenario**: the emissions of HFCs and PFCs according to the selected reference scenario.
2. **own reduction scheme**, the emissions of HFCs and PFCs are reduced following own emission reduction scheme (relative to the 1990-levels) (left-hand box).
3. **related to CO_2 mitigation efforts**: the emissions of HFCs and PFCs are scaled with the fossil fuel CO_2 emissions (following the fossil fuel CO_2 emissions reduction pathway).

The lower box shows the CO_2–equivalent emissions, as built up by its greenhouse gas components.

5.3.10 Kyoto Protocol view

The Kyoto Protocol view shows the short-term CO_2 emissions for the period up to the first commitment period under the Kyoto protocol (1995-2010), both for the Annex-I regions as globally. It offers the option to evaluate your target emission scenario in view of the reduction agreements in the Kyoto Protocol. When you choose one of the target scenarios that includes the Kyoto Protocol, the scenario will follow the emissions pathways as regulated in the Kyoto Protocol.

The Kyoto Protocol view is built up as follows:

- In the upper left sliders you can choose a **reference scenario** and a **target scenario**, similar as in the other views. Including the Kyoto Protocol option in the target scenario implies that *Kyoto* and *Target* in the evaluation graph are similar.
- The **own scenario** offers the possibility to construct your Kyoto Protocol emission reductions. Zoom in and open by using the right mouse button. For each region of the Annex-I group you can change the reduction levels, and assess the impact in absolute emissions (in GtC/yr) in the graph on the left. The default settings reflect the agreements of the Kyoto Protocol (UNFCCC, 1998): the former Soviet Union states have no reduction commitments, and Australia and New Zealand (Oceania) are even allowed to increase their emissions. In the evaluation graph, the fossil CO_2 emissions for the period 1990–1995 are based on the ORNL-CDIAC emission database (Marland *et al.*, 1999), the emissions for the period 1995–2000 are set to stabilise at the 1995 level, and emissions for the period 2000–2010 are reduced to the Kyoto commitments.
- Two more graphs are shown in the lower left part of the view:
  1. **Fossil CO_2 emissions** (Kyoto vs. Target), regional fossil CO_2 emissions according to the target scenario and the Kyoto Protocol (only for Annex I regions)
  2. **Ant. CO_2 emissions** (Kyoto vs. Target): global anthropogenic CO_2 emissions according to the target scenario and the Kyoto Protocol.

  With respect to the fossil CO_2 emissions graph, each Annex-I region can be chosen in the on/off array. In dotted lines, the divergence is shown between the short-term fossil CO_2 emissions targets you have set and the short-term reduction targets set in the Kyoto Protocol.

For more details about the Kyoto protocol implementation in the FAIR model, as well as a comparison between the 1990 CO_2 emissions of the UNFCC and CDIAC database, we refer to Appendix A.2.

5.4 Increasing participation view

5.4.1 Increasing participation basic mode main view

The Increasing participation view offers you the option to investigate a multi-stage approach to the participation of the various regions in a global emission reduction regime. As in the scenario construction mode, there are two main views available: a basic mode with a limited set of policy options and an advanced mode with an extended set of policy options.
The idea behind increasing participation is that every region eventually will participate in a global emission reduction regime. As a starting point, only Annex-I regions share the burden of emission control i.e. by following the Kyoto Protocol. Over time, non-Annex-I regions will gradually start participating and increase the level of commitment until and in the end they join the Annex-1 in full participation in the burden-sharing regime. This approach is called the Multi-stage approach. The FAIR model uses four stages of participation (explained below):

1. Following the reference scenario: non-participation;
2. Decarbonisation of the economy;
3. Stabilisation of emissions;
4. Burden sharing.

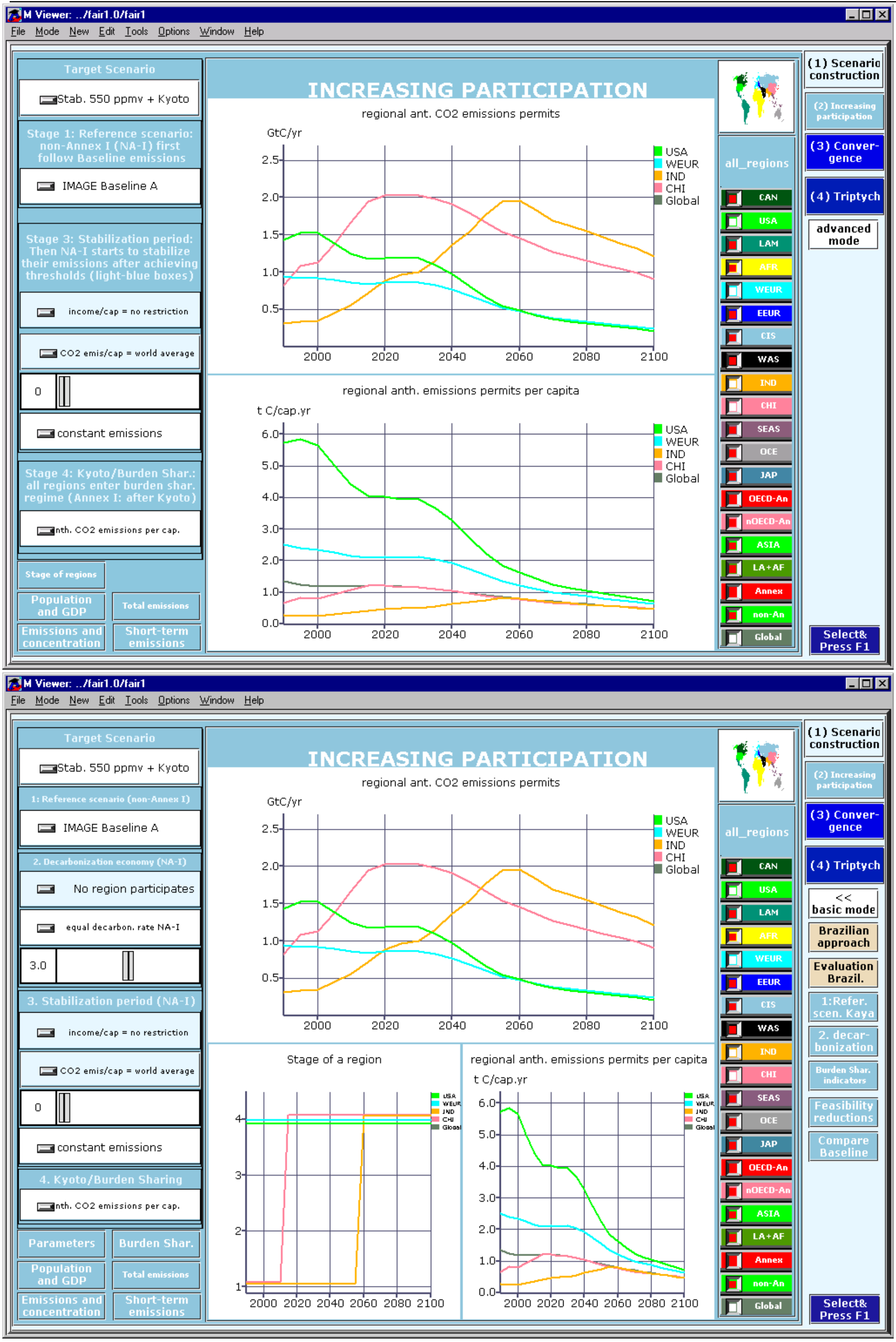


Figure 5.4: The 'Increasing participation' - view of FAIR: basic mode (upper graph) and advanced mode (lower graph)

In the basic view the option of decarbonisation (stage 2) is left out. The main view of the Increasing participation mode consists of two output graphs in the middle, accompanied with a menu bar at the left-hand side and a region selector at the right hand side. On the very right there are selector buttons for other views and modes.

Main policy variables (menu bar)

The menu bar contains options to select reference and target scenarios as well as threshold criteria for participation in the different stages and criteria for burden sharing. Before choosing settings for various participation and burden sharing parameters available in the menu bar, you first have to select the reference and target scenarios (two top sliders).

Reference scenario

The reference scenario determines the CO_2 emissions of the non-participating regions.

Target scenario

The target scenario defines the total allowed global anthropogenic CO_2 emissions (global emissions ceiling). The target scenarios include a set of pre-defined global CO_2 emission profiles resulting in the stabilisation of CO_2 concentrations at various levels (450 to 550 ppmv), and the option to use an *own constructed scenario*, composed in the scenario construction (advanced) mode. It is also possible to select a baseline scenario via the option *reference scenario*. If a target scenario includes the Kyoto Protocol, short-term global emissions are based on the Kyoto Protocol targets for Annex-1 regions and baseline emissions for non-Annex-1 regions.

Participation and contribution to global emission control

For each stage of the increasing participation mode two parameters have to be set: one or two trigger or threshold which determine(s) when a region enters a stage of participation, and a parameter determining the *contribution* (share of the burden). The triggers are shown in pale blue, the *contribution or burden sharing levers* are shown as white buttons or sliders. Below the various stages are described in more detail. The stage of de-carbonisation (stage 2) is not available in the basic view and will be explained in the next paragraph on the advanced mode.

Stage 1 (Reference scenario): The Annex I regions follow the Kyoto Protocol agreements, or their Baseline scenario when the Kyoto Protocol is delayed (depending on starting year of Annex I, default: 2000). The non-Annex I regions first follow their Baseline scenario. Therefore, you need to select a Reference scenario in the Stage 1 slider for the emissions of the non-Annex I regions, which do not participate in any of the following stages yet.

Stage 3 (Stabilisation): Before participating in the final burden sharing regime with the Annex-I regions, the non-Annex I regions may start to stabilise either their total CO_2 emissions or their per capita emissions.

1. Select participation thresholds (which both will have to be achieved):
   - per capita income threshold (percentage of the average 1990 Annex I income of 1990 US$ 14,320);
   - per capita emission threshold (for example: CO_2 emissions per capita (fixed threshold), or world average per capita CO_2 emissions (dynamic threshold)).
2. Select a stabilisation (grace) period (a period of time, in which the emissions of a region in stage 2 will stabilise). Note: a stabilisation period of 0 years means no stabilisation;
3. Select whether the total or the per capita CO_2 emissions will stabilise in this stabilisation period.

Stage 4 (burden sharing): After the period of stabilisation, the (non-Annex-I) regions will start to participate in the burden sharing regime, using a certain burden sharing rule for the allocation of the emissions reductions among all regions participating in the burden sharing regime. The regions will enter this stage once the period of stabilisation (stage 3) is finished, so there is no additional trigger available. Annex-I countries are by definition already participating in the stage of burden sharing, since they all (intend to) comply with the Kyoto Protocol.

- select burden sharing key (e.g. contribution to CO_2 emissions or CO_2-induced temperature increase, etc.) (see burden sharing view). Note: CO_2 emissions per capita (cap population) and temperature increase per capita (cap population) take into account a population cap.

Main output variables

The two graphs show you the main output (results) of the model calculation:

- regional anthropogenic CO_2 emissions permits of the selected regions (in GtC/yr) (top), i.e. the sum of the CO_2 emissions by fossil fuel combustion and industrial production and the CO_2 emissions by land-use changes.
- regional anthropogenic CO_2 emissions permits per capita (tC/cap.yr).

You can select the regions projected by using the region selector in the "*all regions*" column.

Other output variables

The basic mode offers several other output variables in the bottom left boxes of the view. Five boxes are available, which you can all select These can be viewed by zooming in and open with right mouse button.

Stage of a region

This graph indicates the stage each region is in. The x-axis gives the years from 2000 to 2100, and the y-axis gives the stage of a region. Stage 1 means following the baseline, stage 2 indicates de-carbonisation of the economy, stage 3 stabilisation of emissions, and stage 4 full participation in burden sharing regime. Note that Annex-I regions start at stage 4, since they already participate in the Kyoto Protocol. Non-Annex-I regions enter each consequent stage according to the parameters you have set, i.e. the trigger of entering a next stage.

Population and GDP

The population and gdp are determined by the assumed reference scenario.

- Population specifies the total number of people in the selected regions (in billions of individuals).
- Total Gross Domestic Product (GDP) is used as the indicator for economic activity in the IMAGE 2 model (in 10E12 US1990$ per year.
- Gross Domestic Product (GDP) per capita is also an indicator for economic activity, on a per capita basis (in 1000 (10E3) US$ per capita per year).
- The Purchase Power Parity (PPP) is an alternative indicator for GDP/capita, based on relative purchase power of individuals in various regions, that is the value of a dollar in any country, i.e. the amount of dollars needed to buy a set of goods, compared to the amount needed to buy the same set of goods in the United States (see also Box 3.1).

Emissions and concentrations

- Emissions specify the total anthropogenic CO_2 emissions (in GtC/yr) per region.
- Concentration specifies the regional contribution to the CO_2 concentration (in ppmv) taking into account historical anthropogenic emissions (since 1900).

Total emissions

- Fossil CO_2 emissions for the selected regions (in GtC/yr), indicating the absolute amount of fossil emissions per region. Fossil CO_2 emissions and land-use related CO_2 emissions add up to the total CO_2 emissions.

- Fossil CO_2 emissions per capita for the selected regions (tC/cap.yr).
- Land-use related CO_2 emissions for the selected regions (in GtC/yr). Adds up to the total CO_2 emissions together with fossil CO_2 emissions.
- Rate of change in the *total* anthropogenic CO_2 emissions for the selected regions (% change per year).

Short-term emissions
This view shows the CO_2 emissions for the period up to the first commitment period under the Kyoto protocol (1995-2010). On the left-hand side the regional anthropogenic CO_2 emissions (GtC/yr) for the regions are depicted, whereas on the right hand side the per capita anthropogenic CO2 emissions are shown. The left-upper box describes whether Annex I either follows its Baseline emissions, the emissions as regulated in the Kyoto Protocol, or the emissions as calculated under the burden sharing regime. It also indicates whether non-Annex I follows its Baseline emissions, or the emissions as regulated in the de-carbonisation /stabilisation or burden sharing regime.

5.4.2 Increasing participation in the advanced mode

The user that wishes to make use of a more extended set of options in exploring the increasing participation approach should click through to the advanced mode, using the white box at the right column. The set-up is similar to the basic view, but several additional options are added (Figure 5.4). The main addition is the inclusion of an additional stage to the multi-stage approach of increasing participation: de-carbonisation of the economy. Compared to the basic view, this stage is added in between the baseline stage and the stabilisation period:

Stage 2 (De-carbonisation of the economy)*:* The non-Annex I regions adopt (minimum) targets for the de-carbonisation of their economy when they meet de-carbonisation thresholds. De-carbonisation of the economy indicates the reduction in the carbon intensity of the economy, that is the amount of carbon emitted per unit of economic activity (CO_2/GDP). Here, the carbon intensity of the economy only refers to energy (fossil fuel) use related CO_2 emissions. However, also for land-use related CO_2 emission separate decarbonisation targets can be set, defined in terms of carbon emissions per capita emissions (see below: *decarbonisation view*). The effectiveness of de-carbonisation commitments depends on the level of decarbonisation in the baseline scenario (the autonomous development). If the decarbonisation rate in the baseline is higher than the target value regions will follow the baseline value. The decarbonisation option can be used in the following way:

- Select de-carbonisation thresholds (trigger), i.e. percentage of the average 1990 Annex I income, an (fixed or dynamic) emission threshold or a predefined starting year (see: *parameter box*);
- Select the de-carbonisation rate (%/year) for all non-Annex I regions in the de-carbonisation stage.
- Select an equal decarbonisation rate for all regions or a differentiated rate (for defining differentiated rates (see: *decarbonisation view)*

Main output variables
In addition to the two graphs shown in the basic view (regional anthropogenic CO_2 emissions permits of the selected regions (in GtC/yr) (top) and regional anthropogenic CO_2 emissions permits per capita (tC/cap.yr) (bottom-right), now also the stages of participation of the various regions are depicted (bottom-left) (see above: *stage of a region*). You can select the regions projected by using the region selector in the *all regions* column.

Other output variables
In addition to the so-called "other output variables" as explained in the basic-mode paragraph, two new boxes are available in the advanced mode. Zoom in and open by using the right mouse button.

Parameters
- **Starting year** of Annex I and non-Annex I regions before participating in the burden sharing regime. These parameters are important in the following cases: for Annex-1 in case it is assumed that the Kyoto Protocol will not be implemented / Annex-1 action is delayed; for non-Annex-1 in order to select your own starting year for non-annex-1 regions participation in the de-carbonisation stage (see: *thresholds for participation*).
- **Own per capita income threshold** (in 10E3 US$/cap/yr) for the participation in the de-carbonisation stage (left) and the burden sharing regime (right) (only for the non-Annex I regions)
- **Population cut-off year**, i.e. a cap on population growth for the purposes of allocating emissions rights, can be adopted by notional freezing populations for years beyond this cut-off year at the values for that year (can be used in combination with the *burden sharing keys*: CO_2 emissions per capita and per capita contribution to temperature increase (fix)).

Burden Sharing
- the required emission reduction effort (left) is determined by subtracting the baseline emissions of non-participating regions/countries from the global emissions allowed in the next target year.
- the relative share (in %) of the selected region to the chosen burden sharing key (right) (as part of the total shares of the participating regions to the burden-sharing key). The relative share of a non-participating region is set on zero, and the sum of the relative shares of the participating regions is equal to 100%

Additional views
On the right hand side of the advanced mode view, various additional views and options are given. These will be explained in the following paragraphs. The blue boxes offer background information and the evaluation of additional parameters. The brown boxes provide special views about the so-called "Brazilian Approach" and a technical evaluation of the Brazilian methodology (see below). Clicking on the boxes can activate all views.

5.4.3 The Brazilian Proposal

During the negotiations on the Kyoto Protocol, Brazil proposed a methodology to base Annex-I (industrialised) country contributions to emission reductions on their relative responsibilities for global mean temperature increase realised (UNFCCC, 1997). The FAIR model was used to evaluate this proposal (den Elzen *et al.*, 1999). The Brazilian Proposal view (Brazilian approach) shows the consequences of the global application of this proposal. It indicates both the absolute contribution of regions and selected countries to the anthropogenic CO_2 emissions, CO_2 concentrations and global mean surface temperature increase, respectively (three graphs on the left), as well as their relative share (three graphs on the right) for the calculated regional CO_2 emissions for the selected (target) scenario.

Through the second box **Technical evaluation**, you can also assess the uncertainties in the climate change allocations by using different historical data sets, greenhouse gas sources and climate models / climate response functions from different Global Circulation Models (GCMs). The output graphs again show the absolute and relative shares of world regions to CO_2 emissions, CO_2 concentration, and temperature increase.

Historical emissions*:* various data sets are available on the slider at the upper left (default is CDIAC-EDGAR databases). They all offer data per region on the aggregate historical emissions per region, extrapolated to 2100.

Gases*:* in the second slider, a selection can be made between attribution to CO_2 only or including all greenhouse gases [15]. In the case of only CO_2, it is also possible to account for the non-linear contribution to global warming of early versus late emitters (Only CO_2 (Enting)) (Enting, 1998) (see also section 4.1: 'Attribution of climate change').

GCM: various Atmosphere-Ocean General Circulation Models (AOGCMs) can be compared in their climate response functions. Choose 'GCM' instead of 'meta-IMAGE' in the boxes on the right. Then choose one of the GCM's available to assess the Brazilian proposal.

5.4.4 Reference scenario and Kaya indicators view

This view provides background information on the selected reference scenario (top-left), including the Kaya-indices: population (in billions), Gross Domestic Product/capita (income) (in 10E3 US$/cap.yr(1990)), energy intensity of economy (in J/US$) and carbon intensity of energy use (GtC/EJ, indicating emissions per unit of energy produced).
On the left, the carbon intensity of the economy (in 1000 gC/US$) is shown, defined as the product of energy intensity and carbon intensity. In addition, figures on the fossil CO_2 emissions, the land-use related CO_2 emissions and the total anthropogenic CO_2 emissions for regions selected are given. The third box shows the developments in total Gross Domestic Product per region.

5.4.5 De-carbonisation view

De-carbonisation of the economy is the second stage of increasing participation for the non-Annex I regions. De-carbonisation of the economy indicates the reduction in the carbon intensity of the economy, that is the amount of carbon emitted per unit of economic activity (CO_2/GDP). Default equal de-carbonisation rate are applied for all non-Annex I regions in stage 2. The decarbonisation view allows for making more specific assumptions about regional decarbonisation targets and to better evaluation their implications. The view is built-up in three parts:

1. a selector for non-Annex I region on the right,
2. a menu of policy variables on the very left and
3. three output graphs in the central part of the view. In the lower left corner you will also find a box for defining decarbonisation targets for land-use related CO_2 emissions, and a box on overall CO_2 emissions.

[15] the option "*inclusion of the other anthropogenic regional greenhouse gas emissions*" is only valid when the *Target* scenario = reference scenario, since there is no regional specifications of the anthropogenic CH_4 and N_2O emissions for your own constructed emission scen ario, nor for the stabilization scenarios. The burden sharing calculations only focus on the regional allocation of the anthropogenic CO_2 emissions.

After you have selected one of the non-Annex I regions from the list, the output graphs will show the consequences of the settings of the policy variables.
NB: selected policy variable settings (e.g. different decarbonisation targets for non-Annex-1 regions) will also be active when switching back to the main (advanced) increasing participation view and selecting differentiated regional decarbonisation rates.

Policy variables
On the left-hand side of your view, you see an array of decision variables entitled "Participation rules for de-carbonisation of economy." The settings for de-carbonisation are equal to the ones in the advanced mode view.

- The *threshold for participation* slider determines the trigger for entering the second stage of the multi-stage burden sharing, i.e. de-carbonisation of the economy. This may either be a predefined starting year, or a percentage of the Annex-I 1990 income (in GDP or PPP terms).
- The *Stage of a region* is indicated in the small graph on the left (see *stage of a region*).

The rate of de-carbonisation (decarbonisation targets) once this stage is reached, is determined by the settings of the sliders:

- Select either an equal rate of de-carbonisation for all Non-Annex-I regions, or select a differentiated level of de-carbonisation .
- In case of equal de-carbonisation , use the slider to set a common rate of de-carbonisation for all Non-Annex-I regions. Default level for all regions is a de-carbonisation rate of 3 % per year.
- In case of differentiated de-carbonisation , use the graph to set the rate of de-carbonisation for each of the non-Annex-I regions separately, by sliding the columns of the regions in the graph.

Land-use CO_2 emissions
For land-use emissions separate decarbonisation targets can be defined. However, these are based on land-use CO_2 emissions per capita instead of per unit of GDP. In this way, population growth in developing regions is taken into account. This view helps to evaluate the effects of de-carbonisation on land-use emissions. For most regions the effect will be rather low, since the principal part of reductions is achieved through the fossil CO_2 emissions. Here you can select a reduction level for all Non-Annex-I countries or differentiated for all the Non-Annex-I regions, depending on the selection made in the De-carbonisation main view. To specify the assumptions for the reductions of the per capita land-use related CO_2 emissions:[16]

- Select either an equal rate of de-carbonisation for all Non-Annex-I regions, or select a differentiated level of de-carbonisation (see above)
- In case of equal de-carbonisation , use the slider to set a common rate of de-carbonisation of per capita land-use related CO_2 emissions for all Non-Annex-I regions. Default level is a decarbonisation rate of 5% per year per capita.
- In case of differentiated de-carbonisation , use the graph to set the rate of de-carbonisation for each of the non-Annex-I regions separately, by sliding the columns of the regions in the graph.

Note that only one region is graphically evaluated, so not all setting of the individual regions can be investigated immediately. Therefore, you will first have to change the region in the De-carbonisation main view.

[16] To stabilise the total land-use related CO_2 emissions the regional yearly reduction should be equal to the regional population growth.

Main output variables (results)

- The upper graph shows the fossil CO_2 emissions of the non-Annex I region selected, according to the baseline scenario (red), the de-carbonisation regime (green) and the burden sharing regime (blue)(in GtC/yr).
- The lower left-hand graph indicates the change in carbon intensity of the economy (Fossil CO_2 emissions permits/Gross Domestic Product) in 1000 gC/US$ for the selected non-Annex I region in the three stages of Baseline scenario, and defined de-carbonisation and burden sharing regimes.
- The lower right hand graph indicates the rate of de-carbonisation (in %/yr) for the selected non-Annex I region in the three stages of Baseline scenarios, and defined de-carbonisation and burden sharing regimes[17].

Other output variables

In the lower left corner, there is a box with output variable on *Overall CO_2 emission.* This view gives an evaluation for all Non-Annex-I regions of their land-use related CO_2 emissions (top left), their fossil CO_2 emissions (bottom left) and the aggregate overall anthropogenic CO_2 emissions (right).

5.4.6 Burden sharing indicators view

The burden sharing view shows the relative contribution of Annex I versus non-Annex I (or any other selection of regions) to the climate change problem for a number of indicators, which could be used a burden sharing criteria. The main Burden Sharing view shows four columns of graphs:

- The **first column** shows the relative contribution when taking into account different gases and emission sources: fossil CO_2 emissions only, all anthropogenic CO_2 emissions (including land-use CO_2 emissions), and all anthropogenic emissions of CO_2, CH_4, N_2O in terms of anthropogenic CO_2-equivalent emissions. For the IMAGE baseline A scenario, the point where Annex I and non-Annex I contributions to the total global emissions get equal shifts from 2030 (fossil CO_2 emissions) to 2005 (CO_2-equivalent emissions). This is because of the large share of non-Annex-1 regions in (future) non-CO_2 and land-use emissions.
- The **second column** shows different indicators for accounting for historical contributions: cumulative fossil CO_2 emissions only, cumulative anthropogenic CO_2 emissions (including land-use CO_2 emissions), and cumulative anthropogenic CO_2-equivalent emissions. For the IMAGE baseline A scenario, the point where Annex I and non-Annex I contributions get equal shifts from 2085 to 2045. This is again due to the large share of non-Annex-1 regions in (future) non-CO_2 and land-use emissions.
- The **third column** shows the contribution of Annex-1 and Non-annex-1 on the basis of different indicators in the cause-effect chain of climate change: anthropogenic CO_2 emissions, concentrations and temperature increase. For the IMAGE baseline A scenario, the point where Annex I and non-Annex I contributions get equal now shifts from 2015 to 2050, due to the historical contributions of Annex-1 to the CO_2 concentration and temperature increase.
- The **fourth column** shows indicators for the per capita contributions: per capita CO_2 emissions (from 1890), contribution to CO_2 concentration per capita, and per capita contribution to temperature increase. Under assumptions of the IMAGE Baseline A scenario the contributions of Annex I and non-Annex I do somewhat converge, but not get equal.

[17] The final carbon intensity of the economy uses the Gross Domestic Product trend according to the Baseline scenario, and thereby does not account for possible decreases in the Gross Domestic Product as a result of the CO_2 emissions reductions.

In the box on the very left, some additional Burden Sharing keys can be evaluated, such as per capita emissions and temperature change with a cap for the population (note: this cap can be selected in the *parameters* box in the increasing participation main view), the carbon intensity of the economy, gross domestic product (GDP) and GDP per capita.

From this evaluation of indicators for a region's relative contribution to climate change (as criteria for burden sharing) a number of conclusions can be drawn (see also den Elzen *et al.* (1999)):

1. Burden sharing based on criteria accounting for historical emissions is favourable for developing countries. However, due to atmospheric decay of the past anthropogenic CO_2 emissions, the burden for Annex-I will be much larger on the basis of cumulative emissions than a burden based on the Annex-I contribution to CO_2 concentration or temperature increase.
2. Including all sources and greenhouse gases is favourable for industrialised countries. This is because most present land-use related emissions (including deforestation) and anthropogenic methane emissions from agriculture (like rice paddies) stem from developing countries, while relatively little pre-industrial land-use related emissions of industrialised countries are still in the atmosphere.
3. The contribution of Annex I increases with an indicator later in the cause - effect chain, due to their higher historical emission levels.
4. While the contribution of non-Annex I converges and overtakes the Annex I contribution for most absolute indicators, it remains far below Annex I levels for per capita indicators.
5. The burden sharing based on the CO_2 emissions per capita and per capita contribution to temperature increase using a cap for the population is still much favourable for the developing countries (compared with the same cases without population-cap). An opposite pattern can be found for a criteria accounting for the carbon intensity of the economy.

5.4.7 'Feasibility of the emissions permits'-view in the 'increasing participation'-mode

The 'Feasibility of the emissions permits' view allows for a region by region evaluation of the feasibility of the outcomes of the burden sharing regime by giving some indications of the level of efforts needed to restrict a regions' emissions to the level of its emission permits. Real emission reduction efforts may be substantially different in the case of emission trading or the use of other Kyoto Mechanisms.
The first graph (top left) shows the emissions permit level vis a vis a regions' 1990 emissions levels (1990 = 100%) for the total anthropogenic CO_2 emissions. The second graph (bottom left) shows the yearly rate of anthropogenic CO_2 emissions change (%/yr) for the selected region according to the calculated emissions permits. The third and fourth graphs on the right show the absolute (in 1000 gC/US$) and yearly percentage change in the carbon intensity of the economy (Fossil CO_2 emissions permits/Gross Domestic Product) for the selected region according to the calculated emissions permits.

Note: The carbon intensity of the economy is based on the Gross Domestic Product assumptions of the reference Baseline scenario, and thereby does not account for possible decreases in the Gross Domestic Product as a results of the CO_2 emissions reductions.

5.4.8 Compare Baseline-view in the 'increasing participation'-mode

This view shows per region both the allowable fossil and land-use related CO_2 emissions (on the left) as well as the total anthropogenic CO_2 emission permits (in GtC/yr) (on the right). Each graph compares the calculated regional emissions permits with the emission levels in the selected baseline scenario. The area between the baseline and the permits indicates the emission burden for the selected region. The emissions permits scenario starts in 2000 for the Annex-I regions. Note that the land-use related emissions are quite small compared to fossil fuel related emissions.

5.5 Convergence view

5.5.1 Convergence basic mode main-view

The convergence view allows for evaluating various options for convergence of per capita emission right. As explained in the previous chapter, convergence is an emission reduction regime, in which all regions participate immediately after the first commitment period and where per capita emission rights converge towards equal levels over time under a global emission ceiling (Figure 5.5).
In the main view two main boxes are available: a policy options menu bar on the left and output variables in the middle of the screen.

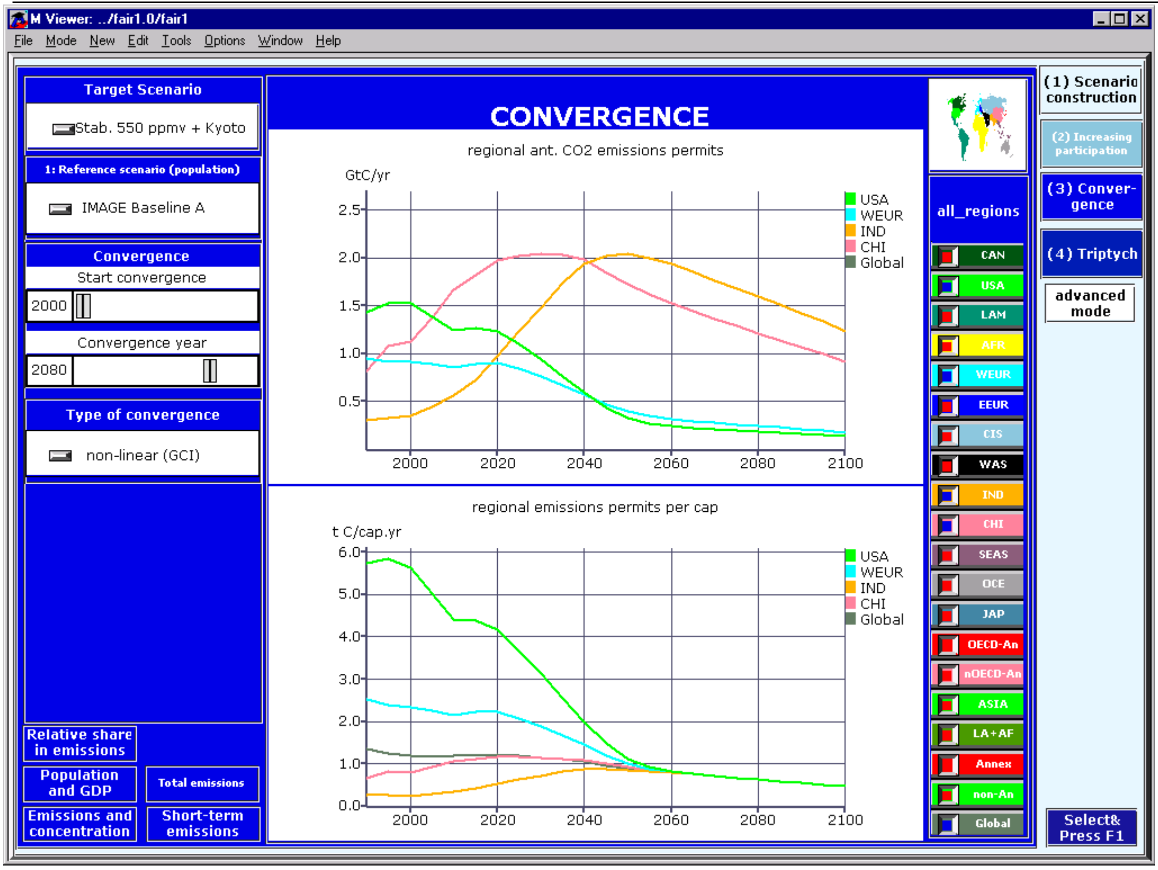
Policy variables (Menu bar)

Target scenario
With the target scenario slider a target scenario can be selected. The target scenarios include a set of pre-defined global CO_2 emission profiles resulting in the stabilisation of CO_2 concentrations at various levels (450 to 550 ppmv), and the option to use an *own constructed scenario*, composed in the scenario construction (advanced) mode. It is also possible to select a baseline scenario via the option *reference scenario*. The selected target scenario defines the global emission ceiling under which the convergence towards equal per capita shares of the overall emission space takes place. If a target scenario includes the Kyoto Protocol, short-term global emissions are based on the Kyoto Protocol targets for Annex-1 regions and baseline emissions for non-Annex-1 regions.

Start convergence
With this slider the starting year of convergence (default set at 2000) can be selected. NB: If a target scenario includes the Kyoto Protocol, convergence only starts after the first commitment period (after 2012).

Convergence year
With this slider the year in which the convergence of per capita CO_2 emissions is completed, that is that per capita emission right are equal.

Type of convergence
In the basic mode, two types of convergence can be selected:
- **non-linear convergence (GCI)**: Here, the convergence method of the GCI is used. The convergence path followed depends upon population assumptions and an arbitrary rate of convergence. In the calculation population assumptions from the reference scenario are used (the reference scenario can be selected in the scenario construction view). The rate of convergence, which determines whether most of the convergence takes place at the beginning or near the end of the convergence period, is fixed on the GCI value. This value can be changed in the advanced mode view.
- **linear convergence**: Here, there is a linear change from an emission allocation based on actual emissions in the starting year to an allocation of emissions on population values (per capita) in the year of convergence. In the calculation population assumptions from the reference scenario are used (the reference scenario can be selected in the scenario construction view).



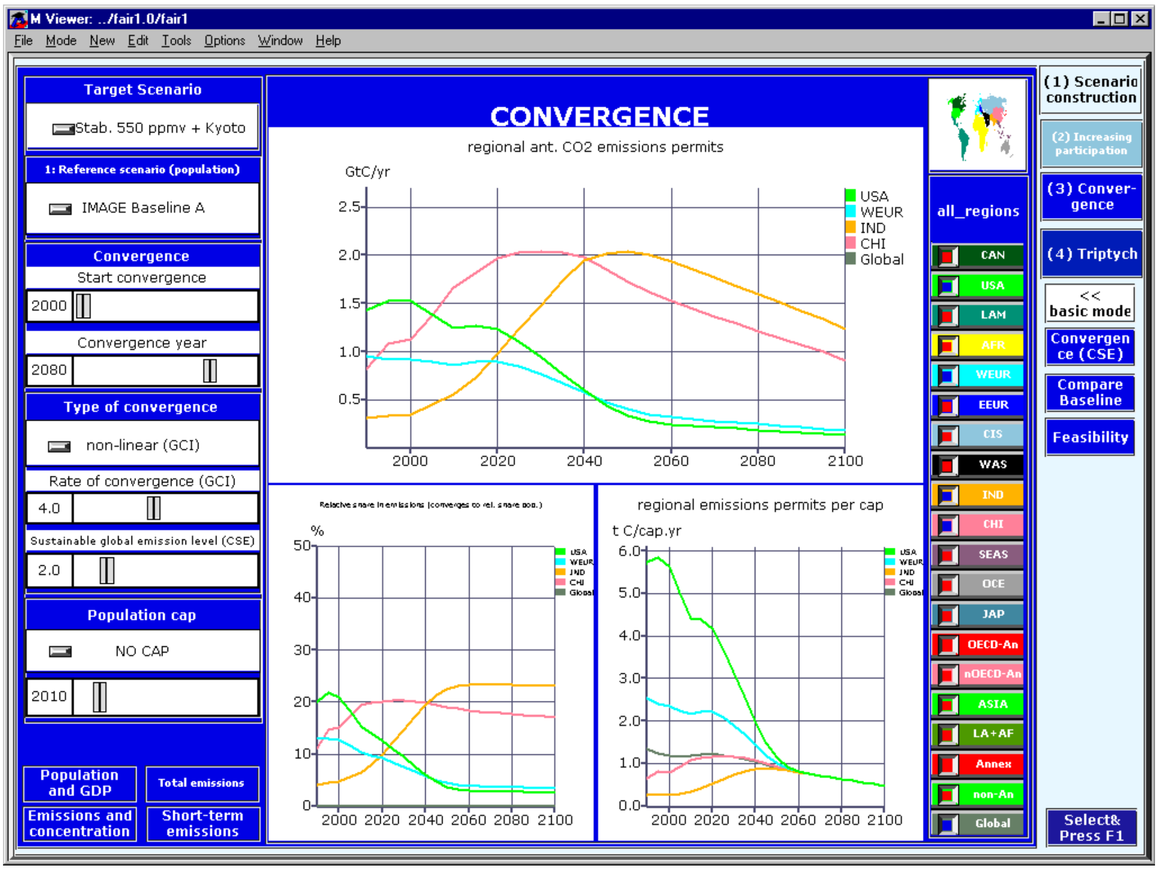


Figure 5.5: The 'Convergence'-view of FAIR: basic mode (upper graph) and advanced mode (lower graph)

Main output variables

Regional anthropogenic CO_2 emissions permits

This graph shows the regional anthropogenic CO_2 emissions permits emission permits resulting from the selected target scenario and policy parameters. The permit levels start at the present level of emissions or the levels after the first commitment period in case of a target scenario including the Kyoto Protocol. Regional emission permits are the sum of *regional emissions permits per capita* and population numbers defined by the reference scenario.

Regional emissions permits per capita

This graph shows the evolution of the emissions permits per capita (in tons of carbon per capita) from the starting year until the set year of convergence. The pattern of convergence is dependent on the shape of the global emission profile of the target scenario and the settings of the policy variables, in particular the type of convergence (linear or non-linear).

Other output variables

Some other output variables are available in the boxes on the lower left corner. Zooming in and open with right mouse button can view these.

Relative share in emissions

This graph shows how the relative share of regions in global anthropogenic CO_2 emissions (permits) changes over time. During the convergence period the shares in emission permits changes from their 'present' or first commitment period levels (under the Kyoto Protocol) to a share equal to their changing share in world population or to a fixed share based on the shares in the population cut-off year (advanced mode)).

Population and GDP

The population and gdp are determined by the selected reference scenario.

- Population specifies the total number of people in the selected regions (in billions of individuals).
- Total Gross Domestic Product (GDP) is used as the indicator for economic activity in the IMAGE 2 model (in 10E12 US1990$ per year.
- Gross Domestic Product (GDP) per capita is also an indicator for economic activity, on a per capita basis (in 1000 (10E3) US$ per capita per year).
- The Purchase Power Parity (PPP) is an alternative indicator for GDP/capita, based on relative purchase power of individuals in various regions, that is the value of a dollar in any country, i.e. the amount of dollars needed to buy a set of goods, compared to the amount needed to buy the same set of goods in the United States (see Box 3.1).

Emissions and concentrations

- Emissions specify the total anthropogenic CO_2 emissions (in GtC/yr) per region.
- Concentration specifies the regional contribution to the CO_2 concentration (in ppmv) taking into account historical anthropogenic emissions (since 1900).

Total emissions

- Fossil CO_2 emissions for the selected regions (in GtC/yr), indicating the absolute amount of fossil emissions per region. Fossil CO_2 emissions and land-use related CO_2 emissions add up to the total CO_2 emissions.
- Fossil CO_2 emissions per capita for the selected regions (tC/cap.yr).
- Land-use related CO_2 emissions for the selected regions (in GtC/yr). Adds up to the total CO_2 emissions together with fossil CO_2 emissions.

- Rate of change in the *total* anthropogenic CO_2 emissions for the selected regions (%-change per year).

Short-term emissions
This view shows the CO_2 emissions for the period up to the first commitment period under the Kyoto protocol (1995-2010). On the left-hand side the regional anthropogenic CO_2 emissions (GtC/yr) for the regions are depicted, whereas on the right hand side the per capita anthropogenic CO2 emissions are shown. The left-upper box describes whether Annex I either follows its Baseline emissions, the emissions as regulated in the Kyoto Protocol, or the emissions as calculated under the burden sharing regime.

Convergence advanced mode main-view

The convergence view advanced mode can be reached through the 'advanced mode' button on the right part of the screen. This offers you several additional policy variables and access to some extra background views (Figure 5.5).

Policy variables
In the previous paragraph, the policy variables in the basic mode (target selection, starting year and convergence year and type of convergence) are explained. Here, only additional policy variables are explained.

Type of convergence
Compared to the basic mode of convergence, two additional types of convergence are added here:
- **CSE convergence**: with this type of convergence, a sustainable level of global CO_2 emissions is allocated to all regions on a per capita basis first, followed by a linear convergence in per capita emissions for the remaining emissions under the global emission ceiling. You can use a slider to select the level of sustainable global emissions (see below).
- **linear convergence of carbon intensity**: here convergence does not take place on an emissions per capita basis, but on a carbon intensity basis. In the convergence year all regions' carbon intensities (Gg C per US$) are equal.
- **linear convergence of PPP carbon intensity**: like *linear convergence of carbon intensity*, but here calculations are based on carbon intensity measured in terms of emissions per unit of PPP. The Purchase Power Parity (PPP) is an alternative indicator for GDP, based on relative purchase power of individuals in various regions, that is the value of a dollar in any country, i.e. the amount of dollars needed to buy a set of goods, compared to the amount needed to buy the same set of goods in the United States.

Rate of convergence
This parameter only works when the non-linear GCI type of convergence in chosen. The rate of convergence is a purely mathematical value, used for the purpose of gaining insight in the various paths of emission reduction a region can follow. A low rate of convergence implies relatively early reduction activities, showing a rather concave path of emissions. A high rate of convergence implies that reduction activities are postponed, showing a rather convex path of emissions.

Population cap
In case of a population cap per capita emissions in the convergence year are no longer calculated on the basis of the population in that same year, but on the basis of the (share in) population in an earlier, so-called population cut-off year. This implies that a country with a growing population is no longer rewarded with similarly growing emission permits as well. The population cut-off year can be set with the slider, and activated by selecting the population cap option. Regional population

assumptions are based on the baseline scenario (which you can set in the scenario construction-view), developments in population numbers are given in one of the boxes in the lower left corner (zoom in and open with right mouse button).

Sustainable global emission level
This option is only available for the CSE type of convergence. Sustainable CO_2 emissions are related to the level of CO_2 emissions that can be emitted on the very long-term without raising the atmospheric concentrations due to carbon sequestered by natural sinks (in particular oceans). Here the sustainable global emission level can be set in GtC/year. Present fossil CO_2 emissions are about 6 GtC/yr. It is generally believed that these emissions will have to drop by at least 50% to reach sustainable levels. Therefore, the sustainable global emission level has a maximum of 3 GtC/yr. A level of 0 GtC/yr means that the sustainable level is 'turned off.'
In the CSE convergence approach the sustainable CO_2 emissions budget is allocated to all regions on a per capita basis. For this allocation again a population cap in a certain year can be selected.

Main output variables
Compared to the basic mode view, an additional output graph, entitled '*relative share in emissions'*, is added. This graph shows the relative share of a region in total emissions. Since convergence takes place on a per capita basis, the relative share of emissions in the year of convergence will be the same as the relative share in total population (if no population cap is applied). Applying a population cap in a certain year shows that the graphs stabilise from this year onwards.

5.5.2 Convergence (CSE) main view

The convergence (CSE) main view offers additional information on the concept of convergence suggested by the Centre of Science and Development in India. In essence, it is a variant on the original per capita convergence combining convergence with the concept of basic sustainable emission rights.
The view consists of two columns of output graphs: one with per capita emission permits on the left, and one with aggregate regional emission permits on the right. Both columns have a similar set up: the bottom graphs offers total (per capita and regional) emissions permits, which are the sum of the basic rights (top graphs) and the remaining per capita emissions (mid-level graphs). The basic rights (per capita) reflect the setting of the *sustainable global emission level* –slider. From the start of convergence year onwards, this level is a straight line in the *'basic right emissions'* graph, evolving with population developments in the *'basic rights per capita'* graph. The *'total emissions permits'* reflect the global emission ceiling according to the target scenario you have selected with the upper left slider. It is recalculated to a per capita basis in the *'total emissions permits per capita'* graph.
Subtracting *basic right emissions* from *total emissions permits* shows the amount of emissions that is left between the emissions according to the target scenario and the emissions according to a sustainable level. This graph, the *'remaining emissions*' graph, therefore shows you the excess emissions above the sustainable level set, and hence the amount to reduce to go from present to a sustainable emission levels.

5.5.3 Compare Baseline-view in the 'convergence-mode'

This view is very similar to the 'Compare baseline-view' in the 'Increasing participation' mode. It shows the fossil CO_2 emissions and the land-use related CO_2 emissions per region in the small graphs on the left, as well as the total anthropogenic CO_2 emissions (in GtC/yr) per region on the right. Each graph compares the Baseline scenario with the calculated emissions permits scenario for the selected region. The area between the baseline and the emission permits graphs indicates the burden for the selected region. Note that the land-use related emissions are quite small compared to fossil fuel related emissions. You can select the region in the list on the right.

5.5.4 Feasibility reductions-view in the 'convergence-mode'

This view is similar to the feasibility reductions-view in the 'Increasing participation'-mode. The *Feasibility of the emissions permits view* allows for a region by region evaluation of the feasibility of the outcomes of the burden sharing regime by giving some indications of the level of effort needed to restrict a regions' emissions to the level of its emission permits. Real emission reduction efforts may be substantially different in the case of emission trading or the use of other Kyoto Mechanisms.
The first graph (top left) shows the emissions permit level vis a vis a regions' 1990 emissions levels (1990 = 100%) for the total anthropogenic CO_2 emissions. The second graph (bottom left) shows the yearly rate of anthropogenic CO_2 emissions change (%/yr) for the selected region according to the calculated emissions permits. The third and fourth graphs on the right show the absolute (in 1000 gC/US$) and yearly percentage change in the carbon intensity of the economy (Fossil CO_2 emissions permits/Gross Domestic Product) for the selected region according to the calculated emissions permits.
Note: The carbon intensity of the economy is based on the Gross Domestic Product assumptions of the reference Baseline scenario, and thereby does not account for possible decreases in the Gross Domestic Product as a results of the CO_2 emissions reductions.

5.6 Triptych

5.6.1 Triptych basic mode main view

The triptych mode offers you the option to develop your own triptych scenario. Triptych is a method of international burden sharing through a sector-oriented approach. It is in many ways a bottom-up approach, although it may be combined with top-down set emissions targets. The method was used in supporting the decision making on burden sharing within the EU.
The triptych mode involves three major sectors: the domestic sector, the industrial sector and the power sector. Paragraph 3.5 offers you some more background on these sectors. For each of these sectors a certain scenario can be set, while FAIR calculates an overall path of anthropogenic CO_2 emissions permits.
The main view of the triptych mode consists of two output graphs in the middle, accompanied with a menu bar at the left-hand side and a region selector at the right hand side (Figure 5.6).

Policy variables

Reference scenario
At the top left of the screen, you will find the setting of the reference scenario. This is the baseline, to which reduction settings are related, and also described the developments in population (domestic emissions), industry valued added (industrial emissions) and gross domestic product (gdp) (power emissions).

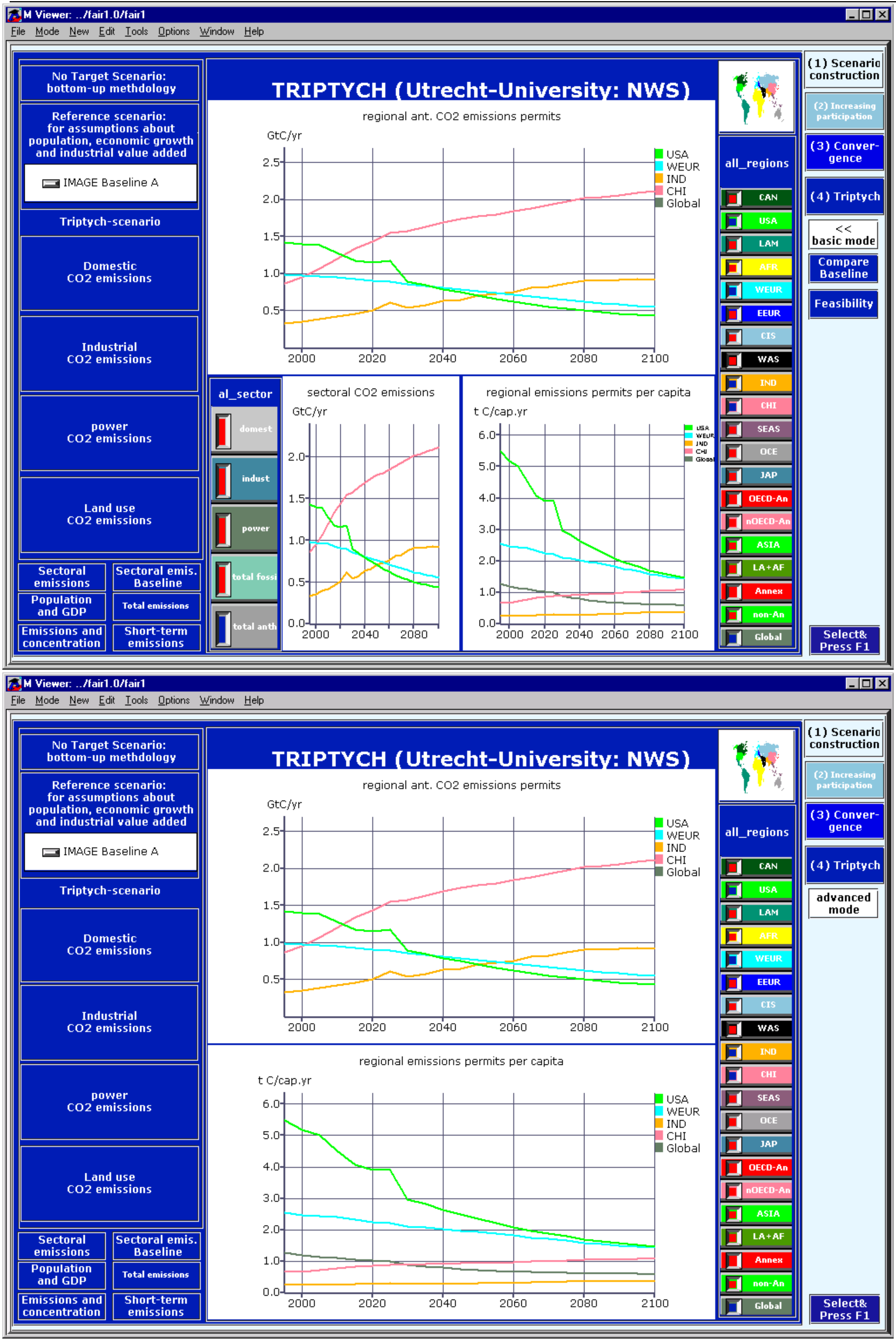


Figure 5.6: The 'Triptych'-view of FAIR: basic mode (upper graph) and advanced mode (lower graph)

Domestic emissions

This box provides you the opportunity to change the settings of the domestic CO_2 emissions. Zoom in and open by using the right mouse button. Domestic emissions reductions are done in convergence in the triptych methodology. This implies choosing a year of convergence (top right) as well as the amount of absolute CO_2 emissions to be reduced in a percentage compared to 1990 (settings on the top left). The rate of convergence is described by a constant yearly emission reduction factor for a region, which is calculated using the difference of the absolute regional emissions level in the start year of convergence and the target emission level in the convergence year, as well as the time-period between those two years. The target emission level in the convergence year is calculated as the population multiplied by the global domestic CO_2 emissions per capita in the convergence year (see paragraph 3.4). Evaluation of your settings is available in the two graphs, one of the domestic CO_2 emissions per capita and another of the absolute domestic CO_2 emissions. Close all boxes and zoom out by using the right mouse button, to be able to change the settings in the other sectors as well.

Note: There is the additional option with the most upper slider, to use the baseline emission scenario developments of the domestic emissions, instead of a convergence in the domestic emissions (choose: follow baseline).

Industrial emissions

This box provides you the opportunity to change the settings of the industrial emissions. Zoom in and open by using the right mouse button. Industrial emissions (Em_{ind}) depend on the industrial growth rate and the projected energy efficiency improvement and the de-carbonisation improvements, using the so-called Kaya identities:

$$Em_{ind}(r,t) \;=\; IVA(r,t)\,.\left[\frac{En_{ind}(r,t)}{IVA(r,t)}\;.\;\frac{Em_{ind}(r,t)}{En_{ind}(r,t)}\right]$$

with: Industry Value Added (*IVA*) represents the share of industry in the economy (in 1990 dollars). Industrial energy intensity is than defined by En_{ind}/IVA, with En_{ind} the industrial primary energy use. The carbon intensity of the Industrial sector is defined by the carbon intensity of industrial primary energy use, i.e. Em_{ind}/ En_{ind}. (see also section 3.5).

This can also be translated into growth trajectories of: (i) the IVA in the reference scenario compared to the 1990 values; (ii) the energy intensity (based on the yearly rate of energy efficiency improvements), and (iii) the carbon intensity (based on the yearly rate of de-carbonisation).

Growth of IVA: The growth of the IVA is described by the simulated pathway of the reference scenario, which is shown in the right-upper box. Many regions will have rather high levels of industrial growth in the various baseline scenarios.

The yearly efficiency improvement of the industrial sector, and the de-carbonisation rate for the industrial sector (left-hand boxes) are policy variables in the FAIR model:
Energy efficiency improvements: Efficiency improvements have a default setting of 2.5 % for all regions except for Western Europe, Japan and Oceania, since these regions already are relatively efficient (so less improvements are achievable). These regions are set to be able to improve at a rate of 1.5%/yr. The improvement rates for *all* regions however will ultimately converge to 1.5 %/yr, when regions with higher rates of energy improvements reach the level of the most efficient regions (i.e. Japan and Western Europe) in 2030. You can change the settings by dragging the columns. If

you change the energy efficiency improvements of Western Europe and Japan, the convergence year changes, and also affects the energy efficiency improvements of the other regions.
De-carbonisation rate: Default setting for all regions is a de-carbonisation rate of 0.25 %/yr. You can change the settings by dragging the columns.

Close the main box by using the right mouse button, to be able to change the settings in the other sectors as well.

Power emissions
This box provides you the opportunity to change the settings of the power emissions. Zoom in and open by using the right mouse button. This view enables you to change the energy efficiencies, de-carbonisation and the CO_2-free electricity rates in the power sector.
Power emissions (Em_{pow}) depend on the industrial growth rate and the projected energy efficiency improvement and the de-carbonisation improvements, using the so-called Kaya identities.

$$Em_{pow}(r,t) = GDP(r,t) \cdot \left[\frac{En_{pow}(r,t)}{GDP(r,t)} \cdot \frac{EnFossil_{pow}(r,t)}{En_{pow}(r,t)} \frac{Em_{pow}(r,t)}{EnFossil_{pow}(r,t)} \right]$$

with: $GDP(r,t)$ is total Gross Domestic Production, $En_{pow}(r,t)/ GDP(r,t)$ represents the convergence efficiency of the power sector, and the changes in the carbon intensity of the Power sector: (i) the share of CO_2-free sources in the primary energy use (i.e. by use of renewables and nuclear) ($EnFossil_{pow}(r,t) / En_{pow}(r,t)$) and (2) the carbon intensity of the fossil fuel based share in primary energy use, related to the fossil fuel mix ($Em_{pow}(r,t)/ EnFossil_{pow}(r,t)$) (see also section 3.5)

This can also be translated into growth trajectories (all in %/yr) of: (i) the Gross Domestic Production in the reference scenario compared to the 1990 values; (ii) the converge efficiency (based on the yearly rate of energy efficiency improvements, and (iii) the CO_2-free share in electricity production, and (iv) the change in index value of the carbon intensity (based on the yearly rate of de-carbonisation of the fossil fuel-based share in primary energy use).

Gross Domestic Product (GDP): The growth of the GDP is described by the simulated pathway of the reference scenario, which is shown in the right-upper box.

The yearly efficiency improvement of the power sector, and the de-carbonisation rate for the industrial sector, and the CO_2 free technology rate are policy variables in the FAIR model:
Energy efficiency improvements: For this triptych scenario a yearly efficiency improvement of 2.5 % is assumed for all regions, except for Western Europe, Japan and Oceania. The regions Western Europe, Japan and Oceania are assumed to improve the end-use efficiency by 1.5 % per year (similar as in the industrial sector). Similar as for the industrial sector, the improvement rates for *all* regions of the power sector however will ultimately converge to 1.5 %/yr, when regions with higher rates of energy improvements reach the level of the most efficient regions (i.e. Japan and Western Europe) in 2030. You can change the settings by dragging the columns. If you change the energy efficiency improvements of Western Europe and Japan, the convergence year changes, and also affects the energy efficiency improvements of the other regions.
de-carbonisation rate: Default setting for all regions is a de-carbonisation rate of 0.25 %/yr. You can change the settings by dragging the columns.
CO_2 free technology rate: The share of 'CO_2-free' electricity generation (renewables, nuclear and CO_2 removal) is assumed to increase by 0.4 % per year from 1990 to 2100 for all regions. Generally speaking, developing countries have relatively more potential for biomass-based electricity production than industrialised countries, which will tend to rely relatively more on alternative forms of renewables. A further reduction of emissions is assumed to be obtainable by improvement of energy conversion and a shift to fuels with a lower carbon content.

Close the main box by using the right mouse button, to be able to change the settings in the other sectors as well.

Land-use emissions
A fourth box of decision options is available through land-use emissions. These emissions are strictly no part of the triptych methodology, but add to a realistic total of anthropogenic CO_2 emissions. In the land-use emissions box you can change the land-use emission scenario through the slider. The slider gives six options:

1. use of **baseline emissions**: follows the baseline (reference) scenario;
2. use of **IPCC IS92a scenario**: somewhat older IPCC scenario, based on earlier IPCC work and Worldbank. Intermediate scenario compared to the newer A1 and B1 scenarios;
3. use of **IMAGE 2.1 IPCC/SRES A1 scenario**: this option uses the IMAGE 2.1 IPCC/SRES A1 scenario for land-use change emissions;
4. use of **IMAGE 2.1 IPCC/SRES B1 scenario**: this option uses the IMAGE 2.1 IPCC/SRES B1 scenario for land-use change emissions;
5. use of a '**no deforestation scenario'**: in this scenario no deforestation is halted before 2010, and the land-use emissions return to zero by 2010.
6. use of an 'own **land-use scenario'**: you can construct your own scenario in the blue box, by dragging the graph line.

The regional land-use emissions for the last two options are calculated using a time-dependent distribution function derived IMAGE 2.1 land-use change data.

Main output variables
The two graphs show you the main output (results) of the model calculation:
- regional anthropogenic CO_2 emissions of the selected regions (in GtC/yr) (top), i.e. the sum of the CO_2 emissions by fossil fuel combustion and industrial production and the CO_2 emissions by land use changes.
- regional anthropogenic CO_2 emissions per capita (tC/cap.yr).

You can select the regions projected by using the region selector in the "*all regions*" column.

Other output variables
The basic mode offers several other output variables in the bottom left boxes of the view. Five boxes are available, which you can all select These can be viewed by zooming in and open with right mouse button.

Sectoral emissions
This box includes the graph showing the emissions for one selected region, as an accumulation of the three sectors domestic, industrial and power, but not including land-use emissions. The graph hence gives an indication of the size of emissions per sector for one particular region.

Sectoral emissions Baseline
This view shows per region both the domestic, industrial and power CO_2 emissions as well as the total fossil CO_2 emission permits (in GtC/yr). Each graph compares the calculated regional emissions with the emission levels in the selected baseline scenario.

Population and GDP
The population and gdp are determined by the selected reference scenario.
- Population specifies the total number of people in the selected regions (in billions of individuals).

- Total Gross Domestic Product (GDP) is used as the indicator for economic activity in the IMAGE 2 model (in 10E12 US1990$ per year.
- Gross Domestic Product (GDP) per capita is also an indicator for economic activity, on a per capita basis (in 1000 (10E3) US$ per capita per year).
- The Purchase Power Parity (PPP) is an alternative indicator for GDP/capita, based on relative purchase power of individuals in various regions, that is the value of a dollar in any country, i.e. the amount of dollars needed to buy a set of goods, compared to the amount needed to buy the same set of goods in the United States (see also Box 3.1).

Emissions and concentrations

- Emissions specify the total anthropogenic CO_2 emissions (in GtC/yr) per region.
- Concentration specifies the regional contribution to the CO_2 concentration (in ppmv) taking into account historical anthropogenic emissions (since 1900).

Total emissions

- Fossil CO_2 emissions for the selected regions (in GtC/yr), indicating the absolute amount of fossil emissions per region. Fossil CO_2 emissions and land use related CO_2 emissions add up to the total CO_2 emissions.
- Fossil CO_2 emissions per capita for the selected regions (tC/cap.yr).
- Land use related CO_2 emissions for the selected regions (in GtC/yr). Adds up to the total CO_2 emissions together with fossil CO_2 emissions.
- Rate of change in the *total* anthropogenic CO_2 emissions for the selected regions (% change per year).

Short-term emissions

This view shows the CO_2 emissions for the period up to the first commitment period under the Kyoto protocol (1995-2010). On the left-hand side the regional anthropogenic CO_2 emissions (GtC/yr) for the regions are depicted, whereas on the right hand side the per capita anthropogenic CO_2 emissions are shown.

5.6.2 Triptych advanced mode main-view

The triptych view advanced mode can be reached through the ‘advanced mode’ button on the right part of the screen. This offers you several additional policy variables and access to some extra background views. Compared to the basic view, an additional variable is also depicted here: sectoral CO_2 emissions, showing the emissions of the three sectors domestic, industrial and power, as well as the fossil CO_2 emissions and the total anthropogenic CO_2 emissions. You can select the sectoral emissions projected by using the sector selector in the al_sector column.

5.6.3 ‘Compare permits with baseline’ -view

This view shows the fossil CO_2 emissions, land-use related CO_2 emissions and the total anthropogenic CO_2 emissions (in GtC/yr) according to the Baseline scenario and the calculated emissions permits scenario for the selected region. This view is very similar to the ‘Compare baseline-view’ in the ‘Increasing participation’-mode and in the ‘Convergence’-mode. It shows the fossil CO_2 emissions and the land-use related CO_2 emissions per region in the small graphs on the left, as well as the total anthropogenic CO_2 emissions (in GtC/yr) per region in the large graph. Each graph compares the Baseline scenario with the calculated emissions permits scenario for the selected region. The area between the baseline and the emission permits graphs indicates the burden that the selected region should take. The emissions permits scenario starts in 2000 for the Annex-I regions. Note that the land-use related emissions are quite small compared to fossil fuel related emissions. You can select the region in the list on the right.

5.6.4 Feasibility view

This view is similar to the feasibility reductions-view in the 'Increasing participation'-mode and in the 'Convergence'-mode. It shows the consequences of your settings to several more or less economic parameters for individual regions. First select from the list of regions one country you would like to investigate.

- The left column shows the emissions reductions compared to the 1990 levels (1990 = 100%) for the total anthropogenic CO_2 emissions, as well as the yearly rate of anthropogenic CO_2 emissions change (%/yr) for the selected region according to the calculated emissions permits scenario;
- The right column shows the carbon intensity of the economy (Fossil CO_2 emissions permits/Gross Domestic Product) (in 1000 gC/US$) as well as its rate of change (%/yr) for the selected region according to the calculated emissions permits scenario[18].

5.7 Frequently Asked Questions (FAQs)

- How do I change the values of the graphs?
You can not change the values of all the graphs. Some graphs show the output of calculations and cannot be changed directly while other graphs show input variables. The last can be changed as follows: Go with the pointer to the line, click on the left button of the mouse and drag the line in the way you want to change the values. If this doesn't work, click the right mouse button and select *Edit free* from the menu.

- How can I change the values beyond the range of the graph?
Select the graph and click on the right button of your mouse. Click on Scale Y. Change the range of the graph by pressing on the left button of the mouse and drag the graph up or down. If the range of the graph is OK, click on the right button of the mouse again and click on *Edit free*. Now you can (again) change the values of the graph as discussed above (if the graph shows input).

- *Is there a warning if one makes inconsistent assumptions?*
No. We, therefore, advise policy makers to use the software together with scientific advisors who may warn in the case of "inconsistent" or "unrealistic" assumptions. Another way to check the consistency and plausibility of a particular scenario is to use more sophisticated models to try to reproduce the constructed scenarios and evaluate with what (policy) assumptions the scenario would be feasible or plausible.

- *What to do if GIM complains about colours?*
GIM tries to allocate at least 180 colours. If your machine does not support so many colours then GIM starts up with a warning that it could only allocate x colours.

- The application gets stuck when I try to load a scenario with the scenario manager. What should I do?
This is a known error caused by a combination of the scenario manager and the start-up program startFAIR.exe. We are working on a solution for this error. Meanwhile, please start the FAIR model

[18] The final carbon intensity of the economy uses the Gross Domestic Product trend according to the Baseline scenario, and thereby does not account for possible decreases in the Gross Domestic Product as a result of the CO_2 emissions reductions.

by double clicking the file *fair.bat*, instead of the startFAIR.exe, if you want to use the scenario manager.

- *I have loaded a scenario, but only a part of the figures appear on the screen. How do I get the other figures?*
If you load a new scenario you will only see the inputs. To derive the figures of the other views, the outputs, you will have to rerun the model.

- *I get an error message: "Critical error". What should I do?*
This is an internal error of the M-interface. If you click yes or cancel, the whole application will quit and you will have to start up FAIR again. In most cases though, you can simply go on with FAIR by ignoring the message. Simply drag the message out of sight and go on with your FAIR session.

6 GUIDED TOUR OF FAIR

This Chapter gives a nutshell overview of the functioning of the FAIR model by subsequently highlighting some of the main results associated with FAIR's four basic modes.

The S450 Kyoto scenario

As an example of using the scenario construction mode of FAIR, the analysis shown here is exploring the construction of an emissions scenario which fulfils the (long-term) climate targets as formulated by the Dutch ministry of Housing, Spatial Planning and the Environment (VROM):

- Global-mean surface temperature increase relative to 1900 less than 2.0 ^{o}C at the long-term.
- Rate of global temperature increase less than 0.1 ^{o}C/decade.
- Global-mean sea level rise less than 50 cm at the long-term.

This scenario is hereafter referred to as *S450 Kyoto* scenario. This guided tour shows some results of the *S450* scenario.

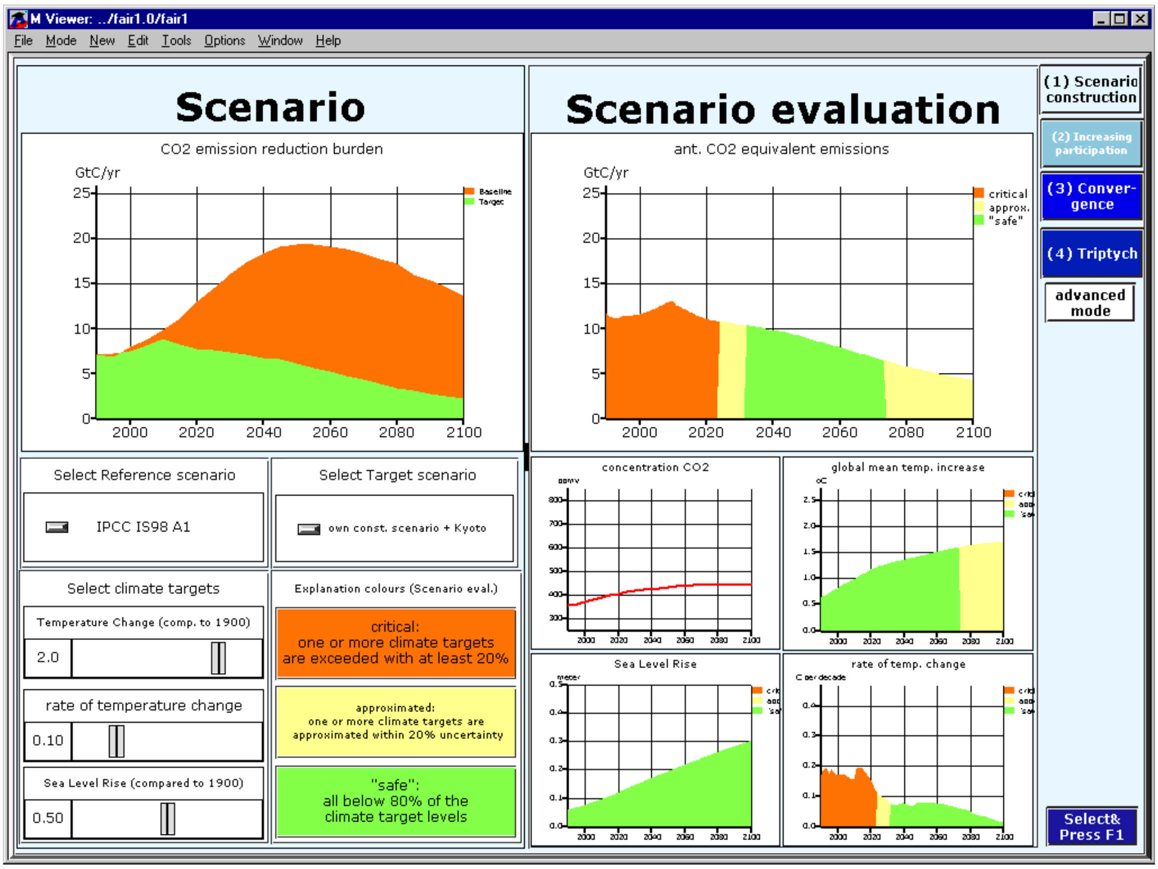


Figure 6.1: The scenario construction main view of the S450 Kyoto scenario.

Fossil and land-use CO_2 emissions

The S450 Kyoto scenario aims at a stabilisation of the CO_2 concentration at 450 ppmv. The emissions assumptions are:

- **Period 1990-2013**
  - *Annex I:* CO_2 emissions from fossil fuel use and industrial production follow the Kyoto Protocol emissions reductions.
  - *non-Annex I:* Fossil CO_2 emissions follow the assumed baseline emissions scenario, namely: *IPCC A1* emissions scenario.
- **After 2010**
  - Global *fossil* CO_2 emissions decrease with more than 50% compared to present levels.
  - *Land use* related CO_2 emissions go to zero, due to a halt of deforestation by 2050.

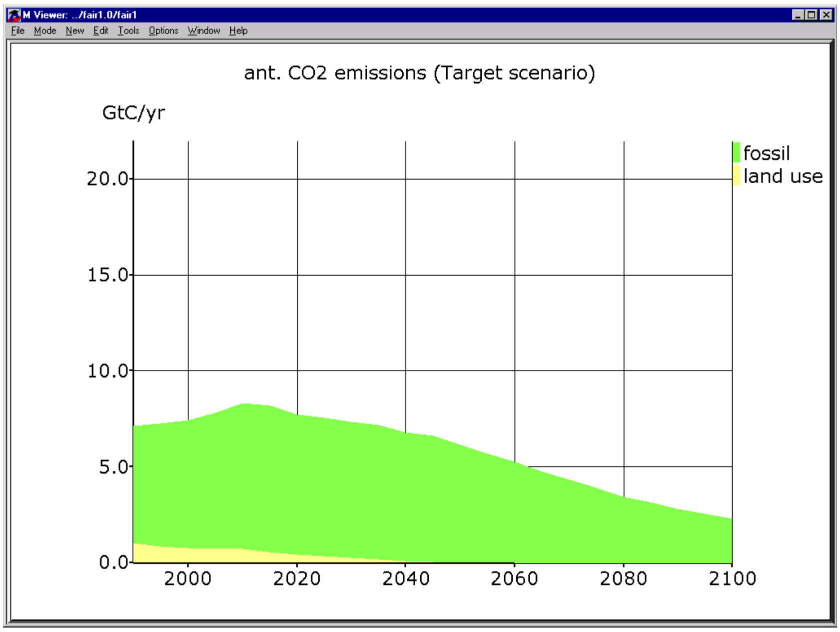


Figure 6.2: The fossil and land-use related CO_2 emissions for the S450 Kyoto scenario (view: Fossil CO_2 emissions).

Other greenhouse gases

For the emissions of the other greenhouse gases the following assumptions were made:
Methane (CH_4): the energy-related CH_4 emissions are strongly reduced due to an 80-90% abatement of the CH_4 leakage's from coal mining and oil production, whereas for the anthropogenic land-use related emissions a slight increase is assumed until 2030, and then a decreasing trend until the present 1990 levels by 2100.
Nitrous dioxide (N_2O): the land-use related N_2O show a similar pattern.
Halocarbons: the emissions of halocarbons follow the IMAGE 2.1 IPCC/SRES A1 emissions scenario.

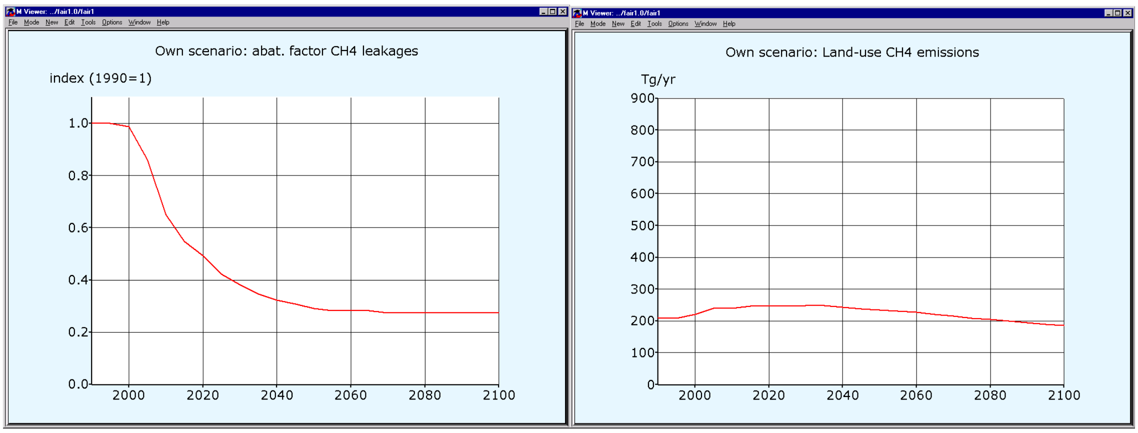


Figure 6.3: The energy- and land-use related CH_4 emissions for the S450 Kyoto scenario. (view: anthrop. CH_4 emissions)

CO_2 equivalent concentration

These emissions assumptions lead to a stabilisation of the CO_2 equivalent concentration on a level of approximately 540 ppmv.

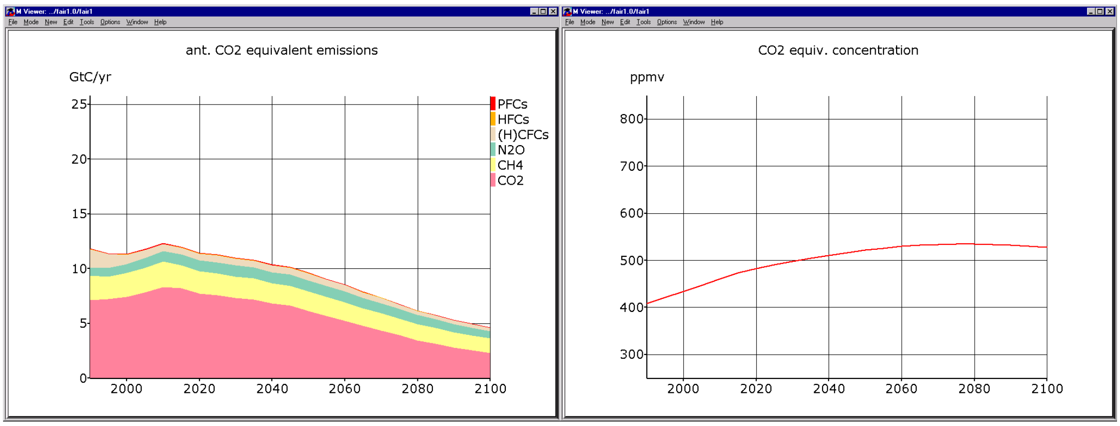


Figure 6.4: CO_2 equivalent emission stabilises at approx. 540 ppmv (view: all ghg emissions).

Climate impacts

The figure shows that for this scenario the formulated climate targets in terms of global temperature and sea level rise are achieved.

Where the climate indicators are all below 80% of the climate target levels, the graph is green, when targets are approximately met, within 20% uncertainty, the graph is yellow, and if one or more climate targets are exceeded with at least 20%, the graph is red.

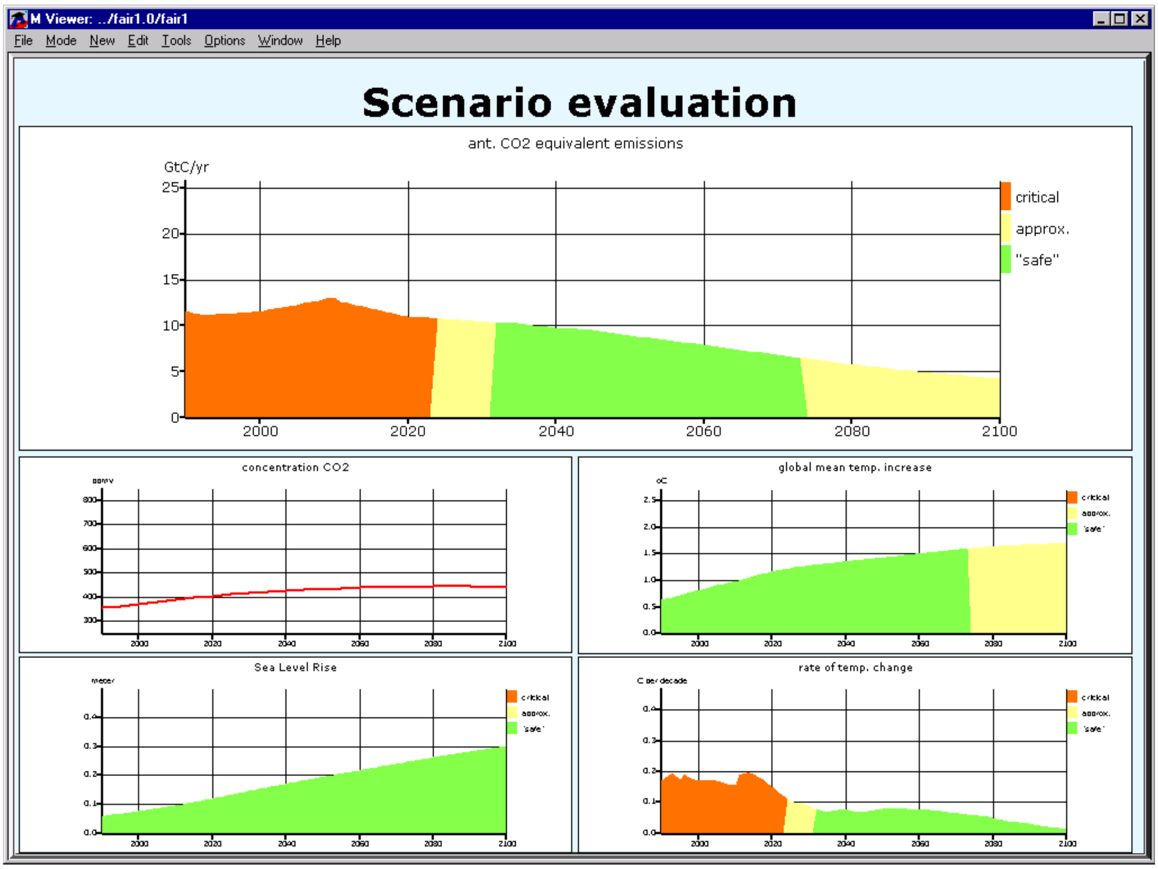


Figure 6.5: The climate impacts of the S450 Kyoto scenario.

Exceedance of the rate of temperature change

Rate of temperature change exceeds 0.1 °C per decade by 2030 (indicated in red).

Cause: The decrease in the anthropogenic SO_2 emissions after 1995 directly leads to an increase in the rate of global mean surface temperature increase, since the cooling effect of the present levels of sulphate aerosols in the atmosphere diminishes. The scenario assumes a moderate desulphurisation, i.e. a decreasing desulphurisation factor from 1.0 by 1990 till 0.8 by 2015, and then it remains at the same level until 2100.

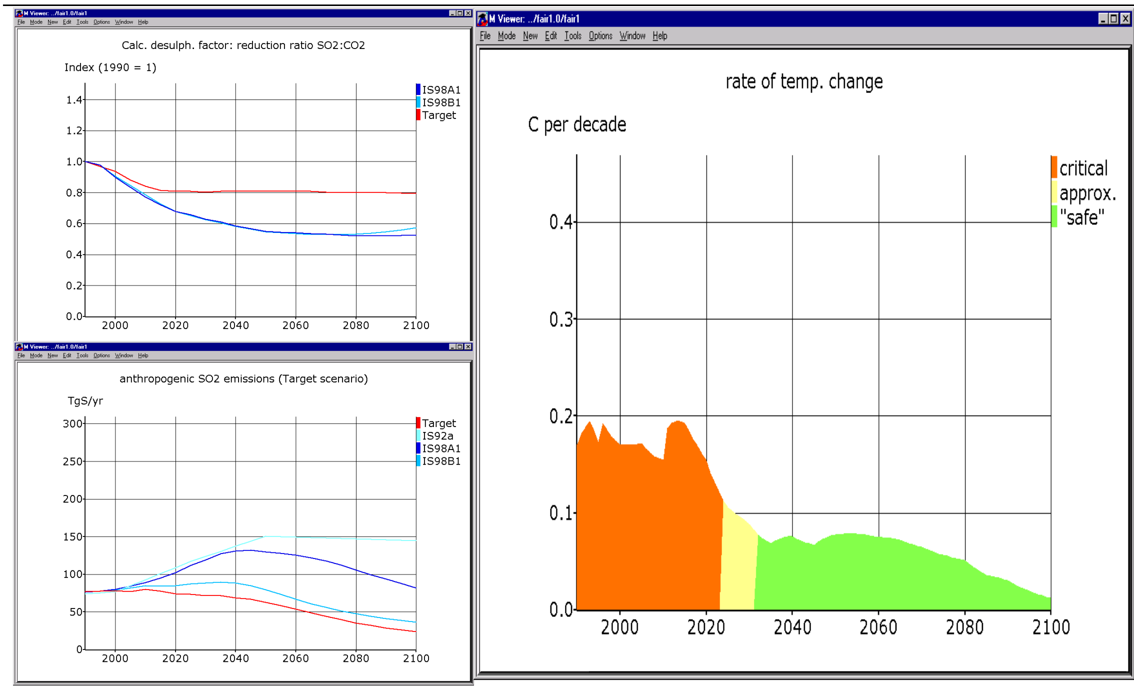


Figure 6.6: Exeedance of 0.1 ^{o}C/decade threshold till 2030

Desulphurisation assumptions are critical

The sensitivity of the rate of global temperature increase to the future anthropogenic SO_2 emissions can be illustrated by assuming constant 1990 emissions for the time period 1990-2100, or assuming the IPCC B1 desulphurisation trend.

In the constant SO_2 emission case, the rate of global temperature increase decreases below the 0.1 ^{o}C/decade level by 2025 (2030 for the reference case), whereas in the IPCC B1 desulphurisation case target will not be achieved before 2035.

Concluding:

It is difficult to achieve the 0.1 ^{o}C/decade threshold in the coming decades.

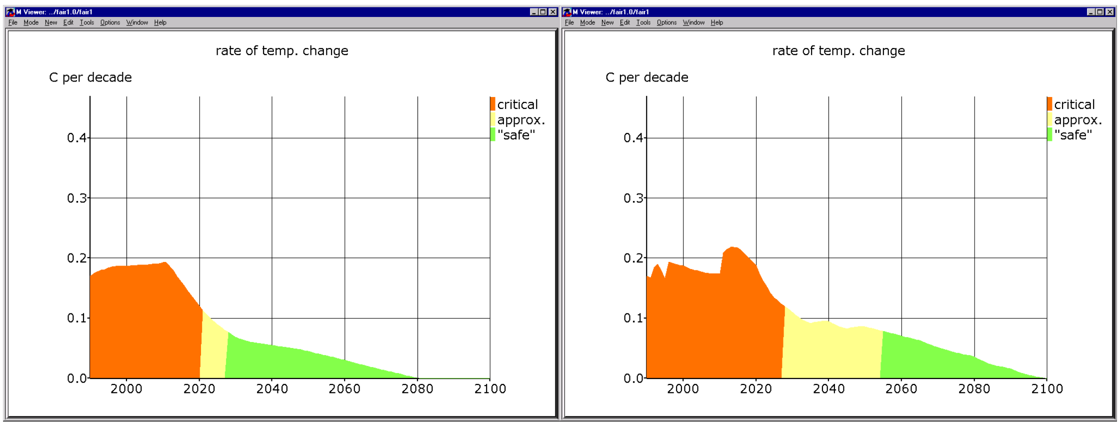


Figure 6.7: The rate of temperature change exceeds 0.1 ^{o}C/decade until 2025 for constant SO_2 emisions (left) or until 2035 for the desulpharisation in the B1 scenario where the rate of temperature increase approaches even the 0.2 ^{o}C/decade (right).

Model uncertainty

The results of this analysis are surrounded with large uncertainties. The major source of uncertainty in the climate projections is possibly the climate sensitivity, i.e. the long-term (equilibrium) change in global mean surface temperature due to a doubling of CO_2 levels. The central IPCC value is 2.25

$^{o}C/Wm^{-2}$, with an IPCC range of [1.5; 4.5] $^{o}C/Wm^{-2}$. In our example, a central value of 2.35 $^{o}C/Wm^{-2}$ is used.
The figure shows that for a simulation run with a climate sensitivity parameter of 4.5 $^{o}C/Wm^{-2}$ none of the climate targets are achieved.

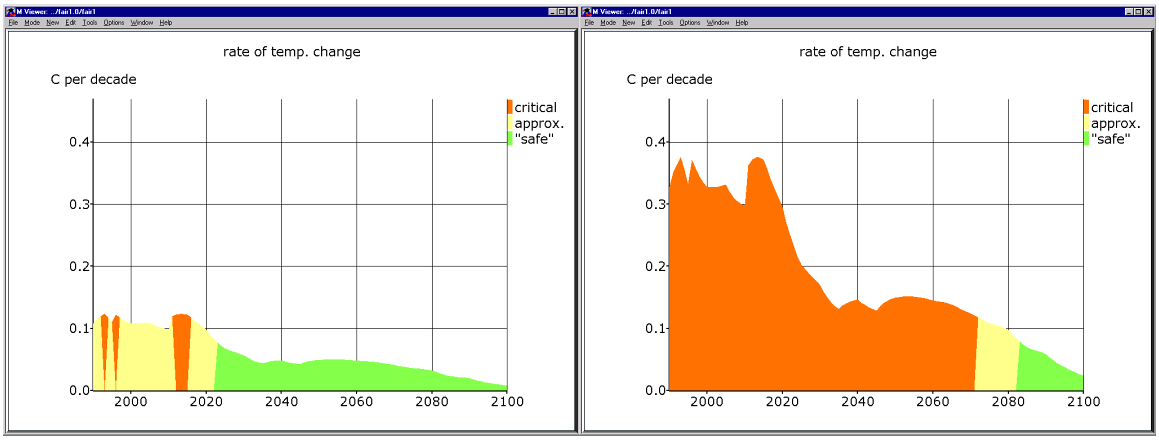


Figure 6.8: An example of the model uncertainty: rate of temperature increase for a climate sensitivity parameter of 1.5 $^{o}C/Wm^{-2}$ (left), and a climate sensitivity parameter of 4.5 $^{o}C/Wm^{-2}$ (right).

Conclusions I

1. Kyoto limits options for limiting the rate of global mean temperature increase:
   - the 0.1 ^{o}C/decade target will be difficult to achieve, certainly before the year 2030
2. Future sulphur emissions largely determine the rate of global mean surface temperature increase
3. The set of climate goals as formulated by the Dutch ministry of the Environment implies a stabilisation of:
   - CO_2 concentration at about 450 ppmv
   - CO_2 *equivalent* concentration at about 540 ppmv (twice pre-industrial CO_2 level)
4. Results are surrounded by large scientific uncertainties

Emission reduction burden
When you have constructed a scenario, you can also see the resulting emission reduction burden.
In this example the IMAGE 2.1 IPCC/SRES A1 emissions scenario is chosen as the **baseline**. This is indicated in **red**.
The allowed global emissions profile (the **target** scenario) is described by the emissions scenario as constructed before, namely the *S450 Kyoto* scenario. This is indicated in **green**.
The required emission **reduction burden** is then determined by subtracting the baseline emissions from the emissions allowed by the target scenario.
In the rest of this tour we will focus on the problem of sharing this reduction burden among the various countries/regions. The burden sharing will be done in three different ways: through increasing participation, through convergence and with the triptych approach.

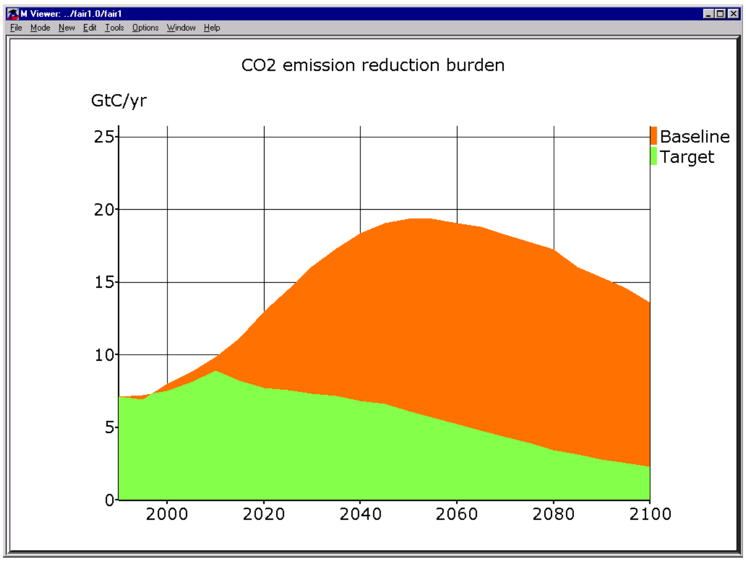


Figure 6.9: Global emission profiles of IMAGE 2.1 IPCC/SRES A1 emissions scenario and the S450 Kyoto scenario for the period 1990-2100. The difference between the two scenarios indicates the emission reduction burden.

The Brazilian approach case

The Brazilian approach of burden sharing is based on a region's relative contribution to temperature change. When applied on a global scale (instead of to Annex I as in the original Brazilian proposal), the implication is that after 2012 all regions/countries contribute to global emission control regardless of their level of economic development.

This does not seem reasonable for developing countries, as it does not leave them room for increase in emissions after 2012. This problem is not typical for the Brazilian approach but for every burden sharing approach that immediately involves all parties in the burden sharing on the basis of their relative contribution to the problem.

Concluding:

Introducing a threshold for participation could account for the need for and right to economic development for developing countries.

Note: using a threshold based on the absolute contribution to temperature increase, however, is a disadvantage for large regions/countries. Instead, a per capita approach for burden sharing and another threshold indicator, like per capita income, can be used.

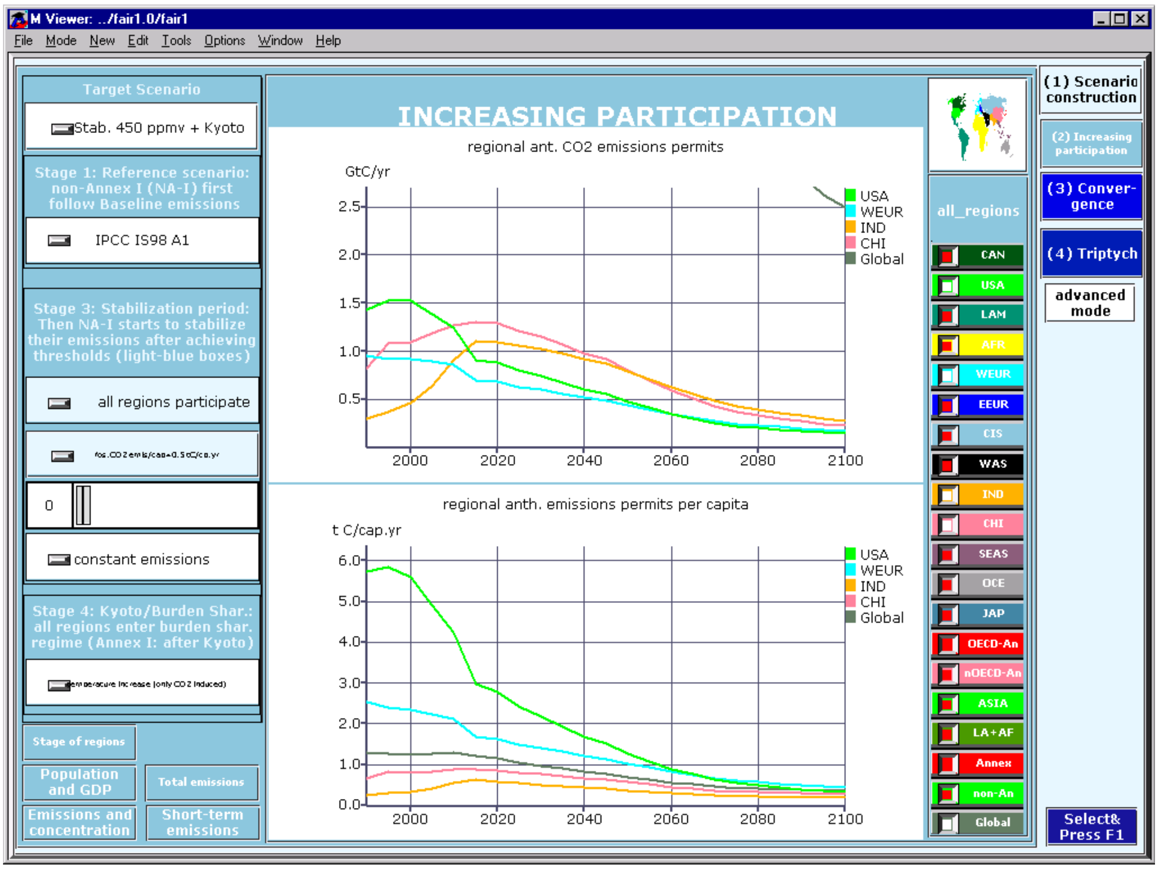


Figure 6.10: Regional CO_2 emission permits for USA, Western Europe (WEUR), Africa (AFR), India (IND) and China (CHI) for the Brazilian approach case and the S450 Kyoto scenario.

Threshold on income

As an example of an income threshold, the figure shows the following setting:

- S450 Kyoto scenario
- non Annex I regions follow IMAGE 2.1 IPCC/SRES A1 scenario until they reach an income threshold of 30% of 1990 Annex I per capita income (ca. $10.800 per capita)
- burden sharing is based on per capita anthropogenic CO_2 emissions

The upper graph shows that in this situation China would start participating only in 2055, India not before 2075. This leads to extremely high emissions for China and India, making it almost impossible to achieve the emission targets. Also, the global emission ceiling for reaching 450 ppmv is violated.

Concluding:

In case of stringent climate goals an income threshold for participating in the burden sharing may not work. Under these climate goal conditions major developing regions will have to participate within a number of decades at much lower levels of per capita income than the average 1990 Annex I.

Figure 6.11: Regional CO_2 emission permits for USA, Western Europe (WEUR), Africa (AFR), India (IND) and China (CHI) for the 30% of 1990 Annex I per capita income case.

Multi-stage approach

In order to have early participation, while leaving room for an increase in emissions for economic development, we will adopt the following multi-stage approach:

- Until 2013 Annex B regions fulfil their targets under the Kyoto protocol, while non-Annex B regions follow baseline A.
- After 2012 all non-Annex B countries adopt de-carbonisation targets of 4% per year.
- non-Annex B countries join the burden sharing when their per capita emissions reach the world average level.
- The burden sharing is based on per capita emissions levels.

The use of a threshold based on world average per capita emissions, rewards both emission reductions by industrialised as well as efforts by developing regions to control the growth in their emissions.

Concluding:

This case shows that China, India and Africa would first be allowed to increase their emissions until 2025, 2030 and 2040 respectively. At the same time, the emission space for the EU and in particular the USA would diminish sharply. However, this will not only demand substantial efforts from developed countries, but also from developing countries, compared to their baseline developments.

Figure 6.12: A multi-stage approach for increasing participation

Convergence

An alternative approach to burden sharing is convergence. Instead of focussing on emission reductions, convergence starts from the idea that the atmosphere is a global common to which each human being is equally entitled. Differentiation of future commitments should be based on an equitable allocation of emission rights. By way of compromise between ideal and reality, the convergence approach allows for a transition period, in which per capita emission rights converge from status quo to equal per capita levels.

Combined with a reduction of global emissions, this approach is also known as "Contraction and Convergence".

We used the FAIR model to analyse the regional distribution of emission rights resulting in convergence per capita CO_2 between 2012 and 2030 with a CO_2 emission profile for stabilising CO_2 concentrations at 450 ppmv.

Concluding:

Convergence in per capita emission rights implies a further strong reduction in allowable emissions for Annex B regions after the Kyoto period, in particular for the USA. At the same time, there is only limited scope for non-Annex-B regions to increase their per capita emissions and in fact, in case of Latin America, it already decreases. In some developing regions, like India and Africa, there may be "tropical air" as their emission rights exceed baseline levels. Over the long term, after full convergence in emission rights, the gap between baseline emissions and emission rights is usually larger for developed than developing regions.

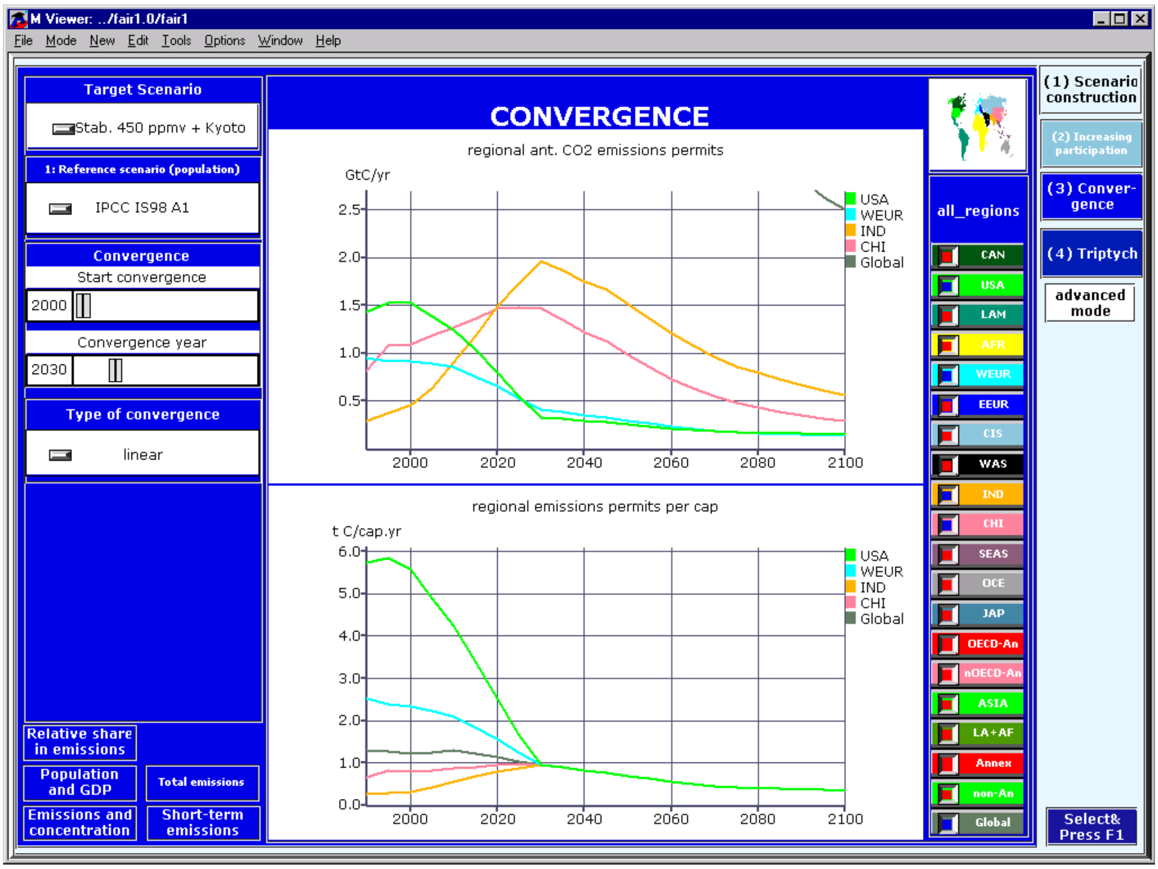


Figure 6.13: Burden sharing in the 'Convergence' mode, with a linear convergence of CO_2 emissions between 2012 and 2030.

The triptych approach

The last option for burden sharing we present is the triptych approach. Triptych is an example of a *bottom-up* approach; i.e. emission permits are calculated by applying specific rules to each of the following sectors:

- domestic sector
- industrial sector
- power generation sector

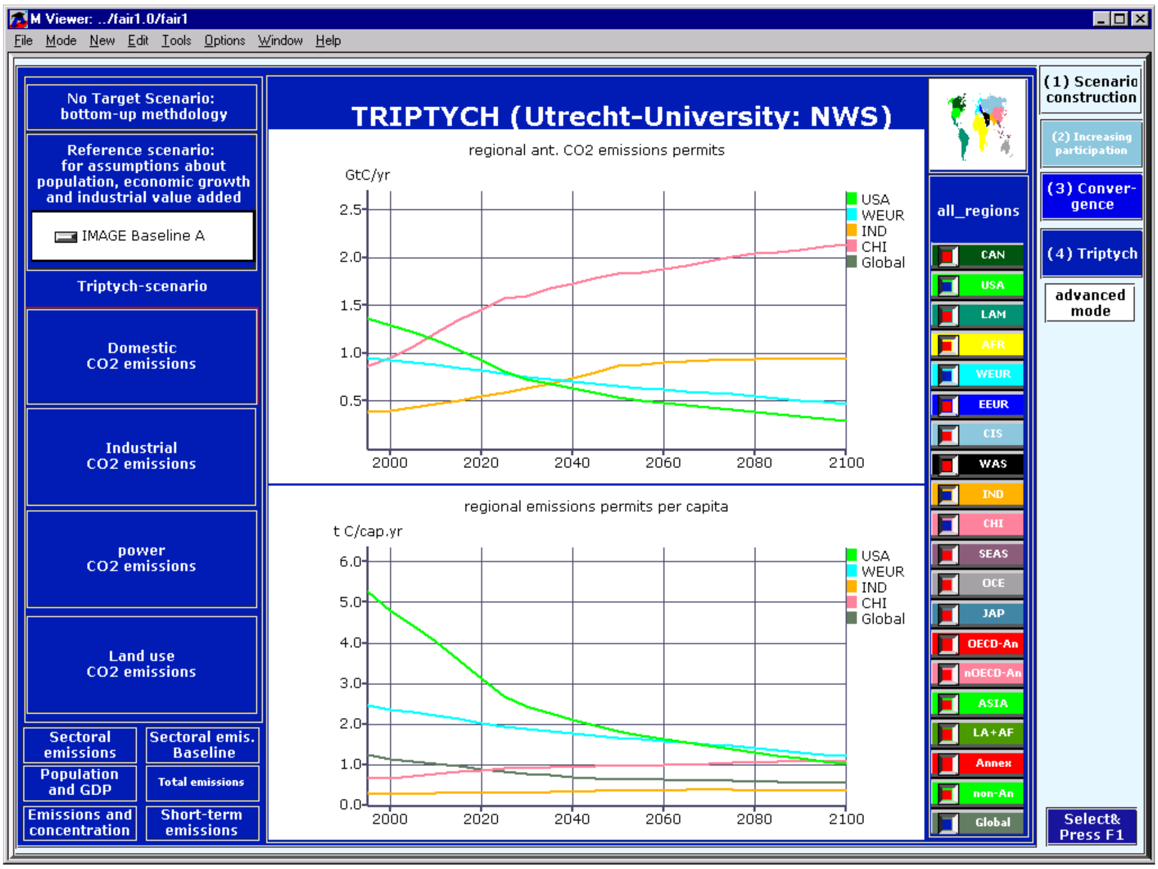


Figure 6.14: The basic view of the Triptych mode

The domestic sector

The assigned amounts of emissions are based on convergence per capita in 2050, assuming total domestic emissions at 1990 level.

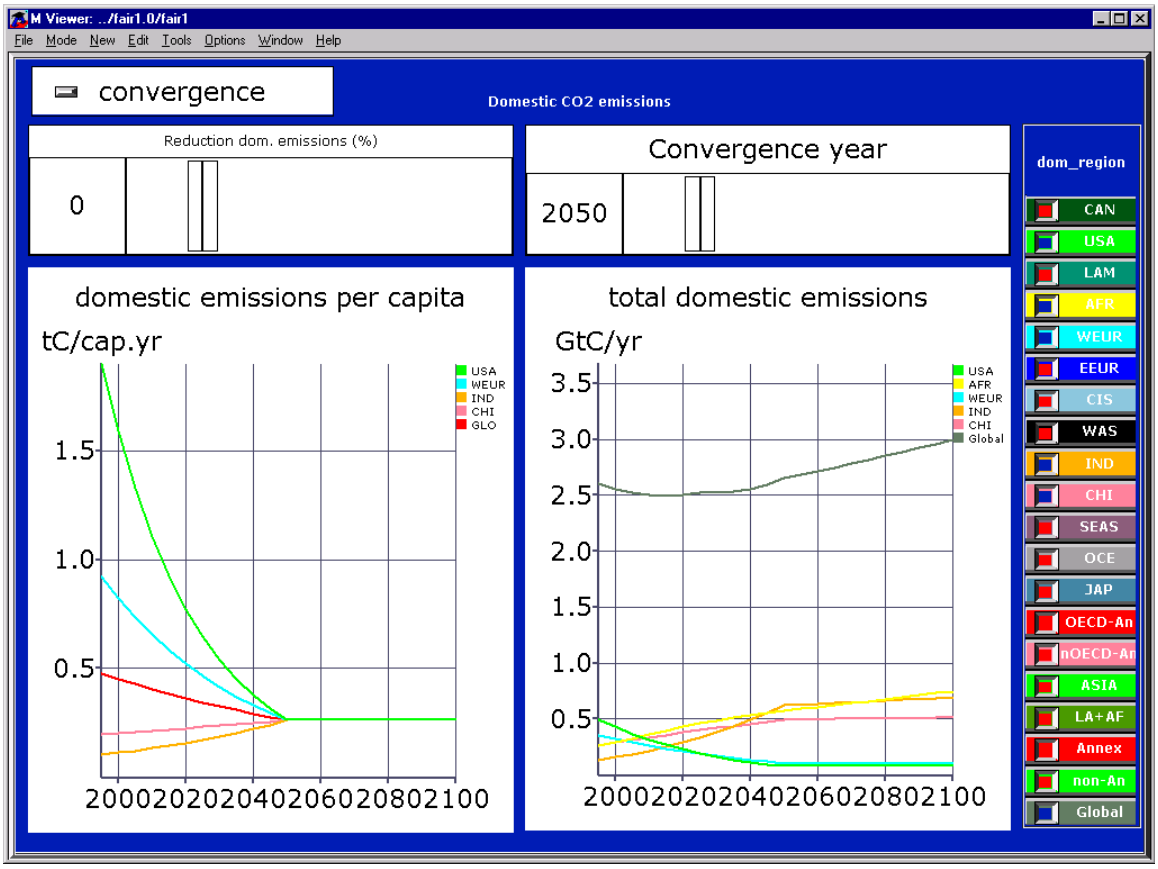


Figure 6.15: Convergence of per capita emissions in the domestic sector

The industrial sector

The assigned amounts of emissions are based on energy efficiency improvement rates and on the decarbonisation rate of the energy supply.

In the example, Western Europe and Japan are assumed to have an *energy efficiency improvement* of 1.5% per year, and all other regions 2.5% per year.

The *decarbonisation* rate is set at 0.25% per year for all regions.

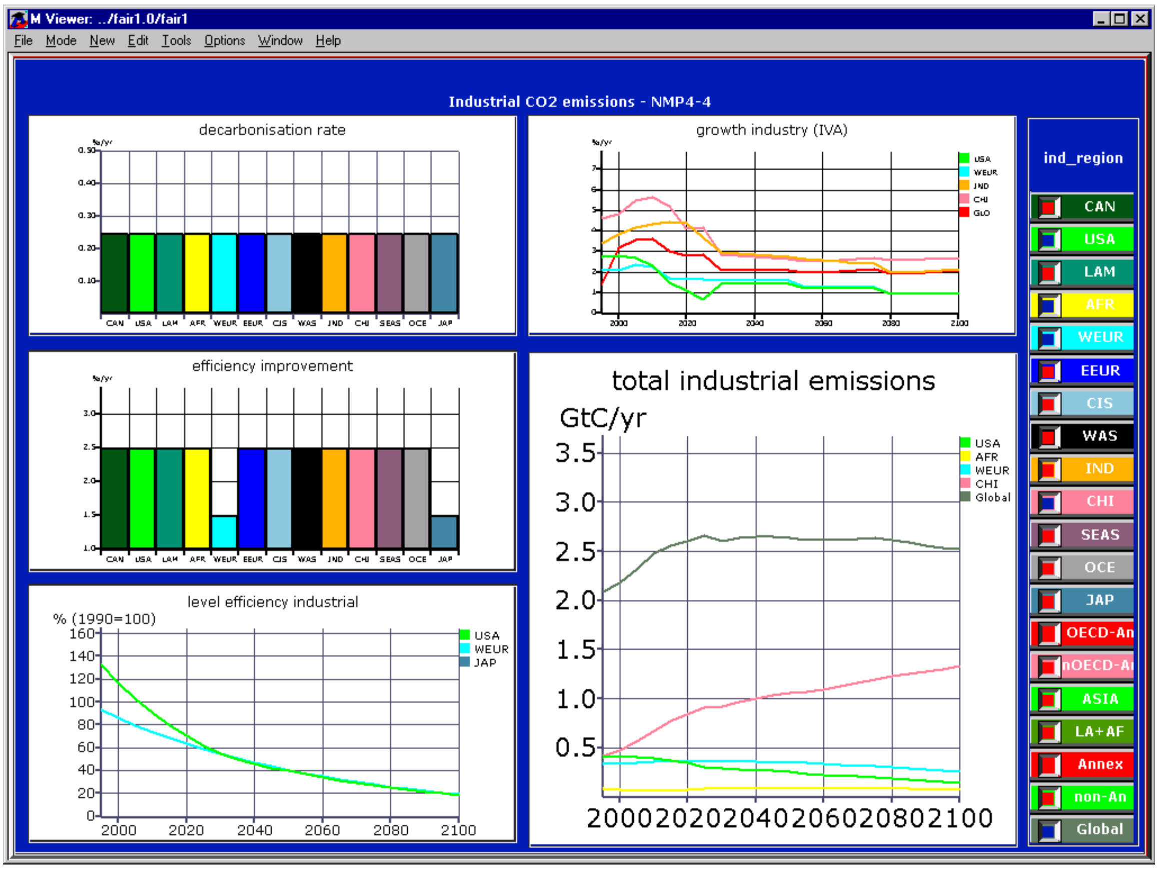


Figure 6.16: Triptych approach in the industrial sector

The power generation sector

The assigned amounts of emissions are based on decarbonisation, growth of carbon free power and efficiency improvement.

In the example, Western Europe and Japan are assumed to have an *energy efficiency improvement* of 1.5% per year, and all other regions 2.5% per year.

The *decarbonisation* rate is set at 0.1-0.5% per year for all regions.

The *carbon free technology* is said to improve with 0.4% per year in all regions.

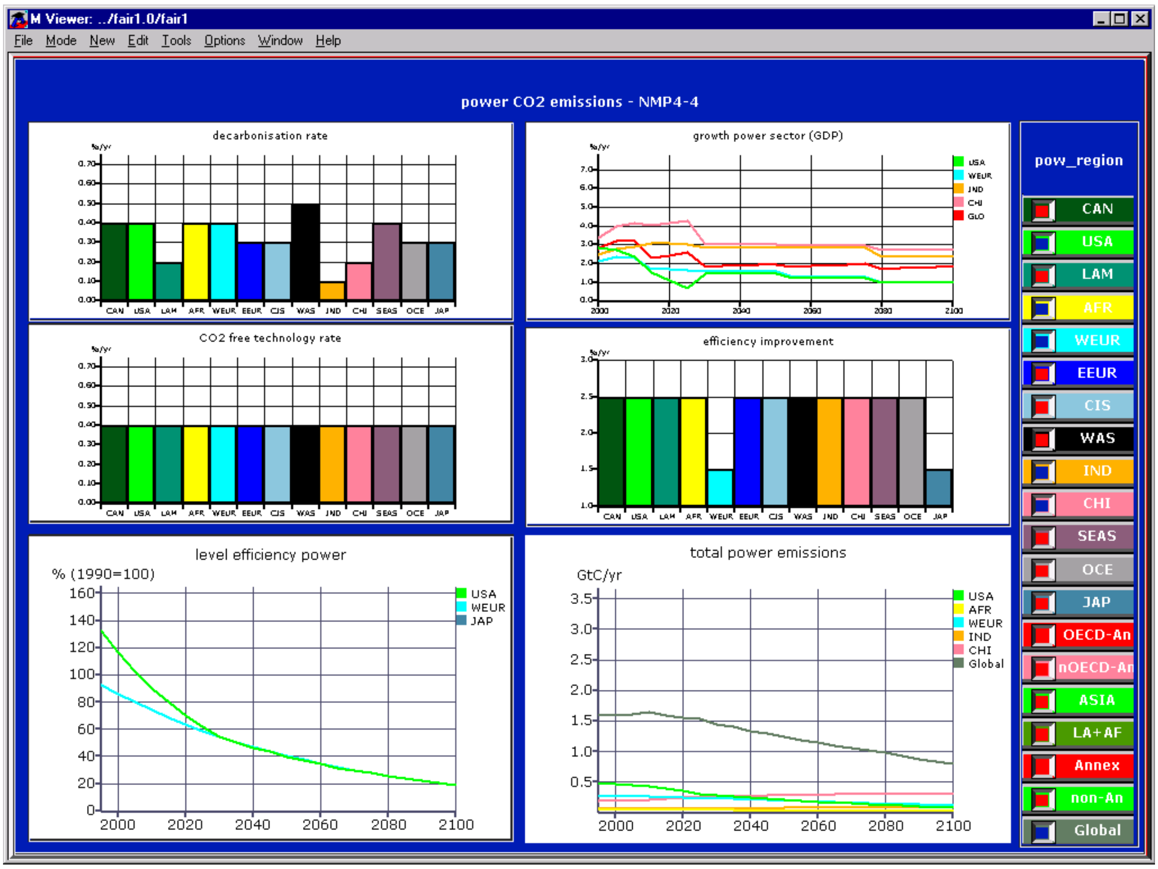


Figure 6.17: Triptych approach in the power generation sector

Emissions in the triptych approach
The figure shows the resulting emissions based on the assumptions made in this example of the triptych approach. It shows that global emissions will stay above 6 GtC per year.

Concluding:
With the chosen settings for the different sectors in the triptych approach, total anthropogenic emissions do *not* lead to a stabilisation of the concentration.

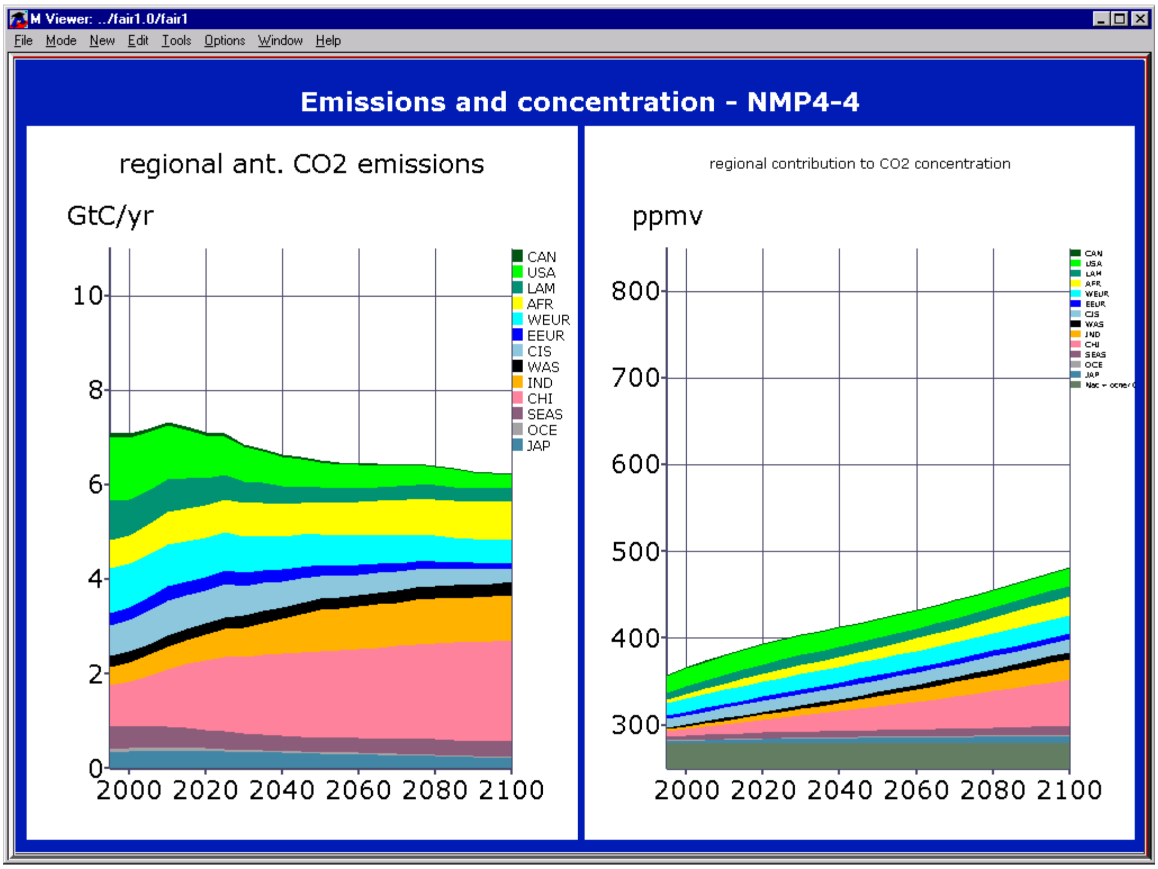


Figure 6.18: Consequences of the Triptych example for the CO_2 emissions. The example does clearly not lead to a stabilisation of the CO_2 concentration.

General Remarks

- FAIR allows evaluation of various options for a global regime in the context of ecological constraints in art 2 UNFCCC.
- Interactive use allows for evaluation various approaches and assumptions, to facilitate policy discussions and negotiations.
- Cost aspects will be included in future versions of the FAIR model.

REFERENCES

Agarwal , A. and Narain, S. (1991), 'Global Warming in an Unequal World, a case of environmental colonialism', Centre for Science and Environment, Delhi.

Agarwal, Anil (1999). Personal communication during visit to RIVM.

Agarwal, Anil, Sunita Narain and Anju Sharma (ed.) 1999. Green Politics - Global Environmental Negotiations 1', Centre for Science and Environment, Delhi, India.

Alcamo, J., Kreileman, G.J.J., Bollen, J.C., Born, G.J. van den, Gerlagh, R., Krol, M.S., Toet, A.M.C., Vries, H.J.M. de (1996), 'Baseline scenarios of global environmental achange'. Global Environmental Change 6, no. 4, 261-303.

Alcamo, J., Kreileman, G.J.J., Krol, M., Leemans, R., Bollen, J., van Minnen, J., Schaeffer, M., Toet, A.M.C., Vries, H.J.M. de (1998). 'Global Modeling of Environmental Change: An overview of IMAGE 2.1'. Elsevier.

Andres, R.J., D.J. Fielding, G. Marland, T. A. Boden and N. Kumar (1999). 'Carbon dioxide emissions from fossil fuel use', 1751-1950'. *Tellus 51B*, 759-765.

Berk, M.M. and M.G.J. den Elzen (1998), 'The Brazilian Proposal evaluated' *CHANGE*, no. 44, 19-23.

Blok, K., Phylipsen, G.J.M. and Bode, J.W. (1997), 'The triptique Approach: Burden Differentiation of CO_2 Emission Reduction Among European Union Member States'. Department of Science, Utrecht University, Department of Science, Technology and Society, Utrecht.

Baumert, Kevin A., Ruchi Bhandari and Nancy Kete (1999), 'What might a Developing Country Commitment Look like? ', Climate Notes, World Resources Institute, Washington DC.

Claussen, Eileen and Lisa McNeilly (1998), 'Equity and Global Climate Change, The Complex Elements of Global Fairness', PEW Centre on Global Climate Change, Arlington.

Centre for Science and Environment (CSE) (1998), 'Definitions of équal entitlements', CSE -dossier, fact sheet 5, CSE, Delhi.

ECE, (UN Economic Commission for Europe) (1994), Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Further Reduction of Sulphur Emissions, ECE/EB.AIR/40, United Nations, New York and Geneva.

Elzen, M.G.J. den, Jansen, M.A., Rotmans, J., Swart, R.J., Vries, H.J.M. de, (1992), 'Allocating constrained global carbon budgets: inter-regional and inter-generational equity for a sustainable world'. International Journal of Global Energy Issues 4, no. 2, 287-301.

Elzen, M.G.J. den, Beusen, A.H.W. and Rotmans, J. (1997), 'An integrated modeling approach to global carbon and nitrogen cycles: Balancing their budgets', Global Biogeochemical Cycles, Vol. 11, No. 2, pages 191-215, June 1997.

Elzen, M.G.J. den (1998), ' The meta-IMAGE 2.1 model: an interactive tool to assess global climate change', RIVM report no 461502020, National Institute of Public Health and the Environment, Bilthoven, the Netherlands

Elzen, M.G.J. den (1999), 'Report on the Expert Meeting on the Brazilian Proposal: scientific aspects and data availability', Cachoeira Paulista, Brazilie, Center Forecasts and Climate Studies (CPTEC), May 19-20, 1999

Elzen, M.G.J. den, M. Berk, M. Scheaffer, J. Olivier, C. Hendriks and B. Metz (1999), 'The Brazilian proposal and other options for International Burden Sharing: an evaluation of merthodological and policy aspects using FAIR', RIVM report no 728001011, National Institute of Public Health and the Environment, Bilthoven, the Netherlands.

Elzen, M.G.J. den and Schaeffer, M. (2001), 'Evaluating major scientific uncertainties of the Brazilian proposal for emission reduction burden sharing', accepted by climatic change.

Enting, I.G., Wigley, T.M.L. and Heimann, M. (1994), 'Future emissions and concentrations of carbon dioxide', Technical Paper, 0 643 05256 9, Mordialloc, Australia.

Enting, I.G. (1998), 'Attribution of greenhouse gas emissions, concentrations and radiative forcing', Technical Paper, 363.738740994, Aspendale Victoria, Australia.

European Commission (1996), 'Communication on Community Strategy on Climate Change', Council Conclusions, European Commissions, Brussels.

Filho, M.L.G. and Miguez, M. (1998), 'Time dependent relationship between emissions of greenhouse gases and climate change', Ministry of Science and Technology, Brasilia, Brazil, november 1998.

Grubb, M. (1989), ‘The Greenhouse Effect: Negotiating Targets’, Royal Institute of International affairs, London.

Grubb, M., Sibenius, J., Magalhaes, A., and Subak, S. (1992), ‘Sharing the Burde’. In: Confronting Climate Change: Risks, Implications and Responses, I.M. Mintzer (ed.), Cambridge University Press, Cambridge.

Grübler, A. and N. Nakicenovic (1994) International Burden Sharing in greenhouse Gas Reductions, IIASA, Laxenburg

Hasselmann, K., R. Sausen, E. Maier-Reimer and R. Voss, R. (1993), ‘On the cold start problem in transient simulations with coupled atmosphere-ocean models’, *Climate Dynamics*, 9, 53–61.

IPCC (1996), ‘Climate change 1995: The science of climate change: contribution of working group I to the second assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK.

IPCC (1997), ‘An introduction to simple climate model used in the IPCC Second Assessment report: contribution of working group I to the second assessment report of the intergovernmental panel on climate change’. Cambridge University Press, Cambridge, UK.

Kawashima, Y. (1996). ‘Differentiation on Quantified Emission Limitation and Reduction Objectives (QUELROs) according to National Circumstances: Introduction to Equality Criteria and Reduction Excess Emissions’, paper presented at 'Informal workshop on quantified limitation and reduction emission objectives', 28 February 1996, in Geneva.

Klein Goldewijk, C.G.M. and J.J. Battjes, (1997), ‘A Hundred Year (1890-1990) Database for Integrated Environmental Assessments (HYDE, version 1.1)’, RIVM report no. 422514 002, National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

Krause, F., Bach, W. and Koomey, J. (1989), ‘Energy policy in the Greenhouse, Vol. 1: From warming Fate to Warming Limit: Benchmarks for a Global Climate Convention’, International Project for Sustainable Energy Paths, El Corrito.

Krol, M.S. and Woerd, H. van der: 1994, ‘Simplified calculation of atmospheric concentration of greenhouse gases and other constituents for evaluation of climate scenarios’, *Water. Air and Soil Pollution* 76 (1-2), 259-281.

Leemans, R., Kreileman, E., Zuidema, G., Alcamo, J., Berk, M., Born, GJ, Elzen, M.G.J. den, Hootsmans, R., Janssen, M.A., Schaeffer, M.S., Toet, S., Vries, B de. (1998), The IMAGE User Support System. Global Change Scenarios from IMAGE 2.1 (CD-rom), RIVM report no. 481508006, National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

Marland, G. and Rotty, R.M.: 1984, ‘Carbon dioxide emissions from fossil fuels: a procedure for estimation and results for 1950-1982’, *Tellus* 36B**,** 232-261.

Marland, G., Boden, T.A., Andres, R. J., Brenkert, A. L., and Johnston C.A.: 1999a, ‘Global, regional, and national fossil fuel CO_2 emissions’. In: *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee (http://cdiac.esd.ornl.gov).

Metz, B. (2000), "International equity in climate change policy", Integrated Assessment 1, pp. 111-126.

Oerlemans, J. (1989), ‘A projection of future sea level’. *Climatic Change*, 15, 151–174.

Olivier, J.G.J., A.F. Bouwman, C.W.M. Van der Maas, J.J.M. Berdowski, C. Veldt, J.P.J. Bloos, A.J.H. Visschedijk, P.Y.J. Zandveld and J.L. Haverlag (1996) ‘Description of EDGAR Version 2.0: A set of global emission inventories of greenhouse gases and ozone depleting substances for all anthropogenic and most natural sources on a per country basis and on 1ox1o grid’, RIVM report no. 771060 002 / TNO-MEP report no. R96/119, RIVM, Bilthoven, the Netherlands.

Pershing, Jonathan (1999), ‘Evolution of mitigation Commitments - Scoping paper’. For discusion by the Annex-1 Expert Group on the UNFCCC, OECD and IEA project for the Annex-1 Expert Group on the UNFCCC, International Energy Agency, September 1999. Paris.

Phylipsen, G.J.M., Bode, J.W., Blok, K., Merkus, H. and Metz, B. (1998), ‘A triptych sectoral approach to burden sharing; Greenhouse gas emissions in the European Bubble’, Energy Policy 26, pp. 929-943.

Reiner, D. M. and Jacoby, H. D. (1997), ‘Annex-1 Differentiation Proposals: Implications for Welfare, Equity and Policy, MIT Global Change Joint Program Report 27, internet site: http://web.mit.edu/globalchnage/www/rpt27.html

Ringius, L. , Torvanger, A. and Holtsmark, B. (1998), ‘Can multi-criteria rules fairly distribute climate burdens? OECD results from three burden sharing rules’. CICERO working paper 1998:6, Oslo.

Ringius, Lasse, Asbjørn Torvanger, Arild Underdal (2000), ‘Burden differentiation of greenhouse gas abatement: fairness principles and proposals’. the joint CICERO-ECN project on sharing the burden of greenhouse gas reduction among countries, ECN Report ECN-C--00-011, Petten, and CICERO Working Paper No. 13 CICERO, Oslo.

Rose, A. (1992), 'Equity Considerations of Tradable Carbon Emission Entitlements'. In: Combating Global Warming, UNCTAD, Geneva.

Rose, A., Stevens, B.and Edmonds, J. (1997), 'International Equity and differentiation in Global Warming policy', Mimeo, The Pennsylvania State University, California Energy Commission, and Pacific Northwest Laboratory, 31 July.

Torvanger, A., Godal, O. (1999), 'A survey of differentiation methods for national greenhouse gas reduction targets', CICERO report 1999:5, University of Olso, Oslo, Norway.

Torvanger, A., Berntsen, T., Fuglestvedt, J.S., Holtsmark, B., Ringius, L. and Aaheim, A. (1996), 'Exploring Distribution of Commitments - a follow-up to the Berlin Mandate', CICERO report 1996:3, , University of Olso, Oslo, Norway.

Torvanger, Asbjørn, Lasse Ringius (2000), 'Burden differentiation: criteria for evaluation and development of burden sharing rules (draft report). The joint CICERE-ECN project on sharing the burden of greenhouse gas reduction among countries, ECN Report ECN-C--00-013, Petten, and CICERO Working Paper, CICERO, Oslo.

UNFCCC (1995), 'Conference of the Parties, first session', Berlin, 28 March-7 April 1995, Secretariat/UNEP, FCCC/CP/1995/7, April 1995.

UNFCCC (1997), 'Paper no. 1: Brazil; Proposed Elements of a Protocol to the United Nations Framework Convention on Climate Change', presented by Brazil in response to the Berlin Mandate, UNFCCC/AGBM/1997/MISC.1/Add.3 GE.97-, Bonn.

UNFCCC (1998), 'The Kyoto Protocol to the Convention on Climate Change', Climate Change Secretariat/UNEP, UNEP/IUC/98/2, June 1998.

De Vries, H. J. M., de Bollen, J., Bouwman, L., Elzen, M.G.J. den, Janssen, M.A., Kreileman G.J. and Leemans, R. (2000). 'Greenhouse-gas emissions in equity, environment- and service-oriented world: an IMAGE-based scenario for the next century', Technological Forecasting and Social Change 63, 137-174.

Wigley, T.M.L. and Schlesinger, M.E. (1985), 'Analytical solution for the effect on increasing CO_2 on global mean temperature', *Nature* 315, 649-652.

Wigley, T.M.L. and Raper, S.C.B. (1992), 'Implications for climate and sea-level of revised IPCC emissions scenarios', *Nature* 357, 293-300.

APPENDIX A.1 THE FRAMEWORK OF INTERNATIONAL SCANNERS

The FAIR model is one of the submodels of the framework of International Scanners. This Framework consists of interactive tools meant to facilitate a dialogue between scientists and policy makers within the climate change issue, and is strongly linked with the IMAGE User Support System contains scenarios from the IMAGE-2.1.

The User Support System (USS)

The IMAGE User Support System contains scenarios from the IMAGE-2.1 or global environmental change model with extensive HTML documentation. The tool is used to interactively explore global change and analyze future developments of the Earth system. IMAGE 2.1 is designed to evaluate cross-linkages in the society-biosphere-climate system.

Simulations with IMAGE 2.1 require large amounts of data. Each simulation (i.e. a scenario) result in data sets on emission profiles, land cover, climate and impacts for a hundred-year period. The User Support System (USS) is especially developed to visualize, analyze and compare such a large quantity of data (Leemans *et al.*, 1998). This USS facilitates the display, use and graphical analysis of all complex data sets used and produced by IMAGE 2. The USS provides access to IMAGE 2 simulation for both novice and experienced users.

The USS classifies the IMAGE-2 data into a cause-effect chain, the Pressure, State and Impacts (PSI) scheme. This classification enhances the understanding of cause and effect and is especially suited for policy makers and other users.

Meta-IMAGE 2.1

This model is an extended version of the meta-IMAGE 2 model, a simple integrated climate assessment model (den Elzen *et al.*, 1997; den Elzen, 1998) which consists of an integration of simple box models, namely; a global carbon cycle model, an atmospheric chemistry model, and an energy balance climate model. The model describes the chain of causality for anthropogenic climate change on a global scale, from emissions of greenhouse gases to the changes in temperature and sea level. A module is developed, which calculates a region's/ country's attribution of the main indicators of global anthropogenic climate change (anthropogenic emissions and concentrations of the major greenhouse gases, radiative forcing and mean surface temperature increase). The aggregation was done by linking attribution of concentrations, radiative forcing and temperature increase to the origin of emissions, using as input the regional anthropogenic emissions of the major greenhouse gases regulated in the Kyoto Protocol (i.e. CO_2, CH_4, N_2O). The anthropogenic emissions of the other greenhouse gases, ozone precursors and sulphur dioxide (SO_2) (related to the sulfate aerosols), as well as the natural emissions, are not aggregated over the regions, but considered as one category.

The Interactive Scenario Scanner (ISS)

The Interactive Scenario Scanner (ISS) was developed to explore long-term policy options for controlling climate change, there is a need to develop and evaluate long-term emission scenarios. ISS is a computer model that assists in the interactive construction and evaluation of long-term emission scenarios using the parameters of the Kaya Identity to define scenarios and the climate indicators of the Safe Landing Approach to scan their likely consequences for global climate change and its impacts. This tool can be used to construct proto-scenarios, which can then be further elaborated and analyzed with such sophisticated energy and climate change models as IMAGE 2. A core element within the ISS forms the climate assessment model meta-IMAGE 2.1, mean for the calculation of the climate implications of the emission scenarios. Recent experiences with the application of ISS indicate that it will indeed be useful in involving policy makers at an early stage of scenario development. Moreover, ISS has also been shown useful in educating policy makers on the complexity of the problem and enhancing communication between, and among, scientists and policy makers.

The Safe Landing Analysis (SLA)

In comparison with the long time horizon of climate change, the time horizon of climate policy-making is by necessity much shorter. To support current climate negotiations, a methodology has been developed to link long-term climate protection goals to decisions on short-term greenhouse gas emission controls: the Safe Landing Analysis. This report describes the tool based on this methodology which is used to calculate the so-called ‘Safe Emission Corridors’. These corridors indicate the range of short term greenhouse gas emissions that are compatible with particular sets of specified short and long-term (2010 to 2100) climate goals (defined as limits for climate impact indicators) and maximum rates of emission reductions (as a proxy for economic and technological constraints for global emission control). The Safe Landing Analysis tool based on regression analyses uses results from the integrated climate change computer model, IMAGE 2, developed at RIVM.

APPENDIX A.2 THE UNFCC EMISSIONS DATA

In this Appendix, we want to give a comparison between the 1990 emissions (base-year in the Kyoto protocol) of the main greenhouse gas CO_2 of this UNFCC emission database, and the historical emission database used by FAIR (see Chapter 5.5) namely the CDIAC database.

UNFCC emission database

The United Nations Framework Convention on Climate Change (UNFCCC) offers a on-line database (http://194.95.39.33/) of emission estimates for three main gases: CO_2, CH_4, N_2O, as well as for CO, NO_X, NMVOCs, and SO_2 for the years 1990-1997. The emission estimates are presented in accordance with the source categories of the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (1996). For the Annex-I countries all data is available from the compulsory National Communications, for some non-Annex-I countries some figures are available as well. Table A.1 gives the 1990 CO_2 emissions data of the Annex I countries and some of the reported non-Annex I countries.

Table A.1 The national total 1990 CO_2 emissions from the Annex-1 countries (regular) and some non-Annex-I countries (italic) according to the UNFCC database

country	IMAGE region	**1990 National Emissions CO_2**	Emissions from Biomass	Emissions from Fuel Combustion	Emissions from Fugitive Emissions from Fuels	Emissions from Industrial Processes	Emissions from Solvent and Other Product Use	Emissions from Agriculture	Emissions from Land-Use Change & Forestry	Emissions from Waste	Other	Emissions from Interna-tional Bunkers
		Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C
Argentina	LAM	**27631**		26564	250	817			-17276			
Armenia	CIS	**6004**		5832		172			-168			110
Australia	OCE	**75094**	4504	71624	1654	1815			16056			1746
Austria	WEUR	**16921**	3650	12715	583	3464	148		-3627	10		254
Belgium	WEUR	**31661**		28887		2506			-561	268		4289
Bulgaria	EEUR	**23020**		20859		1964			-1582	197		238
Canada	CAN	**125795**	18818	112364	2727	8727		1909	-12000	68		1342
Croatia	EEUR											
Czech Republic	EEUR	**45134**		43656		1477			-622			.
Czechoslovakia (Cz. + Slov.)												
Denmark	WEUR	**14257**		13881	65	274	36		-252			1360
Estonia	CIS	**10308**	293	10141		167			-3086			.
Finland	WEUR	**16145**	5018	14700	955	327					164	764
France	WEUR	**107865**	9353	99359	1174	5785	597		-16259	950		4468
Germany	WEUR	**276682**		269136		7546			-9196			5337
Greece	WEUR	**23277**	682	21070		2128	51			28		2843
Hungary	EEUR	**19547**		18574		973			-1218			.
Iceland	WEUR	**586**		457	22	107		1				87
Ireland	WEUR	**8378**		7919		444			-1407	15		320
Italy	WEUR	**117984**	845	109104	642	7505	545		-6807	188		3328
Japan	JAP	**306691**	9531	287172		16035			-22883	3484		8402
Kazakhstan	CIS	**62833**	868	61647		1186			-1094			
Latvia	CIS	**6756**	389	6602		154			-2953			.
Liechtenstein	WEUR	**57**							-6			.

Lithuania	CIS	**10782**		10181		601			-2413			.
Luxembourg	WEUR	**3477**		3309		160	3		-80	5		30
Mexico	LAM	**84172**		81003		3169			37052			
Monaco	WEUR	**29**		29						1		.
Netherlands	WEUR	**44007**	840	42963	115	513	3		-409	415		11
New Zealand	OCE	**6884**	733	6065	168	651			-5697			650
Norway	WEUR	**9601**	1295	7201	518	1832	39		-2615	10		568
Poland	EEUR	**103826**		101300	14	2512			-12181			.
Portugal	WEUR	**12852**	2963	11804	43	933	71		-314			562
Romania	EEUR	**47048**	705	45104		1942			-1540	2		.
Russian	CIS	**646991**	16364	626973	7391	12627			-106909			3
Slovakia	EEUR	**16372**	493	15432		940			-1161			.
Slovenia	EEUR	**3800**		3626		175			-625			.
Spain	WEUR	**61752**	3356	56616	113	4825					198	.
Sweden	WEUR	**15121**	5850	13999	14	1033	75		-9373			1147
Switzerland	WEUR	**12292**		10999	15	917	0	0	-1189	360	0	12292
Ukraine	CIS	**191943**	0	183293		8650	0	0	-14211	0	0	191943
United Kingdom	WEUR	**159319**	1050	152207	3131	3802			5840	180		5822
United States of America	USA	**1344245**	57136	1327091	2291	14864			-311509			27070
Uruguay	LAM	**1047**	588	984		63			538			115
USSR states		**935617**	0	0	0	0	0	0	0	0	0	0
Yugoslavia			0	0	0	0	0	0	0	0	0	0
total Annex 1		***3916500***	***143868***	***3766412***	***21636***	***118374***	***1569***	***1910***	***-530791***	***6180***	***362***	***274877***

These data can be aggregated for the Annex I regions of the IMAGE regions, as follows:

Table A.2 The 1990 CO_2 emissions for the Annex I regions of the IMAGE regions according to the UNFCC database

IMAGE region	**1990 National Emissions CO_2**	Emissions from Biomass	Emissions from Fuel Combustion)	Emissions from Fugitive Emissions from Fuels	Emissions from Industrial Processes	Emissions from Solvent and Other Product Use	Emissions from Agriculture	Emissions from Land-Use Change & Forestry	Emissions from Waste	Other	Emissions from International Bunkers
	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C	Gg C
CAN	**125795**	18818	112364	2727	8727	0	1909	-12000	68	0	1342
USA	**1344245**	57136	1327091	2291	14864	0	0	-311509	0	0	27070
LAM	**112850**	588	108551	250	4049	0	0	20313	0	0	115
WEUR	**932263**	34903	876353	7391	44100	1569	1	-46257	2430	362	43482
EEUR	**258748**	1198	248552	14	9983	0	0	-18929	199	0	238
CIS	**935617**	17913	904670	7391	23557	0	0	-130834	0	0	192057
OCE	**81978**	5237	77690	1822	2466	0	0	10360	0	0	2396
JAP	**306691**	9531	287172	0	16035	0	0	-22883	3484	0	8402
total Annex-I	***3916500***	***143868***	***3766412***	***21636***	***118374***	***1569***	***1910***	***-530791***	***6180***	***362***	***274877***

For most non-Annex I regions there is no data available, except for Latin America, of which only data from Mexico, Argentina and Uruguay are available. These figures should hence not be compared to data on emissions from the whole of Latin America. IMAGE region Eastern Europe contains all former Soviet satellite states, except for the former Yugoslavian states. IMAGE region CIS is the Commonwealth of Independent States, which are all former Soviet states. Data are available from the countries which are adapted to be Annex-I countries (Russian Federation, Baltic

States, Ukraine) as well as from Kazakhstan. In the IMAGE region Oceania, the emission data for all small island states are lacking, but these are minor compared to the emissions from Australia and New Zealand, of which data *are* included.

Kyoto emissions reductions

Table A3 gives the greenhouse gas emission reduction targets in 2012 for the Annex-I countries.

Table A3: Kyoto based greenhouse gas emission reduction targets in 2012 for Annex-I countries.

Country	IMAGE region	1990 National Emissions CO_2	reduction percentage for 2012
Australia	OCE	75094	108
Austria	WEUR	16921	92
Belgium	WEUR	31661	92
Bulgaria	EEUR	23020	92
Canada	CAN	125795	94
Croatia	EEUR		95
Czech republic	EEUR	45134	92
Czechoslovakia (Cz..+ Slov.)			
Denmark	WEUR	14257	92
Estonia	CIS	10308	92
Finland	WEUR	16145	92
France	WEUR	107865	92
Germany	WEUR	276682	92
Greece	WEUR	23277	92
Hungary	EEUR	19547	94
Iceland	WEUR	586	110
Ireland	WEUR	8378	92
Italy	WEUR	117984	92
Japan	JAP	306691	94
Latvia	CIS	6756	92
Liechtenstein	WEUR	57	92
Lithuania	CIS	10782	92
Luxembourg	WEUR	3477	92
Monaco	WEUR	29	92
Netherlands	WEUR	44007	92
New Zealand	OCE	6884	100
Norway	WEUR	9601	101
Poland	EEUR	103826	94
Portugal	WEUR	12852	92
Romania	EEUR	47048	92
Russian Federation	CIS	646991	100
Slovakia	EEUR	16372	92
Slovenia	EEUR	3800	92
Spain	WEUR	61752	92
Sweden	WEUR	15121	92
Switzerland	WEUR	12292	92
Ukraine	CIS	191943	100
United Kingdom	WEUR	159319	92

United States of America	USA	1344245	93
USSR states		935617	
Yugoslavia			
total Annex-1		***3916500***	

* The other (non-Annex I) countries are allowed to increase their emissions

These data can be disaggregated for the 13 IMAGE regions, as depicted in Table A.4. As a first approach to implement the Kyoto protocol in the FAIR model, these overall greenhouse gas emissions reduction percentages have now been applied for only the CO_2 emissions from fossil fuel combustion and industrial processes for the Annex I regions. The other anthropogenic CO_2 emissions of the Annex I regions, minor compared to these energy- and industry related emissions are assumed to remain at their 1990 levels. Similar reduction percentages have been applied on the anthropogenic methane and nitrous dioxide emissions, and no additional reduction percentages for the emissions of halocarbons regulated in the Kyoto Protocol, such as the HFCs and PFCs, which follow the IPCC B1 emissions scenario.

Table A.4 Kyoto based greenhouse gas emission reduction targets in 2012 for the Annex I regions of the IMAGE regions.

IMAGE region	National total CO2 emissions UNFCC	average reduction percentage for 2012	2012 total CO2 emissions UNFCC
CAN	125795	0,94	118248
USA	1344245	0,93	1250148
WEUR	932263	0,92	858651
EEUR	258748	0,93	240515
CIS	935617	0,92	864553
OCE	81978	1,07	87985
JAP	306691	0,94	288289
Annex-I	***3916500***	***0,95***	***3708390***

Comparison between UNFCC and CIAC emission database

In the FAIR model, the historical CO_2 emissions from fossil fuel combustion and industrial processes are based on the CDIAC CO_2 emission database. For the implementation of the Kyoto Protocol in the FAIR model, we want to include the final 2012 CO_2 emissions from fossil fuel combustion and industrial processes for the Annex I regions. This necessary implies that the 1990 CO_2 emissions from fossil fuel combustion and industrial processes for the UNFCC database and the CDIAC database should not differ too much, otherwise also the reductions between the 1990 CDIAC CO_2 emissions (as implemented in FAIR) and the 2012 final UNFCC CO_2 emissions differ too much form the real Kyoto Protocol reduction percentages.

A comparison between the 1990 CO_2 emissions (base-year in the Kyoto protocol) of the UNFCC emission database, and the CDIAC database is needed.

Differences in the definitions:

- The country CO_2 emission totals in the CDIAC database integrate the following categories: production from gas fuels, liquid fuels, solid fuels and gas flaring, as well as from cement manufacturing and bunker fuels. In the UNFCCC totals include the same categories as in the CDIAC database, except that UNFCC includes the emissions from chemical feeedstocks, and excludes the bunker emissions.

Therefore, a comparison should be made between the emission data from the CDIAC-database excluding bunkers emissions, and with the UNFCCC database excluding the emissions from chemical feedstocks (i.e. fugitive emissions from fuels and industrial process emissions). This comparison is made in *Table A.5.*

*Table A.5 1990 CO_2 emissions data from UNFCCC database and from CDIAC database for each of the IMAGE region (in GgC/yr)***.**

IMAGE region	1990 UNFCC total CO_2 emissions	1990 UNFCC CO_2 emissions (excl. emissions from chem. Feedstocks)	1990 UNFCC CO_2 emissions from combustion + fuel emissions	1990 CDIAC total CO_2 emissions (excl bunkers)	CDIAC total/ FCCC total CO_2 emissions	CDIAC total / FCCC total excl. chem. feedstocks	CDIAC total / FCCC total excl. chem. feedstocks
CAN	125795	117068	115091	111798	0,89	0,95	0,97
USA	1344245	1329382	1329382	1316589	0,98	0,99	0,99
WEUR	932263	886594	883744	873149	0,94	0,98	0,99
EEUR	258748	248764	248566	269034	1,04	1,08	1,08
CIS	935617	912061	912061	1011473	1,08	1,11	1,11
OCE	81978	79512	79512	79041	0,96	0,99	0,99
JAP	306691	290656	287172	292212	0,95	1,01	1,01
Annex-I	***3916500***	***3796557***	***3788048***	***3953296***	***1,01***	***1,04***	***1,02***

This Table shows minor differences between the 1990 CO_2 emission from CDIAC-database (excluding bunkers emissions) and the CO_2 emission from UNFCCC database (excluding the emissions from chemical feedstocks), except for Eastern Europe and CIS. For these regions the CDIAC data are somewhat higher than the UNFCC data, which can be explained the missing of the national emission data of states like former Yugoslavia, Belarus, Moldavia, the Kaukasian states, etc in the UNFCC database.

Concluding, the final 2012 CO_2 emissions levels for the Annex I regions as summarized in the Kyoto Protocol can be implemented in the FAIR model. The reductions between the 1990 CDIAC CO_2 emissions (as implemented in FAIR) and the 2012 final UNFCC CO_2 emissions are similar as the reduction percentages as given by the Kyoto Protocol.

Note: the final CO_2 emissions data in the FAIR model are based on the CO_2 emissions from fossil fuel combustion and cement production from the CDIAC database, and the CO_2 emissions from bunkers and chemical feedstocks from the EDGAR database. The latter shows, in contrast with the first, for the year 1990 significant differences with the UNFCC data. However, since these emissions are surrounded with large uncertainties and they only account for 5-10% of the total emissions, this is considered as a minor inadequacy, which will be analyzed in more detail in future versions of FAIR.