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Greenhouse Gas Emission Mitigation Scenarios and Implications

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EXECUTIVE SUMMARY

Introduction: Summary of the Second Assessment Report and progress since this report.

This chapter reviews three scenario literatures: general mitigation scenarios produced since the Second Assessment Report (SAR), narrative-based scenarios found in the general futures literature, and mitigation scenarios based on the new reference scenarios developed in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES).

Scenarios

A long-term view of a multiplicity of future possibilities is required to consider the ultimate risks of climate change, assess critical interactions with other aspects of human and environmental systems and guide policy responses. Scenarios offer a structured means of organizing information and gleaning insight into the possibilities.

Each mitigation scenario describes a future world with particular economic, social, and environmental characteristics, and therefore implicitly or explicitly contains information about development, equity, and sustainability (DES). Since the difference between reference case scenarios and their corresponding mitigation scenarios is simply the addition of deliberate climate policy, it can be the case that the differences in emissions among reference case scenarios are greater than between any one such scenario and its mitigation version.

General Greenhouse Gas Emissions Mitigation Scenarios

This chapter considers the results of 519 quantitative emission scenarios from 188 sources, mainly produced after 1990. The review focuses on 126 mitigation scenarios that cover global emissions and have a time horizon encompassing the coming century.

These mitigation scenarios include concentration stabilization scenarios, emission stabilization scenarios, tolerable windows/safe emission corridor scenarios, and other mitigation scenarios. They all include energy-related carbon dioxide (CO_2) emissions; several also include CO_2 emissions from land-use changes and industrial processes and other important greenhouse gases (GHGs).

Mitigation options used in the reviewed mitigation scenarios take into account energy systems, industrial processes, and land use, and depend on the underlying model structure. Most of the scenarios introduce simple carbon taxes or constraints on emissions or concentration levels to reflect measures that are taken to implement such options. Regional targets are introduced in the models with regional disaggregation. Emission trading is introduced in more recent work. Some models employ supply-side technology introduction, while others emphasize efficient demand-side technology options.

Allocation of emission reduction among regions is a contentious issue. Only some studies, particularly recent ones, make explicit assumptions about such allocations in their scenarios. Some studies offer global emission trading as a mechanism to reduce mitigation costs.

Technological improvement is a critical element in all the general mitigation scenarios.

Detailed analysis of the characteristics of 31 scenarios for stabilization at 550ppmv (and their respective baseline scenarios) yielded several insights[1].

There was a wide range in baselines, reflecting a diversity of assumptions, mainly with respect to economic growth and low-carbon energy supply. High economic growth scenarios tend to assume high levels of progress in the efficiency of end-use technologies; carbon intensity reductions were found to be largely independent of economic growth assumptions. The range of future trends shows greater divergence in scenarios that focus on developing countries than in scenarios that look at developed nations. There is little consensus with respect to future directions in developing regions.

The reviewed 550ppmv stabilization scenarios vary with respect to reduction time paths and the distribution of emission reductions among regions. Some scenarios show that emission trading lowers overall mitigation cost by shifting mitigation to non-OECD countries, where abatement costs are assumed to be lower. The range of assumed mitigation policies is very wide. In general, scenarios in which there is an assumed adoption of high-efficiency measures in the baseline show less scope for further introduction of efficiency measures in the mitigation scenarios. In part this is due to the structure of the models, which do not assume major technological break-

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[1] The selection of 550ppmv scenarios is based on the relatively large number of available studies that use this level and does not imply any endorsement of this particular level of CO_2 concentration stabilization.

throughs. Conversely, baseline scenarios with high carbon intensity reductions show larger carbon intensity reductions in their corresponding mitigation scenarios. Global macroeconomic costs of mitigation in the reviewed scenarios range from 0% to 3.5% of gross domestic product (GDP), while a few simple models estimate more increase in the second half of the 21st century. No clear relationship was discovered between the GDP loss and the GDP growth assumptions in the baselines.

Only a small set of studies has reported on scenarios for mitigating non-CO_2 gases. This literature suggests that small reductions of GHG emissions can be accomplished at lower cost by including non-CO_2 gases; that both CO_2 and non-CO_2 emissions would have to be controlled in order to reduce emissions sufficiently to meet assumed mitigation targets; and that methane (CH_4) mitigation can be carried out more rapidly, with a more immediate impact on the atmosphere, than CO_2 mitigation.

In most cases it is clear that mitigation scenarios and mitigation policies are strongly related to their baseline scenarios, but no systematic analysis in this class of literature has been published on the relationship between mitigation and baseline scenarios.

Global Futures Scenarios

Global futures scenarios do not specifically or uniquely consider GHG emissions. Instead, they are more general "stories" of possible future worlds. They can complement the more quantitative emission scenario assessment because they consider dimensions that elude quantification, such as governance and social structures and institutions, but which are nonetheless important to the success of mitigation policies. Addressing these issues reflects the different perspectives presented in Chapter 1 on cost-effectiveness, equity, and sustainability.

A survey of this literature has yielded a number of insights. First, a wide range of future conditions has been identified by futurists, ranging from variants of sustainable development to collapse of social, economic, and environmental systems. Since the underlying socio-economic drivers of emissions may vary widely in the future, it is important that climate policies should be designed so that they are resilient against widely different future conditions.

Second, the global futures scenarios that show falling GHG emissions tend to show improved governance, increased equity and political participation, reduced conflict, and improved environmental quality. They also tend to show increased energy efficiency, shifts to non-fossil energy sources, and/or shifts to a post-industrial economy. Furthermore, population tends to stabilize at relatively low levels, in many cases as a result of increased prosperity, expanded provision of family planning, and improved rights and opportunities for women. A key implication is that sustainable development policies can make a significant contribution to emission reduction.

Third, different combinations of driving forces are consistent with low emission scenarios. The implication of this would seem to be that it is important to consider the linkage between climate policy and other policies and conditions associated with the choice of future paths in a general sense.

Special Report on Emission Scenarios

Six new GHG emission reference scenario groups (not including specific climate policy initiatives), organised into 4 scenario "families", were developed by the IPCC and published as the Special Report on Emission Scenarios (SRES). Scenario families A1 and A2 emphasize economic development but differ with respect to the degree of economic and social convergence; B1 and B2 emphasize sustainable development but also differ in terms of degree of convergence. In all, six models were used to generate 40 scenarios that comprise the six scenario groups**.** In each group of scenarios, which should be considered equally sound, one illustrative case was chosen to illustrate the whole set of scenarios. These six scenarios include marker scenarios for each of the scenario families as well as two scenarios, A1FI and A1T, which illustrate alternative energy technology developments in the A1 world.

The SRES scenarios lead to the following findings:

- Alternative combinations of driving-force variables can lead to similar levels and structure of energy use, land-use patterns and emissions.
- Important possibilities for further bifurcations in future development trends exist within each scenario family.
- Emissions profiles are dynamic across the range of SRES scenarios. They portray trend reversals and indicate possible emissions cross-over among different scenarios.
- Describing potential future developments involves inherent ambiguities and uncertainties. One and only one possible development path (as alluded to for instance in concepts such as "business-as-usual scenario") simply does not exist. The multi-model approach increases the value of any scenario set, since uncertainties in the choice of model input assumptions can be more explicitly separated from the specific model behaviour and related modelling uncertainties.

Review of Post-SRES Mitigation Scenarios

Recognizing the importance of multiple baselines in evaluating mitigation strategies, recent studies analyze and compare mitigation scenarios using as their baselines the new SRES scenarios. This allows for the assessment in this report of 76 "Post-SRES Mitigation Scenarios" produced by nine modelling teams.

These mitigation scenarios were quantified on the basis of storylines for each of the six SRES scenarios which describe the relationship between the kind of future world and its capacity for mitigation.

Quantifications differ with respect to the baseline scenario including assumed storyline, the stabilization target, and the model that was used. The post-SRES scenarios cover a very wide range of emission trajectories but the range is clearly below the SRES range. All scenarios show an increase in CO_2 reduction over time. Energy reduction shows a much wider range than CO_2 reduction, because in many scenarios a decoupling between energy use and carbon emissions takes place as a result of a shift in primary energy sources.

In general, the lower the stabilization target and the higher the level of baseline emissions, the larger the CO_2 divergence from the baseline that is needed, and the earlier that it must occur. The A1FI, A1B, and A2 worlds require a wider range and more strongly implemented technology and/or policy measures than A1T, B1, and B2. The 450 ppmv stabilization case requires very rapid emission reduction over the next 20 to 30 years.

A key policy question is what kind of emission reductions in the medium term (after the Kyoto protocol commitment period) would be needed. Analysis of the post-SRES scenarios (most of which assume developing country emissions to be below baselines by 2020) suggests that stabilization at 450ppmv will require emissions reductions in Annex I countries after 2012 that go significantly beyond their Kyoto Protocol commitments. It also suggests that it would not be necessary to go much beyond the Kyoto commitments for Annex I countries by 2020 to achieve stabilization at 550ppmv or higher. However, it should be recognized that several scenarios indicate the need for significant Annex I emission reductions by 2020 and that none of the scenarios introduces other constraints such as a limit to the rate of temperature change.

An important policy question already mentioned concerns the participation of developing countries in emission mitigation. A preliminary finding of the post-SRES scenario analysis is that, if it is assumed that the CO_2 emission reduction needed for stabilization would occur in Annex I countries only, Annex I per capita CO_2 emissions would fall below non-Annex I per capita emissions during the 21st century in nearly all of the stabilization scenarios, and before 2050 in two-thirds of the scenarios. This suggests that the stabilization target and the baseline emission level are both important determinants of the timing when developing countries' emissions might need to diverge from their baseline.

Climate policy would reduce per capita final energy consumption in the economy-emphasized worlds (A1F1, A1B, and A2), but not in the environment-emphasized worlds (B1 and B2). The reduction in energy use caused by climate policies would be larger in Annex I than in non-Annex I. However, the impact of climate policies on equity in per capita final energy use would be much smaller than that of the future development path.

No single measure will be sufficient for the timely development, adoption, and diffusion of mitigation options to stabilize atmospheric GHGs. Instead, a portfolio based on technological change, economic incentives, and institutional frameworks could be adopted. Combined use of a broad array of known technological options has a long-term potential which, in combination with associated socio-economic and institutional changes, is sufficient to achieve stabilization of atmospheric CO_2 concentrations in the range of 450–550ppmv or below.

Assumed mitigation options differ among scenarios and are strongly dependent on the model structure. However, common features of mitigation scenarios include large and continuous energy efficiency improvements and afforestation as well as low-carbon energy, especially biomass, over the next one hundred years and natural gas in the first half of the 21st century. Energy conservation and reforestation are reasonable first steps, but innovative supply-side technologies will eventually be required. Possible robust options include using natural gas and combined-cycle technology to bridge the transition to more advanced fossil fuel and zero-carbon technologies, such as hydrogen fuel cells. Solar energy along with either nuclear energy or carbon removal and storage would become increasingly important for a higher emission world or lower stabilization target.

Integration between global climate policies and domestic air pollution abatement policies could effectively reduce GHG emissions in developing regions for the next two or three decades; however, control of sulphur emissions could amplify possible climate change, and partial trade-offs are likely to persist for environmental policies in the medium term.

Policies governing agriculture and land use and energy systems need to be linked for climate change mitigation. Supply of biomass energy as well as biological CO_2 sequestration would broaden the available options for carbon emission reductions, although the post-SRES scenarios show that they cannot provide the bulk of the emission reductions required. That has to come from other options.

2.1 Introduction: Summary of the Second Assessment Report and Progress since this Report

Various options for mitigating climate change, which constitute the basis of this Working Group III report, depend on societal visions of the future. These visions largely define the decision analytical frameworks used (see Chapter 10) and form the basis for evaluating options. As this chapter will make clear, existing visions of the future are very different in scope and scale, in time horizons, in constituents and uncertainties, and cover different areas of human activities, natural conditions, etc. Whereas some authors explore the future by extrapolating trends, others aim at a more desirable future state.

Many visions of the future can be modified into scenarios through the systematization of data and other available information, using various modelling techniques, and thereby leading to quantitative interpretations of the future. The spectrum of scenarios can be as broad as that of visions, however, articulating a scenario can provide a more detailed picture of the framework for decisions and the associated limitations for decision-making processes and policy interventions in any particular area.

Climate change and its impacts have a long history in the existing scenario literature, while mitigation scenarios that explore policy options to be implemented are of more recent origin. In the Second Assessment Report (SAR) of the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas (GHG) mitigation scenarios were reviewed. Since that time, there has been considerable development of such scenarios, focussing on issues of the timing, location, and extent of responses required to stabilize atmospheric concentrations at various levels. These new mitigation scenarios are reviewed in this chapter.

Another literature, consisting of more narrative-based scenarios of alternative global futures, is also reviewed in this chapter. These more general scenarios provide a basis for contextualizing the more traditional emissions scenarios, and providing a link to development, equity, and sustainability (DES).

In addition, in 1996, the IPCC commissioned a new report on emissions scenarios (the Special Report on Emissions Scenarios, or SRES), in which new scenarios were developed (Nakicenovic *et al*., 2000). During 1999 and 2000 various modellers used these new reference scenarios as the basis of new mitigation and stabilization analyses. This post-SRES work is also reviewed in this chapter.

Section 2.2 provides a background of scenarios in general, and emission and mitigation scenarios in particular, and discusses the link between scenarios and DES. Section 2.3 reviews general mitigation scenarios produced since the SAR. Section 2.4 discusses global futures scenarios, which are narrative-based scenarios found in the general futures literature. Section 2.5 provides a review of the SRES and discusses post-SRES mitigation scenarios. Finally, Section 2.6 provides recommendations for future research.

2.2 Scenarios

2.2.1 *Introduction to Scenarios*

Climate change assessment addresses a highly complex set of interactions between human and natural systems, a scientific challenge that is compounded by the cumulative and long-term character of the phenomenon. While the world of many decades from now is indeterminate, scenarios offer a structured means of organizing information and gleaning insight into the possibilities. Scenarios can draw on both science and imagination to articulate a spectrum of plausible visions of the future and pathways of development. Some scenarios are assumed to evolve gradually and continuously from current social, economic, and environmental patterns and trends; others deviate in fundamental ways. A long view of a multiplicity of future possibilities is required to consider the ultimate risks of climate change, assess critical interactions with other aspects of human and environmental systems, and guide policy responses.

The term “scenarios” appears in two distinct streams of inquiry, one based on qualitative narrative and the other on mathematical models. Qualitative scenarios are primarily literary exercises, aimed at holistic and integrated sketches of future visions and compelling accounts of a progression of events that might lead to those futures. Quantitative, formal models seek mathematical representation of key features of human and/or environmental systems in order to represent the evolution of the system under alternative assumptions, such as population, economic growth, technological change, and environmental sensitivity. Qualitative scenarios have a greater power to posit system shifts, to explore the implications of surprise, and to include critical factors that defy quantification, such as values, cultural shifts, and institutional features. On the other hand, qualitative scenarios may appear arbitrary, idiosyncratic, and weakly supported. Model-based scenarios are useful for examining futures that result from variations of quantitative-driving variables, and they offer a systematic and replicable basis for analysis.

A first wave of global assessments began in the 1970s. Ambitious global modelling exercises aimed to forecast the behaviour over many decades of development, resource, and environmental systems, and to assess resource constraints (Meadows *et al*., 1972; Mesarovic and Pestel, 1974). The Latin American world model stressed social and political concerns, rather than physical limits, by positing a normative egalitarian future to examine the actions required to achieve it (Herrera *et al*., 1976). A second wave of integrated global scenario analyses responded to new concerns about sustainable development and the future (WCED, 1987). Many of these were in the qualitative tradition (Svedin and Aniansson, 1987; Toth *et al*., 1989; Milbrath, 1989; Burrows *et al*., 1991; Kaplan, 1994; Gallopin *et al*., 1997; WBCSD, 1997; Bossel, 1998). In addition, stimulated largely by the climate issue, there have been a number of new models that quantitatively link energy and other human activities to atmospheric, oceanic, and terrestrial systems (e.g., Rotmans and de Vries, 1997). Finally, scenario studies have begun recently to synthesize the modelling and qualitative approaches, in order to blend structured quantitative analysis with textured and pluralistic scenario narratives (Raskin *et al*., 1998; Nakicenovic *et al*., 2000).

IPCC GHG emission scenarios were prepared for the first assessment report of 1990. These initial scenarios were updated and extended, and led to the publication in 1992 of alternative emissions scenarios for the period 1990 through 2100 (Leggett *et al*., 1992; Pepper *et al*., 1992). These so-called IS92 emission scenarios were used by the IPCC to assess changes in atmospheric composition and climate over this time horizon. Analysts have used the IS92 scenarios, and particularly IS92a, as the preferred reference scenarios for mitigation and stabilization studies. A subsequent IPCC evaluation of the IS92 scenarios (Alcamo *et al*., 1995) found that for the purposes of driving atmospheric and climate models, the carbon dioxide (CO_2) emissions trajectories of the IS92 scenarios provided a reasonable reflection of variations found in the open literature. However, the review found that these scenarios should not be used for evaluating the consequences of interventions to reduce GHG emissions since the scenarios have insufficient sectoral and regional detail for careful analyses. This review also took into account criticism by Parikh (1992) who suggested the need for a more coherent approach and scenarios that show improved equity between the developed and the developing countries.

The 1995 review also emphasized the need for analysts to consider the full range of IS92 emissions scenarios, rather than a single "business-as-usual" reference scenario. The uncertainties in long-range future assumptions make the assignation of a most-probable trajectory problematic.

In 1996, the IPCC initiated a process for establishing a new set of reference emissions scenarios. The new scenarios are described in the IPCC Special Report on Emissions Scenarios (Nakicenovic *et al*., 2000). These are designed to be non-mitigation or reference scenarios, that is, scenarios in which additional policy initiatives aimed specifically at lowering GHG emissions are assumed to be absent.

Owing to fundamental uncertainties, it is impossible to predict or forecast the long-range global future, even with the most sophisticated methods. Long-range indeterminism implies that probabilities cannot be rigorously assigned for either a given set of driving assumptions or the likelihood of structural shifts in societies and natural systems. Consequently, instead of a single "business as usual" scenario, multiple baseline scenarios are needed to scan a spectrum of plausible possibilities in order to guide the formulation of robust policies that are not geared to an overly rigid sense of where the world is heading.

To account for the wide variety of possible futures and the large uncertainties involved in such forward projections, the SRES team opted for a multiple baseline approach.[2] It also decided to fuse a qualitative, narrative approach with a more formal approach with different models, to guarantee structural variance and methodological diversity in the scenarios. As such, the SRES-scenarios combine elements from both the more story-like scenarios discussed in Section 2.4 below, and the more model-based scenarios discussed in Section 2.3. The relationship between these three kinds of scenarios is shown in *Figure 2.1*.

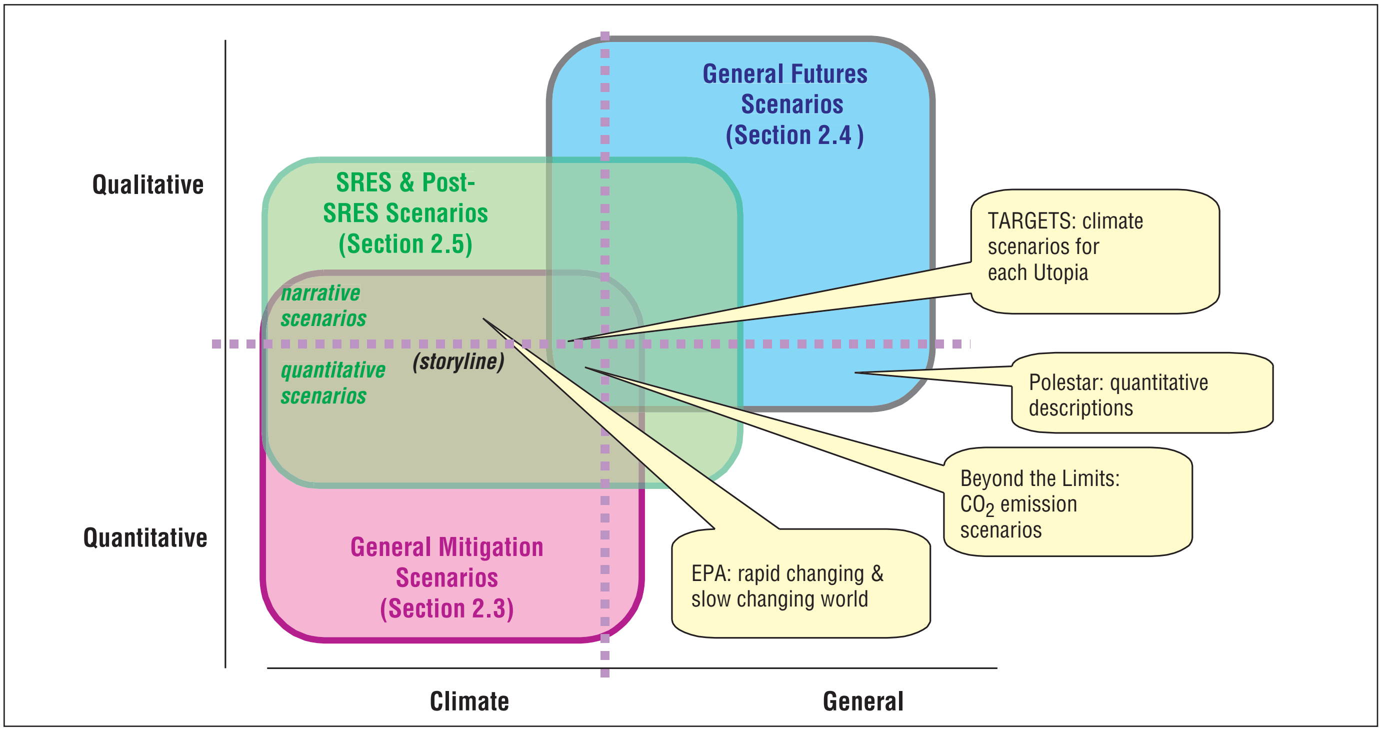

Figure 2.1: *Relationship among the three groups of literature reviewed in Chapter 2.*

2.2.2 Mitigation and Stabilization Scenarios

Mitigation scenarios are usually defined as a description and a quantified projection of how GHG emissions can be reduced with respect to some baseline scenario. They contain new emission profiles as well as costs associated with the emission reduction. Stabilization scenarios are mitigation scenarios that aim at a pre-specified GHG reduction target. Usually the target is the concentration of CO_2 or the CO_2-equivalent concentration of a "basket" of gases by 2100 or at some later date when atmospheric stabilization is actually reached.

There are two common difficulties associated with the formulation and quantification of mitigation scenarios. First, in certain cases there is not a clear-cut distinction between intervention and non-intervention scenarios, that is, scenarios with or without explicit climate policy. This is discussed in detail in *Box 2.1*. The second important problem regarding mitigation scenarios has to do with the difference between top-down and bottom-up models. Whereas the latter focus on engineering trends and technology costs, the former view resource development from a macroeconomic price-mediated perspective. Although, as discussed in the SAR (IPCC, 1995), the differ-

Box 2.1. Differentiating Between Climate Policy and No-climate-policy Scenarios

Recent discussions among IPCC experts and reactions from reviewers of this report and the SRES report revealed the need to clarify differences between various types of GHG emission scenarios, in particular, between climate policy scenarios (CP scenarios) and scenarios without climate policies (NCP scenarios) but with low emissions.

CP scenarios (also known as climate intervention or climate mitigation scenarios) are defined in this report as those that: (1) include explicit policies and/or measures, the primary[3] goal of which is to reduce GHG emissions (e.g., carbon tax) and/or (2) mention no climate policies and/or measures, but assume temporal changes in GHG emission sources or drivers required to achieve particular climate targets (e.g., GHG emission levels, GHG concentration levels, temperature increase or sea level rise limits).[4]

CP scenarios are often, but not always, constructed with reference to a corresponding reference or baseline scenario that is similar to the CP scenario in every respect except the inclusion of climate mitigation measures and/or policies. In fact, climate policy analysis often starts with the construction of such a reference scenario, to which is added climate policy to create the CP scenario.

Another type of CP scenario is not originally built around such "no-policy" baselines. Developers of such scenarios envision future "worlds" that are internally consistent with desirable climate targets (e.g., a global temperature increase of no more than 1°C by 2100), and then work "backwards" to develop feasible emission trajectories and emission driver combinations leading to these targets. Such scenarios, also referred to as "safe landing" or "tolerable windows" scenarios, imply the necessary development and implementation of climate policies, intended to achieve these targets in the most efficient way.

The general definition of CP scenarios provided here enables one to effectively discriminate between CP scenarios and other scenarios with low emissions (e.g., IS92c, SRES-B1). Unlike the former, NCP scenarios have low emissions but do not assume any explicit emission abatement measures or policies, nor are they designed specifically to achieve certain climate targets. NCP scenarios by themselves may explore a wide variety of alternative development paths, including "green" or "dematerialization" futures.

Confusion can arise when the inclusion of "non-climate-related" policies in a NCP scenario has the effect of significantly reducing GHG emissions. For example, energy efficiency or land use policies that reduce GHG emissions may be adopted for reasons that are not related to climate policies and may therefore be included in a NCP scenario. Such a NCP scenario may have GHG emissions that are lower than some CP scenarios.

The root cause of this potential confusion is that, in practice, many policies can both reduce GHG emissions and achieve other goals. Whether such policies are assumed to be adopted for climate or non-climate policy related reasons in any given scenario is determined by the scenario developer based on the underlying scenario narrative. While this is a problem in terms of making a clear distinction between CP and NCP scenarios, it is at the same time an opportunity. Because many decisions are not made for reasons of climate change alone, measures implemented for reasons other than climate change can have a large impact on GHG emissions, opening up many new possibilities for mitigation. Chapters 7, 8, and 9 discuss ancillary benefits of climate mitigation and the co-benefits of policies integrating climate mitigation objectives with other goals.

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[2] It is perhaps worth noting in this connection that, in a similar way, the IPCC had originally recommended that climate and other modellers use the full set of IS92 scenarios but, in practice, this advice has not been followed by most researchers who have focussed primarily on the "central" IS92 case, thereby potentially contributing to an unjustified sense of probability or accuracy.

[3] Some climate polices have multiple benefits. For example, a particular policy designed to reduce methane leaks from natural gas systems may also increase the operating company's profitability and improve safety. However, if this policy was originally developed to reduce emissions it should be classified as a climate policy, not as a policy to increase profitability or improve safety.

[4] Such targets may be reached without specific additional climate policies, e.g., by pursuing particular development pathways.

ences between these approaches are continiously narrowing as each incorporates elements of the other, there is still quite a difference in their formulation of emission reduction strategies. This suggests the importance of including multiple methodological approaches in scenario analysis.

2.2.3 Scenarios and "Development, Equity, and Sustainability (DES)"

The climate issue is embedded in the larger question of how combined social, economic, and environmental subsystems interact and shape one another over many decades. There are multiple links. Economic development depends on maintenance of ecosystem resilience; poverty can be both a result and a cause of environmental degradation; material-intensive lifestyles conflict with environmental and equity values; and extreme socio-economic inequality within societies and between nations undermines the social cohesion required for effective policy responses.

It is clear that climate policy, and the impacts of climate change, will have significant implications for sustainable development at both the global and sub-global levels. In addition, policy and behavioural responses to sustainable development issues may affect both our ability to develop and successfully implement climate policies, and our ability to respond effectively to climate change. In this way, climate policy response will affect the ability of countries to achieve sustainable development goals, while the pursuit of those goals will in turn affect the opportunities for, and success of, climate policy responses.

In this report and its Working Group II companion report, climate change impacts, mitigation, and adaptation strategies are discussed in the broader context of DES (see Munasinghe, 1999).

The issues raised by a consideration of DES are of particular relevance to the scenarios discussed in this chapter. Because they are necessarily based upon assumptions about the socio-economic conditions that give rise to emissions profiles, mitigation and stabilization scenarios implicitly or explicitly contain information about DES. In principle, each stabilization or mitigation scenario describes a particular future world, with particular economic, social, and environmental characteristics. Given the strong interactions between development, environment, and equity as aspects of a unified socio-ecological system and the interplay between climate policies and DES policies, emissions scenarios are viewed in this report as an aspect of broad sustainable development scenarios.

The allocation of emissions in a scenario is coupled closely to an important policy question in climate negotiations: the fair distribution of future emission rights among nations, or "burden sharing". For example, an egalitarian formulation of the rights of developing countries to future "climate space" is often expressed in terms of equal per capita emissions allocations. Alternative assumptions on burden sharing have important implications for equity, sustainable development, and the economics of emissions abatement. However, it is noteworthy that this critical conditioning variable is usually not explicitly treated in mitigation scenarios in the literature (see section 2.3 below). Indeed, documentation of scenarios generally does not address the implications of the scenarios for equity and burden sharing. In rare cases, mitigation scenarios have been developed which explicitly impose the simultaneous co-constraints of climate and equity goals (e.g., Raskin *et al*., 1998).

In this and other ways scenario analysis could become an important way of linking DES issues to climate policy considerations. However, as discussed in more detail in section 2.4, many quantitative mitigation and stabilization scenarios have not been designed with this purpose in mind. As a result, it is not always easy to draw out the DES implications of particular stabilization and mitigation scenarios.

Although this chapter focuses on mitigation and stabilization scenarios, it is important to note that DES issues are also implicit in the base case or reference scenarios that underlie mitigation and stabilization scenarios. Since the difference between reference case scenarios and stabilization and mitigation scenarios is simply the addition of deliberate climate policy, it can be the case that the DES differences among different reference case scenarios are greater than between any one such scenario and its stabilization or mitigation version. This is of particular relevance in the discussion below in section 2.5.2 of scenarios based on the baselines produced in the IPCC's SRES (Nakicenovic *et al*., 2000).

2.3 Greenhouse Gas Emissions: General Mitigation Scenarios

This chapter reviews three scenario literatures, which span a range from more quantitative scenario analysis to analysis that is based more on narrative descriptions (see *Figure 2.1*). At the quantitative end of the spectrum are the "general mitigation scenarios" reviewed in this section, which consist mainly of quantitative descriptions of driving forces and emission profiles.

2.3.1 Overview of General Mitigation Scenarios

More than 500 emission scenarios have already been quantified, including non-mitigation (non-intervention) scenarios and mitigation (intervention) scenarios that assume policies to mitigate climate change. These scenarios have been published in the literature or reported in conference proceedings, and many of them were collected in the IPCC SRES database (Morita & Lee, 1998a) and made available through the Internet (Morita & Lee, 1998b). Using this database, a systematic review of non-mitigation scenarios has already been reported in the SRES

(Nakicenovic *et al*., 2000). However, several mitigation and other scenarios were missing from this database and new emission scenarios have been quantified since the SRES review. Accordingly, the missing scenarios and new scenarios were collected and the database revised for this new review of mitigation scenarios (Rana and Morita, 2000).

The current database collection, covered in this report, contains the results of a total of 519 scenarios from 188 sources. These scenarios were mainly produced after 1990. Two questionnaires were sent to representative modellers in the world, and sets of scenarios from the International Energy Workshop (IEW) and Energy Modelling Forum (EMF) comparison programmes were collected. The database is intended to include only scenarios that are based on quantitative models. Therefore, it does not include scenarios produced using other methods; for example, heuristic estimations such as Delphi.

Of the 519 scenarios, a total of 380 were global GHG emission scenarios, most of which were disaggregated into several regional emission profiles. Of these 380 global emission scenarios, a total of 150 were mitigation (climate policy) scenarios. This review focuses on mitigation scenarios that cover global emissions and also have a time horizon encompassing the coming century. Of the 150 mitigation scenarios, a total of 126 long-term scenarios that cover the next 50 to 100 years were selected for this review. 24 scenarios were excluded on the basis of their short time coverage.

Table 2.1 presents an outline of several representative scenarios in this review; these scenarios exemplify the modelling literature. Columns 1 and 2 of the table show the main identifiers of the scenarios, namely, the model name and source and the policy scenario name, as given by the modellers. The third and fourth columns show the policy scenario type and specific scenario assumptions. The remaining columns contain additional important features of the policy scenarios, including reduction time-paths and burden sharing, GHGs analyzed, policy options and approaches, and feedback. Only five studies among the selected sources of *Table 2.1* have detailed policies. Most of the other scenarios assume very simple policy options such as carbon taxes and simple constraints.

Based on the type of mitigation, the scenarios can be classified into four categories: concentration stabilization scenarios, emission stabilization scenarios, safe emission corridor (tolerable windows/safe landing) scenarios, and other mitigation scenarios.

Scenarios for concentration stabilization account for a large proportion of the mitigation scenarios, with 47 of the 126 mitigation scenarios being classified into this type. Many scenarios of this type were quantified in the process of the EMF comparison (Weyant and Hill, 1999) where a systematic guideline was prepared for stabilization quantification. Of the 47 scenarios, two-thirds are intended to stabilize atmospheric concentrations of CO_2 at 550ppmv. The concentration of 550ppmv was used as a benchmark for stabilization in the previous studies on mitigation scenarios. This number may be related to the frequent references made to it in political discussions. The adoption by the European Union of a maximum increase in global average temperature of 2°C above pre-industrial levels is roughly equivalent to a stabilization level of 550ppmv CO_2 equivalent or 450ppmv CO_2. It does not imply an agreed-upon desirability of stabilization at this level. In fact, environmental groups have argued for desirable levels well below 550ppmv, while other interest groups and some countries have questioned the necessity and/or feasibility of achieving 550ppmv. Scenarios with levels of concentration stabilization other than 550ppmv are contained in IPCC (1990), Manne *et al*. (1995), Alcamo and Kreileman (1996), Ha-Duong *et al*. (1997), Manne and Richels (1997), and Fujii and Yamaji (1998).

The emission stabilization scenarios account for 20 of the 126 mitigation scenarios. Most scenarios of this type are intended to stabilize at 1990 emission levels in Annex I or the Organization for Economic Co-operation and Development (OECD) countries. Some scenarios have emissions stabilizing at other levels, for example, the emissions stabilization scenario of DICE (Nordhaus, 1994) aims at a level of 8GtC/yr of CO_2 and chlorinated fluorocarbons (CFCs) by 2100. Other stabilization scenarios, namely the “Safe Emissions Corridor” or “Tolerable Windows” (WBGU, 1995; Alcamo and Kreileman, 1996; Matsuoka *et al*., 1996) and “Climate Stabilization” (Nordhaus, 1994) scenarios, determine the upper limit of emissions based on a constraint of some natural threshold, such as global mean temperature increase rate. Only a few studies are based on such scenarios.

Other scenarios based on DICE (Nordhaus, 1994), MERGE (Manne and Richels, 1997) and MARIA (Mori and Takahashi, 1998) determine the level of emission reduction based on net benefit maximization, which is estimated as the benefit produced by climatic policy minus the policy implementation cost. In addition to the above, the low CO_2-emitting energy supply system (LESS) constructions should be noted. These scenarios were developed on the basis of detailed assessments of technological potentials, and can therefore be distinguished from many other mitigation scenarios (see Box 2.2).

Of the remaining mitigation scenarios, a total of 50 adopt other criteria to reduce GHGs. Some of these scenarios assume the introduction of specific policies such as a constant carbon tax, while others assume the Kyoto Protocol targets for Annex I countries up to 2010 and a stabilization of their emissions thereafter at 2010 levels.

While all the scenarios deal necessarily with energy-related CO_2 emissions that have the most significant influence on climate change, several models include CO_2 emissions from land use changes and industrial processes (e.g., IPCC, 1992; Nakicenovic *et al*., 1993; Matsuoka *et al.*, 1995; Alcamo and Kreileman, 1996). Some of them include other important GHGs in their calculations, such as methane (CH_4) and nitrous

Table 2.1: *Overview of mitigation scenarios: the main futures of representive scenarios from 26 sources*

	Model name and source	**Policy scenario name**	**Policy scenario type**	**Specific scenario assumptions[2]**	**Reduction time paths and burden sharing**	**GHGs analyzed**	**Sectors in which policies are introduced**	**Feedbacks[3]**
1	ASF	RCWP	Emission stab.	475ppm	Based on policy scenario	CO_2, CO, CH_4, N_2O	Detailed policy scenario	EP to M
	EPA (1990)	RCWR	Emission stab.	350ppm		NO_x, CFCs	Energy supply; Land use; End use	EP to M
2	ASF/ IMAGE	Control policy ($2x CO_2$ by 2090)	Conc. stab.	540ppm	Based on policy scenario	CO_2, CO, CH_4, N_2O	Detailed policy scenario	EP to M
	IPCC (1990)	Accelerated control (< $2x CO_2$)	Conc. stab.	465ppm		NO_x, CFCs	Energy supply; Land use; End use	
3	ASF	IS92b	Other mitigation[1]	18.6BtC		CO_2, CO, CH_4, N_2O,	Energy supply; Industrial processes	EP to M
	IPCC (1992)			(CO_2 emissions)		VOC. SO_x, CFCs, NO_x		
4	MESSAGE	ECS'92 +	Other mitigation[1]			CO_2	Energy supply; Industrial processes; End use	
	Nakicenovic *et al.* (1993)							
5	DICE	Optimal policy;	Other mitigation[1]		Utility maximization	CO_2, CFCs	Energy	C to M
	Nordhaus (1994)	10-yr delay of optimal policy	Other mitigation[1]		Utility maximization	Other GHGs are		
		emission stabilization	Emission stab.	8BtC/yr (CO_2+CFCs)	Based on policy scenario	Exogenous		I to M
		20% emission cut	Other mitigation[1]	6BtC/yr (CO_2+CFCs)	Based on policy scenario			C to M
		Geoengineering	Other mitigation		Based on policy scenario			I to M
		Climate stabilization	Slow global temp. increase	0.2°C/decade	Based on policy scenario			
6	CETA	"Selfish" case	Emissions cont. by OECD		Cost minimization (regional)	CO_2, CO, CH_4, N_2O,	Energy	C to M
	Peck and Tiesberg (1995)	"Altruistic" case	Emissions cont. by OECD		Cost minimization (global)	CFCs		
		"Optimal" case	Emissions cont. by both		Cost minimization (global)			

(*continued*)

Table 2.1: *continued*

	Model name and source	Policy scenario name	Policy scenario type	Specific scenario assumptions[2]	Reduction time paths and burden sharing	GHGs analyzed	Sectors in which policies are introduced	Feedbacks[3]
7	LESS (IPCC, 1996)	LESS Constructions	Other mitigation[1]			CO_2	Energy supply	
8	Manne et al. (1995)	Delayed tax; Early tax	Other mitigation[1]	750 ppm; 540 ppm	Utility maximization	CO_2, CH_4, N_2O	Energy	C to M
	MERGE	Emission stab.	Emission stab.	540 ppm	Utility maximization			
		Conc. stab.	Conc. stab.	415 ppm	Utility maximization			
9	MESSAGE	Case C	Other mitigation[1]	430 ppm	Based on policy scenario	CO_2, CO, CH_4, N_2O,	Energy supply	
	WEC (1995)	Ecologically driven				SO_x, CFCs NO_x, VOC.	End use	
10	WBGU (1995) (German Adv. Council)	Tolerable temp. window	Safe corridor temp. rise constraint	deltaT = 1°C (upper limit)	Temp. rise constraint	CO_2		
11	AIM/Top-down	Negotiable safe emiss. corridor	Safe corridor	deltaT = 1-2°C	Temp. rise constraint	CO_2	Energy	EP to M
	Matsuoka et al. (1996)		Temperature rise const.					
12	DICE/RICE	Cooperative RICE	Other mitigation[1]		Global welfare optimization	CO_2	Energy; Land use	C to M
	Nordhaus and Yang (1996)	Non-cooperative RICE	Other mitigation[1]	Regional welf. optimization				I to M
13	IMAGE 2	Stab 350–650 ppm	Conc. stab.	367–564 ppm		CO_2, CH_4, N_2O	Energy supply; Industrial processes; Land use	
	Alcamo and Kreileman (1996)	Stab yr 1990	Conc. stab.	354 ppm				
		St2000-a - St2000-e	Other mitigation[1]	633–433 ppm				
		Safe emissions corridor	Safe corridor	deltaT = 1–2°C deg	Temp. rise constraint			
14	MiniCAM	Adv. tech	Other mitigation[1]		Based on policy scenario	CO_2, CH_4, N_2O, SO_x, aerosols, Halocarbons	Energy supply	EP to M
	Edmonds et al.	(5 Cases using						

(*coninud*)

Table 2.1: *continued*

	Model name and source	Policy scenario name	Policy scenario type	Specific scenario assumptions[2]	Reduction time paths and burden sharing	GHGs analyzed	Sectors in which policies are introduced	Feedbacks[3]
15	YOHE Yohe and Wallace (1996)	Stabilization	Conc. stab.		Based on policy scenarios	CO_2	Energy	C to M
16	DIAM Ha-Duong, *et al.* (1997)	450A-D; 550A-D; 650A	Conc. stab.		Cost minimization	CO_2	Energy	
17	FUND 1.6 Tol (1997)	Non-cooperative optimum Cooperative optimum	Other mitigation[1] Other mitigation[1]		Regional welf. optimization Generational welf. optim.	CO_2, CH_4, N_2O		
18	MERGE 3.0 Manne and Richels (1997)	Range of scenarios 350 to 750 ppm	Conc. stab.	350 to 750ppm depending on scenario	Utility maximization (non-Annex I begin limit in 2030)	CO_2	Energy	C to M
19	SGM Edmonds *et al.* (1997)	M1990 ; M1990+10%; M1990–10%; M1995	Other mitigation[1]			CO_2, CO, CH_2, N_2O, NO_x, VOC, SO_x.	Energy	EP to M
20	ABARE/GTEM Tulpule *et al.* (1998)	Independent abatement; Annex B trading; Double bubble	Other mitigation[1]	Kyoto targets		CO_2	Energy	C to M
21	AIM/Top-down Kainuma *et al.* (1998)	No trading; Annex I Trading; Global trading; Double bubble; Annex I + Chn&Ind; No trading 5% offset	Other mitigation[1]	Kyoto targets	Based on policy scenario			C to M

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Table 2.1: *continued*

	Model name and source	Policy scenario name	Policy scenario type	Specific scenario assumptions[2]	Reduction time paths and burden sharing	GHGs analyzed	Sectors in which policies are introduced	Feedbacks[3]
22	G-CUBED McKibbin (1998)	Annex I trading; Double bubble Global permit trade	Other mitigation[1]			CO_2	Energy	C to M
23	MARIA Mori and Takahashi (1998)	Case B	Emission stab.	1990 level			Energy supply; End use; Land use	C to M
24	NE21 Fujii and Yamaji (1998)	Conc. regulation	Conc. stab.	Below 550ppm	Cost minimization	CO_2	Energy	C to M
25	WorldScan Bollen *et al.* (1996)	No Trade; Full trade; Clubs Restricted trade; CDM	Other mitigation[1]	Kyoto targets		CO_2		EP to M
26	FUND 1.6 Tol (1999)	EMF-14 scenarios (WRE/WGI+ 450/550/650+ NC/C)	Conc. stab.	Various	Various			

Notes:

[1] Other mitigation means emission reduction not necessarily leading to stabilization.

[2] Specific scenario assumption indicates year 2100 level of emissions/conc. unless specified otherwise.

[3] EP: Energy price; M: Macro economy; C: Cost; I: Impact.

Box 2.2. Review of Low Carbon Dioxide Emitting Energy Supply System (LESS) Constructions from the Second Assessment Report

The LESS constructions described in the IPCC's SAR, Working Group II (IPCC, 1996, Ch19), were probably the only constructions akin to mitigation "scenarios" taken up in SAR. They are similar to the mitigation scenarios reviewed in this chapter in that they also explore alternative paths to energy futures in order to achieve mitigation of carbon dioxide.

A number of technologies with potential for reducing CO_2 emissions exist or are in a state of possible commercialization. The LESS constructions illustrate the potential for reducing emissions by using energy more efficiently and by using various combinations of low CO_2-emitting energy supply technologies, including shifts to low-carbon fossil fuels, shifts to renewable and nuclear energy sources, and decarbonization of fuels. The assumed technological feasibility and costs of each of the technologies included in these variants is based on an extensive literature review.

Both bottom-up and top-down approaches were used in the LESS constructions. For the reference cases in the bottom-up analyses, the energy demand projections for the high economic growth variant of the "Accelerated Policies" scenarios developed by the Response Strategies Working Group (RSWG, 1990) were adopted.

The five variants constructed in the bottom-up analyses were (1) BI: biomass intensive, (2) NI: nuclear intensive, (3) NGI: natural gas intensive, (4) CI: coal intensive, and (5) HD: high demand. The BI variant explores the potential for using renewable electricity sources in power generation. Both intermittent renewables (wind, photovoltaics, and solar thermal-electricity technologies) and advanced biomass electricity-generating technologies (biomass-integrated gasifier and/or gas turbine technologies through 2025 and biomass-integrated gasifier and/or fuel-cell technologies through 2050 and beyond) were applied. The NI variant involves a revitalization of the nuclear energy option and deployment of nuclear electric power technology worldwide. In the NGI variant, the emphasis is on natural gas. Any natural gas in excess of that for the reference cases is used to make methanol (CH_4O) and hydrogen (H_2). These displace CH_4O and H_2 produced from plantation biomass. In the CI variant, the strategy for achieving deep reductions involves using coal and biomass for CH_4O and H_2 production, along with sequestration of the CO_2 separated out at synthetic fuel production facilities. Finally, in the HD variant the excess demand is met by providing an extra supply of fuels with low emissions. To illustrate the possibilities, the HD variant is constructed with all of the incremental electricity provided by intermittent renewables.

A top-down exercise was carried out to test the robustness of the bottom-up energy supply analyses by incorporating performance and cost parameters for some of the key technologies in the BI variant. Six technology cases were modelled using the Edmonds–Reilly–Barns (ERB) model. The results for CO_2 emissions in two cases (cases 5 and 6) were comparable to the bottom-up LESS variants, but the energy end-uses were different owing to different assumptions.

The central finding of the LESS construction exercise is that deep reductions of CO_2 emissions from the energy sector are technically possible within 50 to 100 years, using alternative strategies. Global CO_2 emissions could be reduced from about 6GtC in 1990 to about 2GtC in 2100, in many combinations of the options analyzed. Cumulative CO_2 emissions, from 1990 to 2100, would range from about 450 to about 470GtC in the alternative LESS constructions. Higher energy efficiency is underscored in order to achieve deep reductions in CO_2 emissions, increase the flexibility of supply-side combinations, and reduce overall energy system costs.

oxide (N_2O) (e.g., EPA, 1990; IPCC, 1990; Manne *et al*., 1995; Tol, 1997), and a few go even further to include sulphates, volatile organic compounds (VOCs), and halocarbons (e.g. IPCC, 1992; WEC, 1995; Edmonds *et al*., 1996, 1997). With respect to the policy options used in the scenario quantifications, three fields are taken into account in the reviewed studies: energy systems (including both supply and demand), industrial processes (including cement and metal production), and land use (including agriculture and forest management).

Since most of the modelling exercises have been carried out to study the CO_2 emissions from human activities linked to the use of energy, energy supply and end-use are naturally the areas where policy is applied. Energy supply options include natural gas, renewable energy, and commercial biomass; introduction of new technologies; and so on. End-use options chiefly pertain to increased energy efficiency in industry, transport, and residential and/or commercial applications.

The policy instruments analyzed depend on the underlying model structure. Most of the scenarios introduce policies such as simple carbon taxes or a constraint on emissions or concentration levels for achieving the desired reduction or stabilization. How the constraint is imposed varies from scenario to scenario. Among the models with regional disaggregation, a few regional targets have been introduced (e.g., Nordhaus, 1994; Tol, 1999). Regional disaggregation also allows modellers to let the regions trade in emission permits. Permit trading is introduced in more recent work, especially just before and after the Third Conference of the Parties to the United Nations Framework Convention on Climate Change in Kyoto (December 1997). Some studies offer permit trading as a

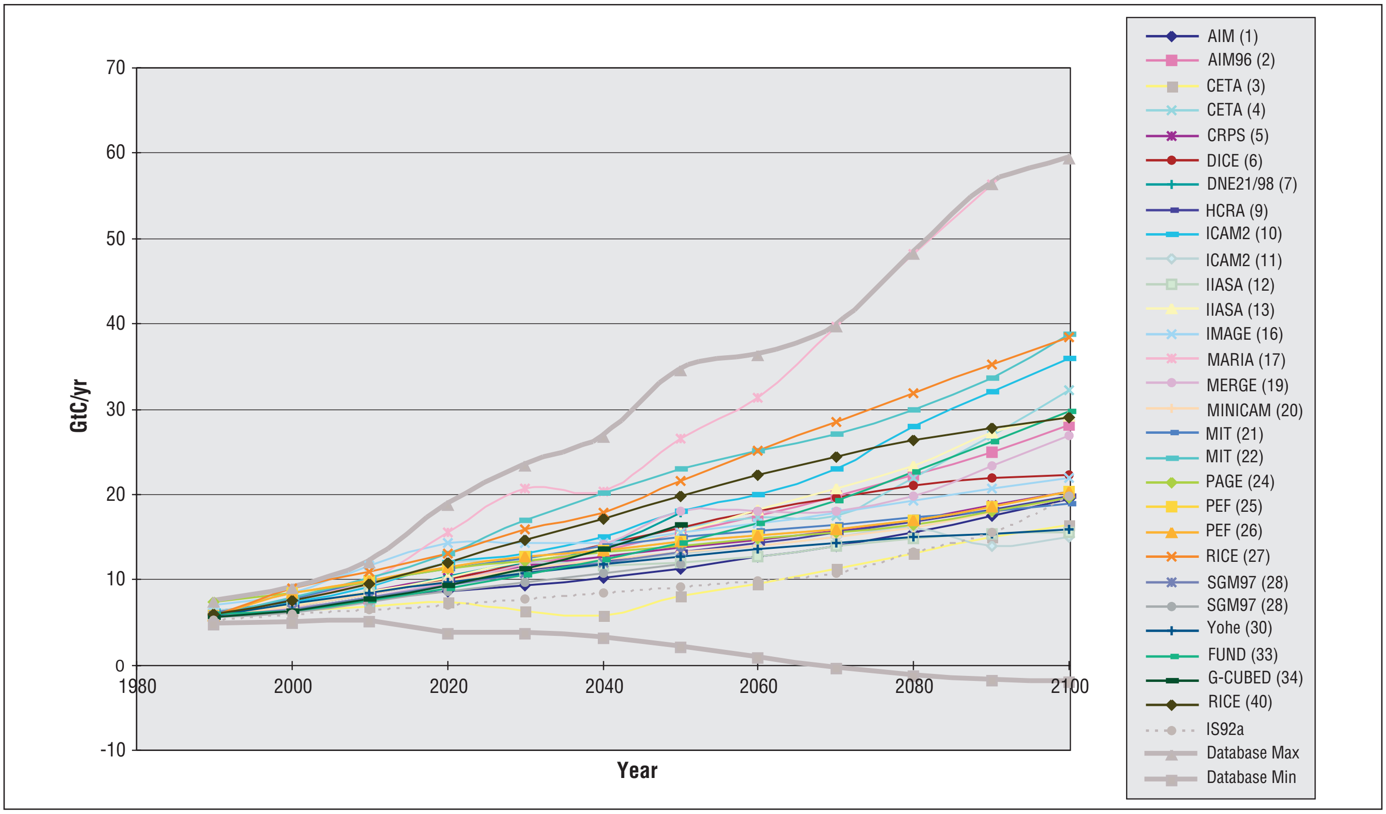

Figure 2.2: *Global CO_2 emissions from baseline scenarios used for 550ppmv stabilization quantification (fossil fuel CO_2 emissions over the period 1990 to 2100 with the maximum and minimum numbers of the database of scenarios). This figure excludes the SRES scenarios (for legend details see Appendix 2.1).*

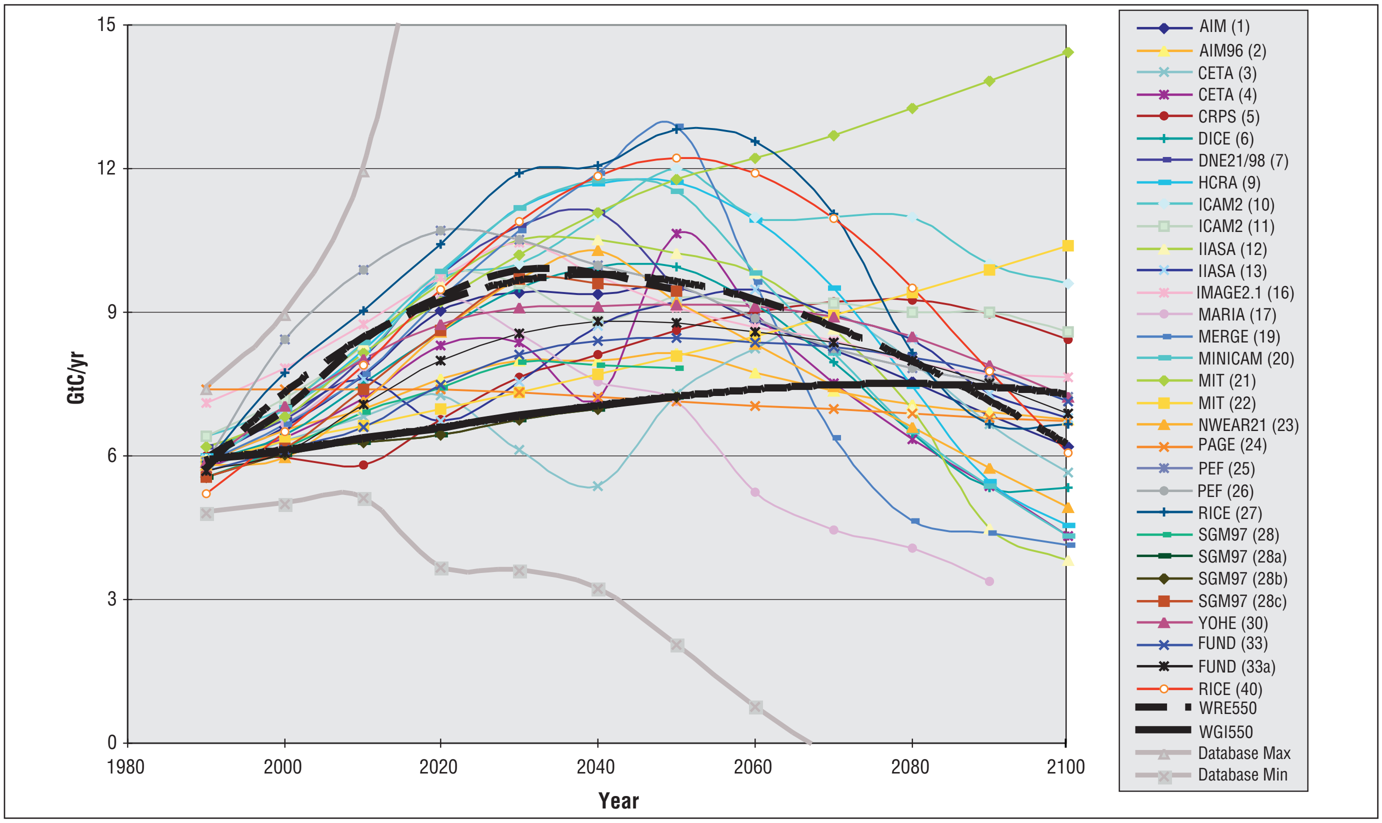

Figure 2.3: *Global CO_2 emissions from mitigation scenarios for 550ppmv stabilization (fossil fuel CO_2 emissions over the period 1990 to 2100 with the maximum and minimum numbers of the database of scenarios). This figure excludes the post-SRES scenarios (for legend details see Appendix 2.1).*

mechanism to reduce the overall costs of abatement. Much of the work done in the early 1990s led to the development of detailed scenarios for introducing such policies (EPA, 1990; IPCC, 1990, 1992). Some models employ policies of supply-side technology introduction (Nakicenovic *et al*., 1993; Edmonds *et al*., 1996; Fujii and Yamaji, 1998), while other models emphasize the introduction of efficient demand-side technology (EPA, 1990; Kainuma *et al*., 1999a).

The issue of burden sharing among regions is a contentious one and it was sparsely treated in the first half of the 1990s. Most discussions about burden sharing are of a qualitative and partial nature and are not related to model-based mitigation scenarios. A few studies (most notably Rose and Stevens, 1993; Enquete Commission, 1995; and Manne and Richels, 1997) present a set of burden-sharing rules in their scenarios. Of late, the EMF exercises looking at the Kyoto scenarios have treated this issue better than in the past (Weyant, 1999).

The time-paths of emission reduction are determined in three ways in the reviewed studies. First, the emission trajectories are determined by policy scenarios that have been designed in detail for regions over the time frame (EPA, 1990; IPCC, 1990; WEC, 1995; Edmonds *et al*., 1996; Yohe and Wallace, 1996; Kainuma *et al*., 1998). Second, dynamic optimization models automatically determine these reduction time-paths by global cost minimization over time (e.g., Peck and Tiesberg, 1995; Fujii and Yamaji, 1998) or economic welfare maximization (Nordhaus, 1994; Manne *et al.*, 1995). Third, mitigation scenarios of tolerable windows/safe landing, or safe emission corridors, can fix the time series of emission reduction by introducing a specific constraint of the rate of change in natural systems including the global temperature change rate (e.g., Alcamo and Kreileman, 1996).

Finally, there are differences in the treatment of feedback to the macro-economy in the models. While most bottom-up models have no feedback from cost to the macro-economy, top-down models allow for the feedback of energy prices to the macro-economy. The MERGE (Manne *et al.*, 1995) and CETA (Peck and Tiesberg, 1995) models also have feedback from impacts to the macro-economy.

Technological improvement is a critical element in all the general mitigation scenarios. This is apparent when the detailed policy options are studied, where such literature is available. For instance, Nakicenovic *et al*. (1993) (using MESSAGE) incorporated policies of dematerialization and recycling, efficiency improvements and industrial process changes, and fuel-mix changes in the industrial sector; fuel efficiency improvements, modal split changes, behavioural change, and technological change in the transport sector; and efficiency improvements of end-use conversion technologies, fuel-mix changes, and demand-side measures in the household and services sector. It should be noted that efficiency improvement through technological advancement is emphasized in all sectors. Similar policies leading to efficiency improvement were also underlined in earlier modelling studies such as EPA (1990), IPCC (1990), and IPCC (1992).

2.3.2 *Quantitative Characteristics of Mitigation Scenarios*

From the large number of mitigation scenarios, a selection must be made in order to clarify in a manageable way the quantitative characteristics of mitigation scenarios. One of the efficient ways to analyze them is to focus on a typical mitigation target. As the most frequently studied mitigation target is the 550ppmv stabilization scenario, a total of 31 stabilization scenarios adopting that target were selected along with their baseline (reference or non-intervention) scenarios in order to analyze the characteristics of the stabilization scenarios as well as their baselines[5]. *Figure 2.2* shows these baseline scenarios, and *Figure 2.3* shows the mitigation scenarios for 550ppmv stabilization. (The sources and scenario names are noted in *Appendix 2.1*).

2.3.2.1 Characteristics of Baseline Scenarios

In order to analyze the characteristics of stabilization scenarios, it is very important to identify the features of the baseline scenarios that have been used for mitigation quantification. Although the general characteristics of non-intervention scenarios have already been analyzed in the SRES (Nakicenovic *et al*., 2000), more specific analyses are conducted here, focusing on the baseline scenarios that have been used for 550ppmv stabilization quantification.

First, it is clear that the range of CO_2 emissions in baseline scenarios used for 550ppmv stabilization quantification is very wide at the global level, as shown in *Figure 2.2*. The maximum levels of CO_2 emissions represent more than ten times the current levels, while the minimum level represents four times current levels. The range of baseline scenarios covers the upper half of the total range of the database, and most of them were estimated to be larger than IS92a (IPCC 1992 scenario "a"). This means that the baseline scenarios used for the 550ppmv stabilization analyses have a very wide range and are high relative to other studies.

This divergence can be explained by the Kaya identity (Kaya, 1990), which separates CO_2 emissions into three factors: gross domestic product (GDP), energy intensity, and carbon intensity[6]:

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[5] This closer look at 550ppmv CO_2 stabilization scenarios is solely based on the frequency of their occurrence in the literature, which in turn has been influenced by frequent reference to this level in the policy area (e.g., it has been selected as a long-term target by the European Union). The discussion in this chapter does not imply any endorsement of this particular level as a policy target. There is a need for analysis of the feasibility and implications of stabilization levels other than 550 ppmv.

[6] The usual form of the Kaya identity separates the GDP term into population × GDP/capita. However, population assumptions were not provided for most scenarios and thus the GDP term was not disaggregated.

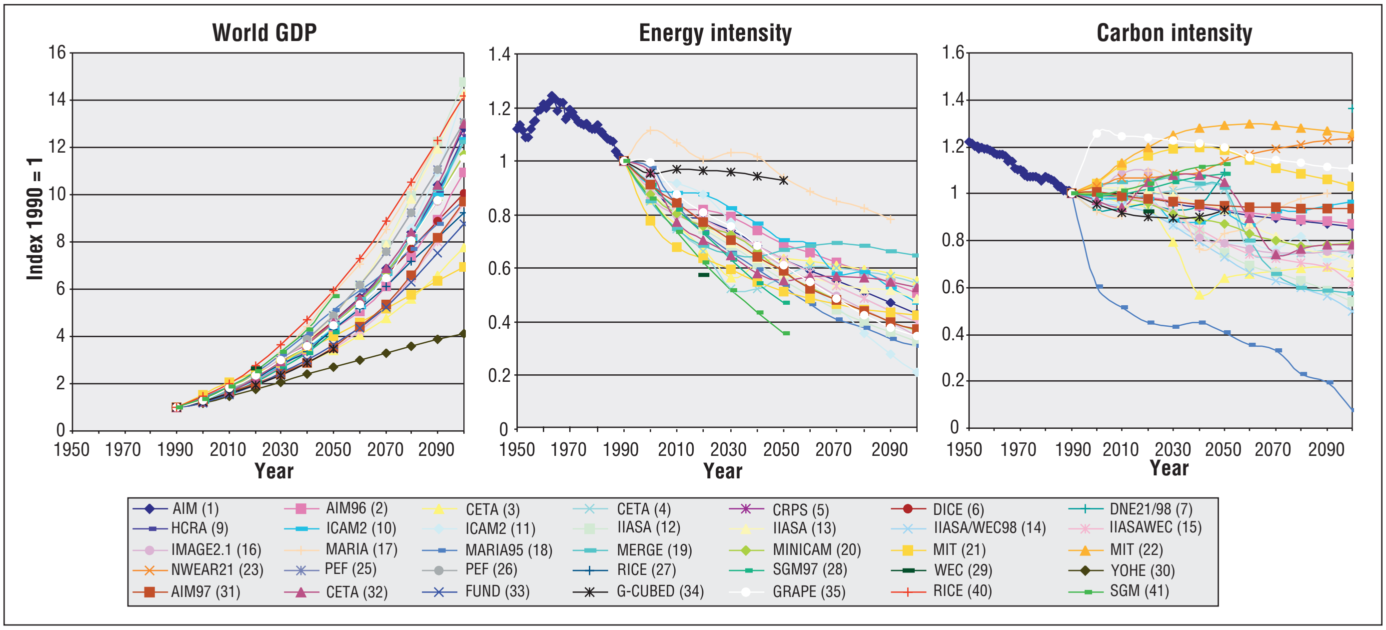

Figure 2.4: *Range of baseline assumptions in GDP, energy intensity, and carbon intensity over the period 1990 to 2100 used for 550 ppmv stabilization analyses (indexed to 1990 levels), with historical trend data for comparison (for legend details see Appendix 2.1).*

$$\begin{aligned} CO_2 \text{ emissions} &= \text{GDP} * \text{Energy intensity} * \text{Carbon intensity} \\ &= \text{GDP} * (\text{energy/GDP}) * (\text{emissions/energy}) \end{aligned}$$

Figure 2.4 shows these factors. For comparability of the factors, which were not harmonized to be the same number among models in the base year of 1990, all the values are indexed to 1990 levels. CO_2 emissions are mostly determined by energy consumption. This, in turn, is determined by the levels of GDP, energy intensity, and carbon intensity. However, the ranges of GDP and of carbon intensities in the scenarios are larger than the range of energy intensities. This suggests that the large range of CO_2 emissions in the scenarios is primarily a reflection of the large ranges of GDP and carbon intensity in the scenarios. Thus, the assumptions made about economic growth and energy supply result in huge variations in CO_2 emission projections.

These characteristics are also observed in regional scenarios. For example, in both the OECD and non-OECD scenarios, CO_2, GDP, energy intensity, and carbon intensity have wide ranges, and in particular, the range among scenarios for the non-OECD nations is wider than the range among scenarios for OECD nations. In addition, the growth of CO_2 emissions in non-OECD nations is generally larger than the growth of emissions in OECD nations. This is mainly caused by higher GDP growth in the non-OECD countries.

With regard to regional comparisons, it is very difficult to come to any general conclusions, as the ranges involved in the regional scenarios are extraordinarily large. Moreover, with the exception of the USA, Europe, the Former Soviet Union (FSU) and China, the number of available scenarios is limited. However, some general trends can be identified that are associated with the medium ranges of the scenarios: for Asian countries, GDP growth is the most significant factor, resulting in high levels of energy use and CO_2 emissions; energy efficiency improvements are the most significant factor in the scenarios for China; and carbon intensity reductions are very high in Africa, Latin America, and Southeast Asia, because of drastic energy mix changes.

Other interesting characteristics at the global level can be identified in the relationships among GDP, energy intensity, and carbon intensity. *Figure 2.5* shows a scatter plot of GDP growth rate versus energy intensity reduction from the baseline scenarios. As might be expected, the energy intensity reduction is higher with a higher GDP growth rate, while a lower energy intensity reduction is associated with a lower GDP growth rate. This relationship suggests that high economic growth scenarios assume high levels of progress in end-use technologies.

Unlike energy intensity reductions, carbon intensity reductions in the models are apparently seen as largely independent of economic growth and consequently are a function of societal choices, including energy and environmental policies. The scenarios do not show any clear relationship between energy intensity reduction and carbon intensity reduction. The values depend on regional characteristics in energy systems and technology combinations. Energy intensity reduction can include many measures other than fuel shifting. Most of the efficiency measures will result in lower carbon emissions, and fuel shifts from high-carbon to low- or non-carbon fuels can increase the efficiency of energy systems in many cases. However, carbon intensity reductions can also lead to reduced efficiency in energy systems, as in the case of shifts to biomass gasification or liquefaction, or result in increased energy consumption, as in the case of industrial carbon sequestration.

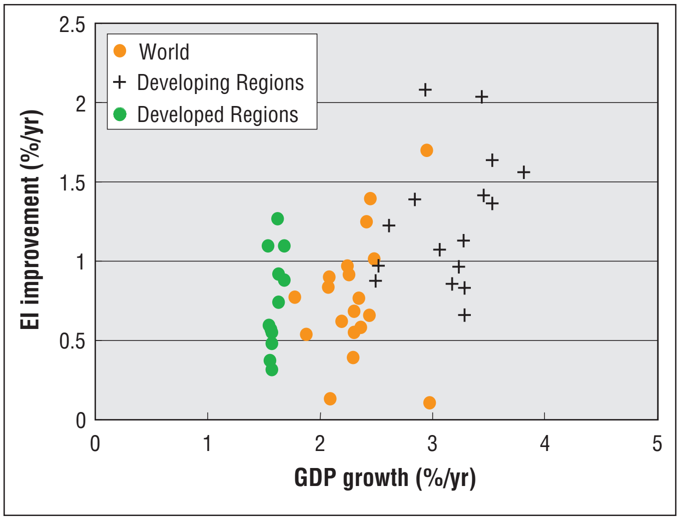

Figure 2.5: *Scatter plot of GDP growth versus energy intensity reduction in baseline scenarios (including world and regional data).*

2.3.2.2 Characteristics of Stabilization Scenarios

The stabilization scenarios that were estimated based on the above baselines also have a very wide range, as shown in *Figure 2.3*. This wide range is caused by several factors, including differences in emission time-paths for the stabilization, differences in timing of the stabilization at 550 ppmv, and different carbon cycle models used to assess the stabilization.

The divergence in reduction time-path has been discussed based on two sets of popular scenarios. One is a set of IPCC Working Group (WG) I scenarios (Houghton *et al*., 1996) which is sometimes referred to as "early action scenarios" and denoted as "WGI"; the other is a set of scenarios published by Wigley *et al*. (1996), sometimes referred to as "delayed action scenarios" and denoted "WRE". Chapter 8 explains that these terms are misleading, since WRE scenarios may not assume early emissions reductions, but do assume early actions to facilitate such reductions later. *Figure 2.3* compares the 550 ppmv stabilization scenarios of these two scenario sets with the reviewed scenarios, and it shows that scenarios reviewed here cover a wider range than that of the WGI and WRE scenarios. While the RICE and MERGE scenarios show late reduction (WRE type) trajectories, the CETA, MARIA and MIT scenarios show more severe reduction (WGI type) trajectories.[7] A few scenarios, for example ICAM2, show no drastic reduction even in the latter half of the 21st century. Most of the scenarios have emissions trajectories that lie in between.

The reduction time-path of emissions is a controversial point, which is closely related to the intergenerational equity issue. However, no conclusion can be drawn from such global trajectories, since behind them lies a distribution between countries and the political, technical, economic, and social acceptability of this distribution would depend on how the equity concerns are sorted out.

Figures 2.6 and *2.7* show energy-related CO_2 reduction at the global and the non-OECD levels, respectively, which were estimated for each scenario source by subtracting stabilization scenario emissions (*Figure 2.3*) from baseline scenario emissions (*Figure 2.2*). These figures show that the range of reduced CO_2 emissions for 550ppmv stabilization is also very wide both at the global and the non-OECD levels. This wide range is apparently caused by the divergent baseline scenarios shown in *Figure 2.2*, while other factors such as differences in emission time-path, in timing of stabilization and in the carbon cycle model used also tend to increase the range.

Figures 2.6 and *2.7* show the simulation results of models, assuming that non-OECD countries would participate in mitigation. The distribution of mitigation among the countries is based on different approaches, such as the introduction of emission caps, or the assumption of the same rate of emission reduction for all countries, or global emission trading. The results show that emission trading may lower the mitigation cost, and could lead to more mitigation in the non-OECD countries.

The regional allocation of reductions is a controversial and highly political issue from the equity viewpoint. Mostly, modellers do not explicitly state the burden-sharing rule. Nevertheless, the emission reduction from baseline by the non-Annex I countries is a good indicator of when it is assumed that these countries start sharing the reductions. The data set used in this analysis is limited in the sense that models have different regional specifications; it was therefore difficult to obtain a large number of data points to analyze non-Annex I emissions. As a proxy, emission reduction from the baseline by the non-OECD region is used, which includes Russia and Eastern Europe. This is shown in *Figure 2.7*. In part of the AIM, MiniCAM, FUND, and PEF scenarios, introduction of climate policy in the non-OECD region is assumed not to begin by 2010. Although Russia and Eastern European countries are included in the Kyoto Protocol, the models do assume that because of the decreased emissions in these countries since 1990, actual climate policies would not be needed until 2010. Some scenarios show that non-OECD regions may not have to significantly reduce emissions before 2030. However, there are still other scenarios that show an opposite picture. The RICE, MERGE, MIT, and MARIA scenarios show a very steep increase in emission reduction from baseline levels in the non-OECD region starting very early in the 21st century.

One of the ways to explain this divergence in reduction time series is to differentiate the assumptions about trade in these scenarios. Some scenarios assume trade in emission credits, which are allotted initially to each country or region. This allows some countries to purchase emission rights from other countries to minimize the cost of meeting their emission tar-

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[7] For a more detailed discussion of the WRE and WGI trajectories, see Chapters 8 and 10 of this report.

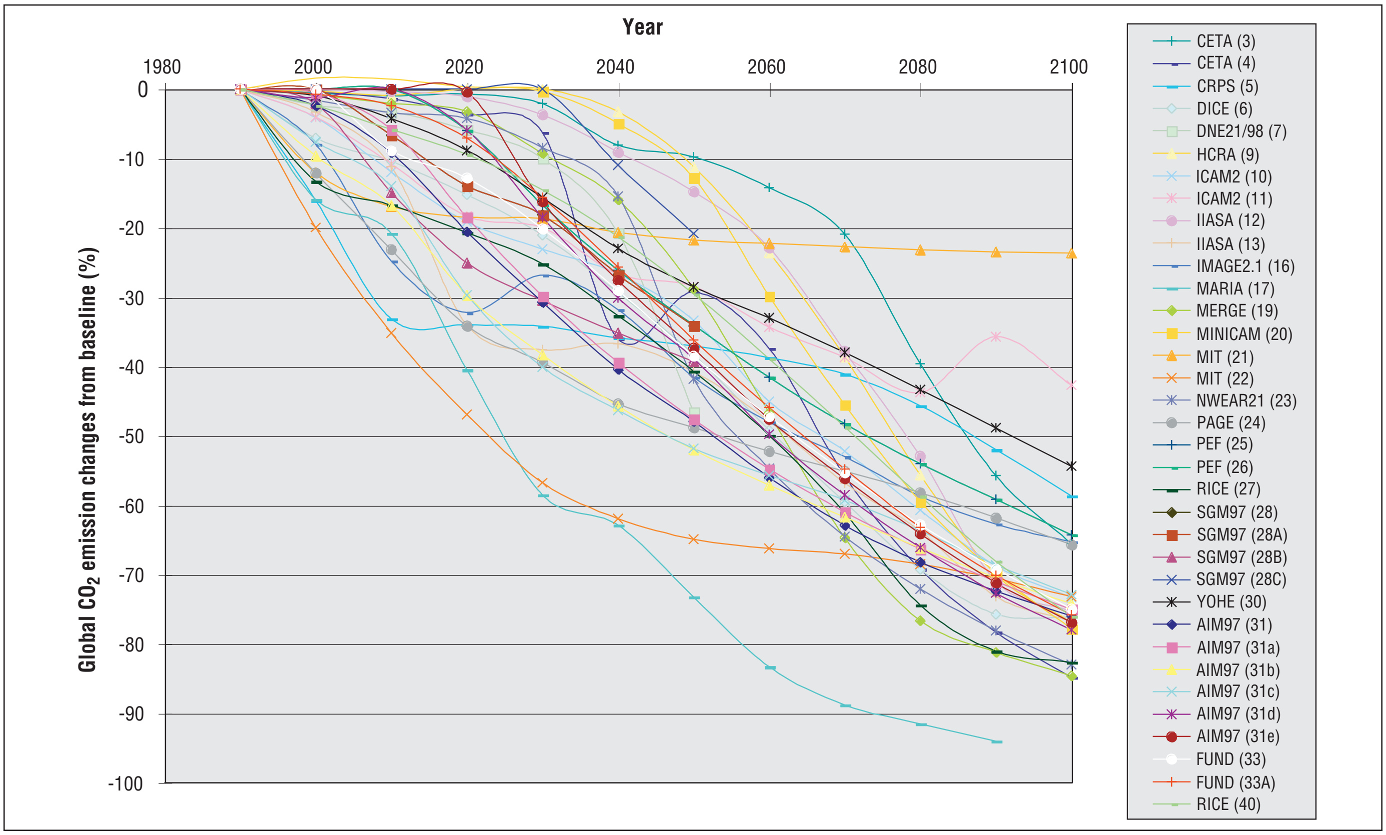

Figure 2.6: *Global CO_2 emission reduction from baseline for 550ppmv stabilization scenarios, estimated for each scenario source as baseline emissions minus emissions in the 550ppmv stabilization scenario (for legend details see Appendix 2.1).*

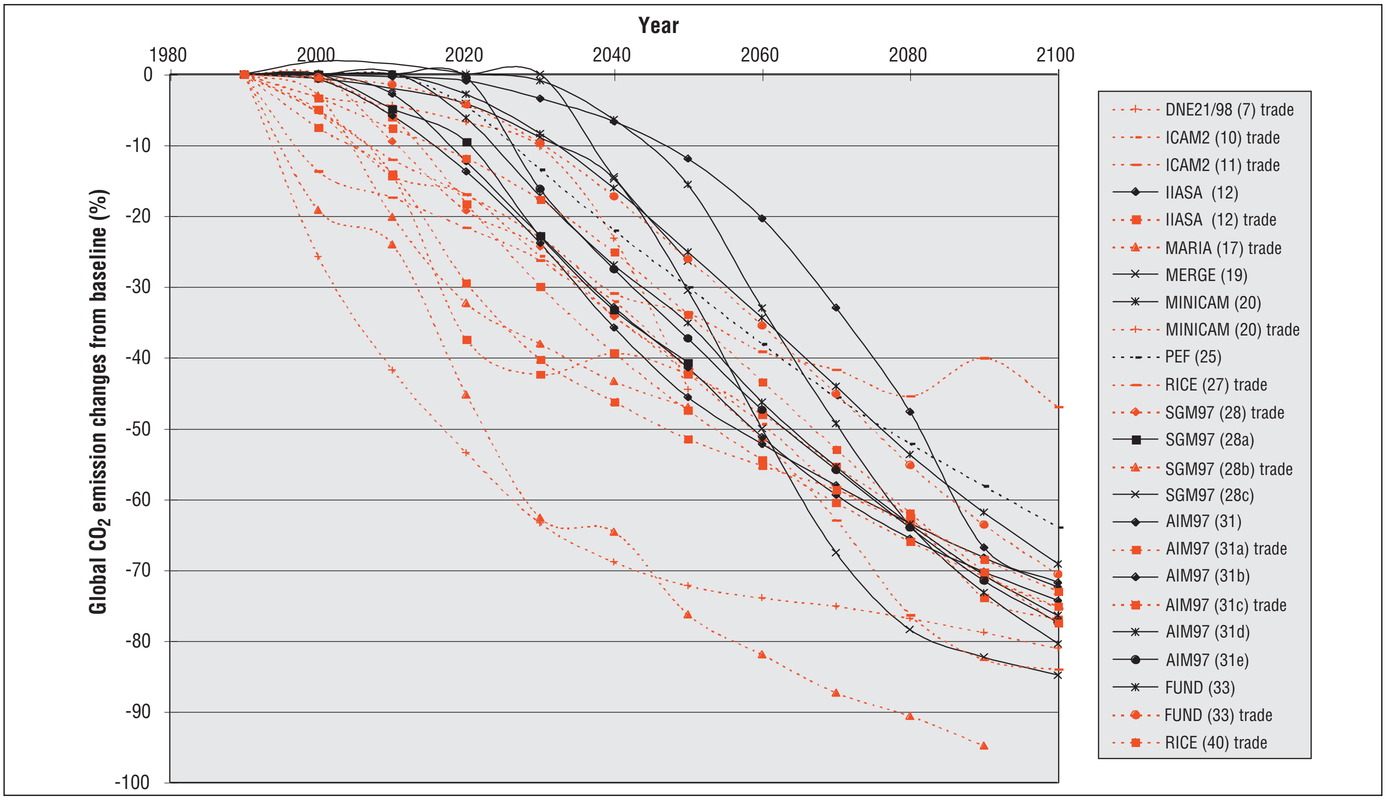

Figure 2.7: *Non-OECD CO_2 emission reduction for 550ppmv stabilization, estimated for each scenario source as baseline emissions minus emissions in the 550ppmv stabilization scenario divided by baseline emissions. Dotted lines show the scenarios which assume carbon credit trading between the OECD and developing regions (for legend details see Appendix 2.1).*

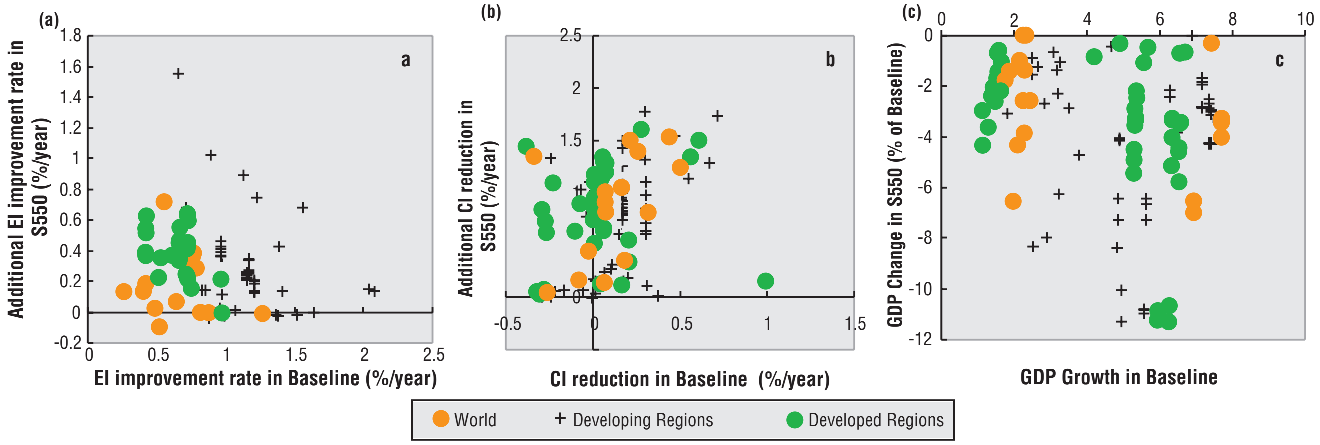

Figure 2.8: *Scatter plots to analyze the relationships between baseline scenario assumptions and mitigation scenario outputs in Energy Intensity (a), Carbon Intensity (b), and GDP growth (c).*

gets. The dotted lines in *Figure 2.7* show the scenarios that assume trade in emission credits between the Annex I and non-Annex I countries. The scenarios that show an early reduction of emissions in the non-OECD region are included in the trade scenarios, and they assume the OECD region would transfer funds to the non-OECD region via emission credit trading. Most of the other scenarios assume that the non-OECD region would start to introduce reduction policies after 2010.

With regard to overall mitigation, the range of assumed policies is very wide, resulting in a wide range of emission reductions. The additional increase in energy efficiency improvement from the baseline ranges between minus 0.04 and 1.56% per year within the sampled data, while the additional reduction in carbon intensity from the baseline is between zero and 3.76% per year. Although it is difficult to identify detailed policy assumptions from the database, the range of these factors suggests divergent policy options among scenarios. These policy options are dependent not only on the level of CO_2 reduction, but also on the baseline scenarios that have been used for 550 ppmv stabilization quantification.

Figure 2.8 (a) shows the relationship between the effects of efficiency improvement policy in mitigation scenarios and the energy intensity reduction assumption in baseline scenarios. This figure suggests an inverse relationship between them. The implication of this is that scenarios in which there is an assumed adoption of high-efficiency measures in the baseline usually would have less scope for further introduction of efficiency measures in the mitigation scenarios, as compared to scenarios that have a lower level of efficiency improvement in their baseline.[8] As a result, the additional reduction of energy intensity in mitigation scenarios over the base cases would be lower when the assumed energy intensity reduction is high in the base case, and vice versa. In the case of unanticipated technological breakthroughs, of course, this relationship may not hold and one could expect further energy efficiency improvements, even when the baseline has a fair amount of energy efficiency built into it.

Figure 2.8 (b) shows the relationship between the effects of decarbonization policies and the carbon intensity reductions assumed in the baseline scenarios. This figure suggests that baseline scenarios with high carbon intensity reductions show larger carbon intensity reductions in their mitigation scenarios, while those with low carbon intensity reductions in the base case show smaller reductions in carbon intensity in their corresponding stabilization cases. This is somewhat counterintuitive and difficult to explain simply on the basis of the results available. One might expect that high carbon intensity reductions in the base case might "use up" decarbonization potential, giving rise to lower additional reduction of carbon intensity in mitigation scenarios. On the other hand, increased investment in low-carbon energy technology in the base case could increase the resource base of low-carbon energy, thereby providing more opportunity to reduce CO_2 emissions in the stabilization case. The mitigation potential in this direction depends not only on the technology but also, and perhaps more, on the economics and social acceptance of the technology. A closer and more careful analysis of which particular mitigation policies were assumed in constructing the scenario than was possible on the basis of the available information, would reveal the underlying reasons for such a pattern.

Finally, *Figure 2.8 (c)* shows the relationship between macroeconomic costs[9] in the mitigation scenarios and GDP growth assumptions in the baseline scenarios. No clear relationship is visible, but it can be observed that macroeconomic costs for the world as a whole are estimated to range between 0% and 3.5% of GDP in 2100, while a few simple models estimate more

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[8] In part this is an artefact of the structure of the models, which cannot easily account for changes in social and technological structure such as significant changes in consumption patterns, land use, or urban form.

Box 2.3. Non-CO_2 Mitigation Scenarios

Since the publication of IPCC's SAR, the literature on mitigation scenarios has continued to focus on the reduction of CO_2 emissions rather than on other GHGs. This is unfortunate because non-CO_2 emissions make up a significant fraction of the total "basket of gases" that must be reduced under the Kyoto Protocol. However, a small set of papers has reported on scenarios for mitigating non-CO_2 gases, especially CH_4 and N_2O. In one such paper, Reilly *et al*. (1999) compared scenarios for achieving emission reductions with and without non-CO_2 emissions in Annex B countries (those countries that are included in emission controls under the Kyoto Protocol). Scenarios that omitted measures for reducing non-CO_2 gases had 21% higher annual costs in 2010 than those that included them. Tuhkanen *et al*. (1999) and Lehtilä *et al*. (1999) came to similar conclusions — in a scenario analysis for 2010, they found that including CH_4 and N_2O in mitigation strategies for Finland reduced annual costs by 20% in the year 2010 relative to a baseline scenario. The general conclusion of these papers is that small reductions of GHG emissions, for example of the magnitude required by the Kyoto Protocol, can be accomplished at a lower cost by taking into account measures to reduce non-CO_2 gases, and that a small reduction of non-CO_2 gases can produce large impacts at low cost because of the high global warming potential (GWP) of these gases.

In another type of scenario analysis, Alcamo and Kreileman (1996) used the IMAGE 2 model to evaluate the environmental consequences of a large set of non-CO_2 and CO_2 mitigation scenarios. They concluded that non-CO_2 emissions would have to be controlled along with CO_2 emissions in order to slow the increase of atmospheric temperature to below prescribed levels. Hayhoe *et al*. (1999) pointed out two additional benefits of mitigating CH_4, an important non-CO_2 gas. First, most CH_4 reduction measures do not require the turnover of capital stock (as do CO_2 measures), and can therefore be carried out more rapidly than CO_2 reduction measures. Second, CH_4 reductions will have a more immediate impact on mitigating climate change than CO_2 reductions because the atmosphere responds more rapidly to changes in CH_4 than to CO_2 concentrations.

increase in the second half of the 21st century. The GDP loss may or may not be related to the GDP growth assumptions in baselines. For instance, high baseline economic growth would lead to higher emissions of GHGs, which would lead to increased GHG reduction costs compared to the corresponding mitigation scenario for a low-growth baseline. On the other hand, high economic growth could provide increased funds for research and development (R&D) of advanced technologies, which would decrease the cost of GHG reduction. The net cost would depend on the relative strengths of these effects. Another aspect is that the costs are also dependent upon the structure of economies, i.e., economies with high fossil fuel dependence, via either exports or domestic consumption, are likely to experience higher costs compared with economies with relatively lower fossil fuel dependence.

2.3.3 *Summary of General Mitigation Scenario Review*

Many mitigation as well as stabilization scenarios have already been quantified and published. Most assume very simple policy options for their mitigation scenarios, and only some of them have detailed policy packages. These policy options have a very wide range in their level, which is apparently caused by the divergent baseline scenarios and GHG reduction targets, with other factors such as differences in models and reduction time-paths also acting to increase the range. Allocations of emission reductions between OECD and non-OECD countries also vary widely, and are affected by policy assumptions and model structures.

The mitigation scenarios under review were quantified based on a wide range of baselines that reflect a diversity of assumptions, mainly with respect to economic growth and low-carbon energy supply. The range of future trends shows greater divergence in scenarios that focus on developing countries than in scenarios that consider developed nations. There is little consensus with respect to future directions among the existing disaggregated scenarios in developing regions.

Some general conclusions about the relationships between baseline scenarios and mitigation policies are suggested by this review: an assumption of high economic growth in the baseline tends to be associated with more technological progress; the additional improvement of energy efficiency in mitigation scenarios tends to be lower when the energy efficiency improvement is high in the base case; and baseline scenarios with high carbon intensity reductions lead to mitigation scenarios with relatively more carbon intensity reduction. The counterintuitive nature of some of these conclusions suggests that the relationship between economic growth and the macroeconomic cost of emission reduction is very complicated.

Most generally, it is clear that mitigation scenarios and mitigation policies are strongly related to their baseline scenarios, but no systematic analysis has been published on the relationship between mitigation and baseline scenarios.

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[9] The macroeconomic cost is defined here as the reduction of GDP caused by GHG emission reduction in comparison to baseline GDP. It should be noted that these costs do not take into account the benefits that would occur from avoiding climate change-related damages or any co-benefits. See also Chapters 7 and 8 for a discussion of these issues.

2.4 Global Futures Scenarios

2.4.1 The Role of Global Futures Scenarios

In contrast to the GHG emission scenarios discussed in sections 2.3 and 2.5 of this chapter, "global futures" scenarios do not specifically or uniquely consider GHG emissions. Instead, they are more general "stories" of possible future worlds. Global futures scenarios can complement the more quantitative emission scenario assessments, because they consider several dimensions that elude quantification, such as governance, social structures, and institutions, but which are nonetheless important to the success of mitigation (and adaptation) policies and, more generally, describe the nature of the future world.

In this assessment, the global futures scenario literature was reviewed to achieve three objectives. First, it was consulted in order to determine the range of possible future worlds that have been identified by futurists. This aids climate change policy analysis by providing a range of potential futures against which the robustness of policy instruments may be assessed.

Second, global futures scenarios were analyzed to determine whether they displayed any relationships between the various scenario dimensions and GHG emissions. Although these relationships are often based entirely on qualitative analysis, they might nonetheless yield insights about the relationships between some dimensions, especially those that are difficult to quantify, and emissions.

Third, global futures scenarios may provide a link between the more quantitative emission scenarios and sustainable development issues. Global futures scenarios generally provide good coverage of sustainable development issues, while the quantitative emission scenarios generally provide only limited coverage of these issues. Linking the global futures scenarios with the quantitative emission scenarios therefore might also provide a link between the latter and sustainable development issues.

2.4.2 Global Futures Scenario Database

An extensive review of the futures literature was conducted and, from this review, a database of scenarios was constructed. This database contains 124 scenarios from 48 sources.[10] Scenarios were selected which were global[11], long-term, and multidimensional in scope. The scenarios consider timelines that run from the base year to anywhere between 2010 and 2100. Most scenarios are detailed and comprehensive depictions of possible future worlds, with descriptions of the social, economic, and environmental characteristics of these worlds. Others are less detailed but still describe more than one characteristic of the future world. Some scenarios are derived from the authors' judgement about most likely future conditions. Others are part of sets of possible futures, usually posited as alternatives to a reference case. Still others are normative scenarios, in that they describe the authors' visions of desirable future worlds.

In general, the global futures scenarios provide few quantified projections, although there are some notable exceptions such as CPB (1992), Meadows *et al*. (1992), Duchin *et al*. (1996), Gallopin *et al*. (1997), OECD (1997), Rotmans and de Vries (1997), Glenn and Gordon (1998), Nakicenovic *et al*. (1998), and Raskin *et al*. (1998). Several scenarios explicitly consider energy use, GHG emissions, and/or future climate change, but not all of these provide numerical estimates of the relevant variables. These quantified scenarios are different from the scenarios in the previous section since they present quantifications of primarily narrative scenarios. The basis of the scenarios in the previous section is a purely quantitative analysis of emissions profiles without narrative description.

2.4.3 Global Futures Scenarios: Range of Possible Futures

The global futures scenarios vary widely along different demographic, socio-economic, and technological dimensions, as shown in *Table 2.2*. Scenarios range from economic collapse to virtually unlimited economic prosperity; from population collapse (caused by famine, disease, and/or war), to stabilization near current levels, to explosive population growth. Governance systems range from decentralized, semi-autonomous communities with a form of direct democracy to global oligarchies. Some scenarios posit large improvements in income and social equality, within and among nations, while others foresee a widening of the income gap. Many scenarios envisage a future world that is high-tech, with varying rates of diffusion, but some envisage a world in which a crisis of some kind leads to a decline in technological development and even a loss of technological capability. Most scenarios are pessimistic with respect to resource availability; some are more

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[10] See Barney, 1993; Bossel, 1998; Coates and Jarratt, 1990; Coates, 1991, 1997; Cornish, 1996; Costanza, 1999; CPB, 1992; Duchin *et al.*, 1994; Gallopin *et al.*, 1997; GBN, 1996; Glenn and Gordon, 1997, 1998; Henderson, 1997; Hughes, 1997; IDEA Team, 1996; Kahane, 1992; Kinsman, 1990; Linden, 1998; Makridakis, 1995; McRae, 1994; Meadows *et al.*, 1992; Mercer, 1998; Millennium Project, 1998; Nakicenovic *et al.*, 1998; OECD, 1997; Olson, 1994; Price, 1995; Ramphal, 1992; Repetto, 1985; Rotmans and de Vries, 1997; Schindler and Lapid, 1989; Schwartz, 1991, 1995; Schwartz and Leyden, 1997; Science Advisory Board, 1995; Shinn, 1982; Stokke *et al.*, 1991; Sunter, 1992; Svedin and Aniansson, 1987; Toffler, 1980; van den Bergh, 1996; Wallerstein, 1989; WBCSD, 1997; 1998; Wilkinson, 1995; World Bank, 1995; WRI, 1991.

[11] The literature contains a great many scenarios that focus on specific countries or regions. However, time and space limitations precluded including these scenarios in this review.

Table 2.2: *Descriptive statistics for global futures scenario dimensions*

	Number of scenarios	**Range**	**Most common (mode)**	**Number of scenarios showing changes (compared to current situation)**		
				Declining	**Same**	**Rising**
Total Scenarios	**124**					
Size of Economy	102	collapse to high growth	Rising	24	13	65
Population Size	84	collapse to high growth	Rising	10	5	69
Level of Technology	98	stagnation & decline to very high	Rising	4	9	85
Degree of Globalization	84	isolated communities to global civilization	More global	22	1	61
Government Intervention in Economy	76	laissez-faire to strong regulation	Declining	36	9	31
Pollution	85	very low to very high	Rising	34	3	48
International Income Equality	99	very low to very high	Rising	32	16	50
Intranational Income Equality	53	very low to very high	Rising	24	0	29
Degree of Conflict	76	peace to many wars/world war	Rising	26	14	36
Fossil Fuel Use	49	virtually zero to high		24	1	24
Energy Use	51	low to high	Rising	14	0	37
GHG Emissions	45	low to high	Rising	11	1	33
Climate Change (yes/no)	0	no climate change to severe climate change				
Structure of Economy	50	agrarian/subsistence to “quaternary” (leisure)	Increasingly post-industrial	4	6	40
Percentage of Older Persons in Population	11	primarily young population to ageing population	Rising	2	0	9
Migration	30	low to high	Rising	10	0	20
Human Health	38	worsening to improving	Improving	13	3	22
Degree of Competition	41	low to high	Rising	14	0	27
Citizen Participation in Governance	56	autocracy to meaningful participation	Rising	14	14	28
Community Vitality	42	breakdown to very strong	Rising	12	0	30
Responsiveness of Institutions	75	irrelevant to very responsive/citizen-driven	Improving	21	16	38
Social Equity	38	low to high		19	1	18
Security Activity	30	low to high	Rising	13	0	17
Conflict Resolution	30	inadequate to successful	Improving	10	1	19
Technological Diffusion	58	low to high	Improving	9	13	36
Rate of Innovation	45	low to high	Rising	3	14	28
Renewable Resource Availability	28	low to high	Declining	19	1	8
Non-renewable Resource Availability	35	low to high	Rising	15	4	16
Food Availability	45	low to high	Rising	16	4	25
Water Availability	18	low to high	Declining	12	0	6
Biodiversity	33	low to high	Declining	21	2	10
Threat of Collapse	26	unlikely to likely	Rising	9	1	16

optimistic, pointing to the ability of technology and demand changes to alleviate scarcity. Most scenarios also project increasing environmental degradation; more positively, many of these scenarios portray this trend reversing in the long-term, leading to an eventual improvement in environmental quality. The sustainable development scenarios, on the other hand, describe a future in which environmental quality improves throughout the scenario.

The scenarios were grouped together according to their main distinguishing features and were combined into four groups, according to whether they described futures in which, accord-

Table 2.3: *Global futures scenario groups*

Scenario group	Scenario subgroups	Number of scenarios
1. Pessimistic Scenarios	Breakdown: collapse of human society	5
	Fractured World: deterioration into antagonistic regional blocs	9
	Chaos: instability and disorder	4
	Conservative: world economic crash is succeeded by conservative and risk-averse regime	2
2. Current Trends Scenarios	Conventional: no significant change from current and/or continuation of present-day trends	12
	High Growth: government facilitates business, leading to prosperity	14
	Asia Shift: economic power shifts from the West to Asia	5
	Economy Paramount: emphasis on economic values leads to deterioration in social and environmental conditions	9
3. High-Tech Optimist Scenarios	Cybertopia: information & communication technologies facilitate individualistic, diverse and innovative world	16
	Technotopia: technology solves all or most of humanity's problems	5
4. Sustainable Development Scenarios	Our Common Future: increased economic activity is made to be consistent with improved equity and environmental quality	21
	Low Consumption: conscious shift from consumerism	16

ing to the scenario authors, conditions deteriorate (group 1), stay the same (group 2), or improve (groups 3 and 4). These groups are summarized in Table 2.3.

The scenarios in group 1 describe futures in which conditions deteriorate from present. Some of these scenarios describe a complete breakdown of human society, because of war, resource exhaustion, or economic collapse. Other scenarios describe a future in which the world is fractured into antagonistic blocs or in which society deteriorates into chaos. Still others describe futures in which the global economic system crashes and is succeeded by a conservative, risk-averse regime.

The scenarios in group 2 describe futures in which conditions do not change significantly from the present, or in which current trends continue. Many of these scenarios are "reference" scenarios, which are used by their authors to contrast other alternative future scenarios. In general, these scenarios are pessimistic; they describe futures in which many current problems get worse, although there may be improvement in some areas. This is particularly true of the "Economy Paramount" scenarios, which describe futures in which an emphasis on economic over other values leads to deteriorating environmental and social conditions. Other scenarios in group 2 describe a more optimistic future in which government and business co-operate to improve market conditions (generally through market liberalization and free trade), leading to an increase in prosperity. Several of the group 2 scenarios foresee a shift in economic power from the West to Asia.

The group 3 scenarios could be characterized as "High-Tech Optimist" scenarios. They describe futures in which technology and markets combine to produce increased prosperity and opportunity. Many of these scenarios describe "Cybertopias" in which information and communication technologies enable a highly individualistic, diverse, and innovative global community. Other group 3 scenarios describe worlds in which technological advances solve all or most of the problems facing humanity, including environmental problems.

The scenarios in group 4 are "Sustainable Development" scenarios. In general these scenarios envisage a change in society towards improved co-operation and democratic participation, with a shift in values favouring environment and equity. These scenarios can be subdivided into two subgroups. The first subgroup might be described as "Our Common Future" scenarios in which economic growth occurs, but is managed so that social and environmental objectives may also be achieved. The second subgroup could be characterized as "Low Consumption" sustainable development scenarios. They describe worlds in which economic activity and consumerism considerably decline in importance and, usually, population is stabilized at relatively low levels. Many of these scenarios also envisage increasing regional autonomy and self-reliance.

These groups correspond quite closely with the scenario archetypes that have been developed by the Global Scenarios Group (see Box 2.4). They also roughly correspond with the 4 new emission scenario "families" that were developed in the IPCC SRES (see Section 2.5.1 below) and the scenarios developed by the World Business Council for Sustainable Development (WBCSD, 1997).

2.4.4 Global Futures Scenarios, Greenhouse Gas Emissions, and Sustainable Development

Of the 124 global futures scenarios in the database, 35 provide some kind of projection of future GHG (usually CO_2) emis-

Box 2.4. The Global Scenarios Group: Scenarios and Process

A few organizations have been developing futures scenarios that incorporate both narrative and quantitative elements, including, for example, the Dutch Central Planning Bureau (CPB, 1992), the Millennium Project (Glenn and Gordon, 1998), and the Global Scenario Group (Gallopin *et al*., 1997). The latter is discussed here as an illustration of this kind of approach to scenario development.

The Global Scenario Group (GSG) was convened by the Stockholm Environment Institute in 1995 as an international process to illuminate the requirements for a transition to global sustainability. It is a continuing and interdisciplinary process involving participants from diverse regional perspectives, rather than a single study. The GSG scenarios are holistic, developed both as narratives — accounts of how human values, cultural choices, and institutional arrangements might unfold — and detailed quantitative representations of social conditions such as level of poverty, economic patterns, and a wide range of environmental issues.

The GSG framework includes three broad classes of scenarios for scanning the future — “Conventional Worlds”, “Barbarization”, and “Great Transitions” — with variants within each class. All are compatible with current patterns and trends, but have very different implications for society and the environment in the 21st century (Gallopin *et al*., 1997). In “Conventional Worlds” scenarios, global society develops gradually from current patterns and dominant tendencies, with development driven primarily by rapidly growing markets as developing countries converge towards the development model of advanced industrial (“developed”) countries. In “Barbarization” scenarios, environmental and social tensions spawned by conventional development are not resolved, humanitarian norms weaken, and the world becomes more authoritarian or more anarchic. “Great Transitions” explore visionary solutions to the sustainability challenge, which portray the ascendancy of new values, lifestyles, and institutions.

“Conventional Worlds” is where much of the policy discussion occurs, including most of the analysis of climate mitigation. The integrated GSG approach situates the discussion of alternative emission scenarios in the context of sustainable development, by making poverty reduction an explicit scenario driver, and highlighting the links between climate and other environment and resource issues (Raskin *et al*., 1998). The regional distribution of emissions becomes an explicit consideration in scenario design that is linked to poverty reduction, equity, and burden sharing in environmentally-sound global development. By underscoring the interactions between environmental and social goals, the policy strategies for addressing climate are assessed for compatibility and synergy with a wider family of actions for fostering sustainable development.

sions. These projections range from narrative descriptions (e.g., “emissions continue to rise”) to numerical estimates. *Figure 2.9* shows global carbon dioxide emissions projections from the scenarios that provide numerical estimates.

Most (22) of these scenarios project increased emissions, but several (13) foresee declining emissions. All but one of the latter scenarios are Sustainable Development scenarios in which there is a concerted policy effort towards emission reduction, innovation in energy development towards improved efficiency and conservation, and/or alternatives to fossil fuels. The exception is a High-Tech Optimist scenario in which energy efficiency technologies and a shift to low- and non-fossil fuels bring about declining emissions.

The Sustainable Development scenarios that project declining emissions are in general characterized by increased co-operation and political participation; many assume that there is strong international agreement on the environment and development in general and climate change in particular. There is improved environmental quality and equity and, in several scenarios, increased material affluence globally (although some scenarios indicate a decline in consumerism). Population continues to grow but at slower rates and stabilizes at relatively low levels. In most scenarios significant developments of energy efficiency, energy conservation, and alternative energy technologies are key to emission reduction; a number of scenarios assume a tax on fossil fuels.

Table 2.4 summarizes the apparent relationships between emissions and scenario dimensions. It is important to note that there is considerable variety among the scenarios; *Table 2.4* therefore shows relationships that were in the majority, but not necessarily all, of the scenarios. It should also be noted that the relationships shown in *Table 2.4* do not by themselves prove causation; they simply reflect what the majority of scenarios with rising and falling GHG emissions, respectively, indicate for each scenario dimension.

What is clear from *Table 2.4* is that there are no strong patterns in the relationship between economic activity and GHG emissions. Growth in economic activity is compatible, across this set of scenarios, with both increasing and decreasing GHG emissions. In the latter case, mediating factors include increased energy efficiency, shifts to non-fossil energy sources, and/or shifts to a post-industrial (service-based) economy. Similarly, population growth is present in scenarios with rising emissions as well as scenarios with falling emissions, although in the latter group of scenarios, population tends to stabilize at relatively low levels, in many cases owing to increased prosperity, expanded provision of family planning, and improved rights and opportunities for women.

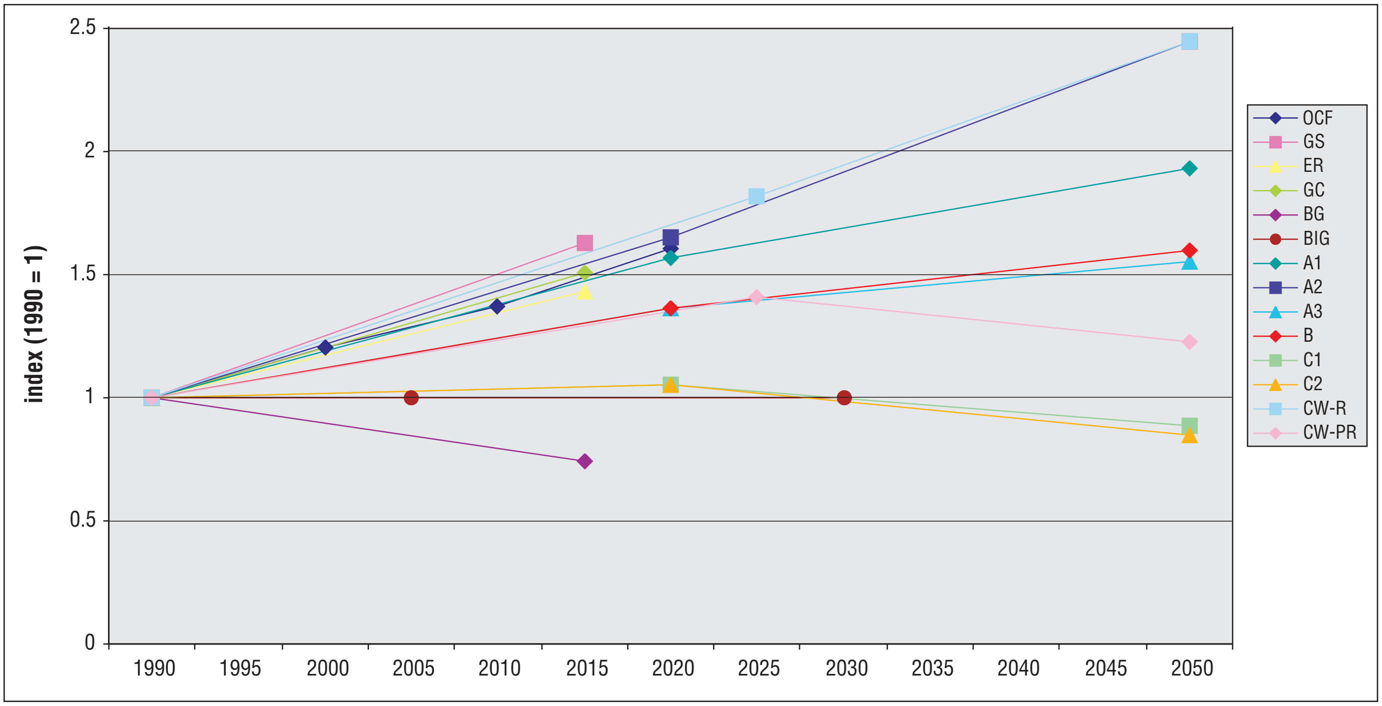

Figure 2.9: *CO_2 Emissions in Global Futures Scenarios (narrative scenarios). Acronyms: OCF, the "Our Common Future" scenario from Duchin et al., 1994; GS, the "Global Shift"; ER, the "European Renaissance"; GC, the "Global Crisis"; and BG the "Balanced Growth" scenarios from the Central Planning Bureau of the Netherlands (CPB, 1992); A1, A2, A3, B, C1 and C2, scenarios from Nakicenovic et al., 1998; CW-R, "Conventional Worlds – Reference"; and CW-PR, "Conventional Worlds – Policy Reform" from Gallopin et al., 1997 and Raskin et al., 1998. Note that this figure shows emission projections from a subset of the Global Futures Scenarios which discuss emissions, and a slightly higher proportion of scenarios in this larger group foresee declining emissions (13 of 35 scenarios, compared to 4 of 14 scenarios shown in the figure).*

Table 2.4: *Factors associated with changing GHG emissions in global futures scenarios*

Factor	**Rising GHGs**	**Falling GHGs**
Economy	Growing, post-industrial economy with globalization, (mostly) low government intervention, and generally high level of competition	Some scenarios show rising GDP, others show economic activity limited to ecologically sustainable levels; generally high level of government intervention
Population	Growing population with high level of migration	Growing population that stabilizes at relatively low level; low level of migration
Governance	No clear pattern in governance	Improvements in citizen participation in governance, community vitality, and responsiveness of institutions
Equity	Generally declining income equality within nations and no clear pattern in social equity or international income equality	Increasing social equity and income equality within and among nations
Conflict/ Security	High level of conflict and security activity (mostly), deteriorating conflict resolution capability	Low level of conflict and security activity, improved conflict resolution capability
Technology	High level of technology, innovation, and technological diffusion	High level of technology, innovation, and technological diffusion
Resource Availability	Declining renewable resource and water availability; no clear pattern for non-renewable resource and food availability	Increasing availability of renewable resources, food and water; no clear pattern for non-renewable resources
Environment	Declining environmental quality	Improving environmental quality

The major visible difference has to do with environmental impacts. As might be expected, pollution and the risk of ecological collapse are generally high in scenarios which show rising GHG emissions, and low in scenarios which show falling GHG emissions. Water availability and biodiversity decline in the scenarios with rising GHG emissions, and rise or stay the same in the scenarios with falling GHG emissions.

On a different front, in the scenarios with rising GHG emissions, conflict and security activity are generally high, while government intervention in the economy and income equality (within nations) are generally low. The reverse is true in the scenarios with falling GHG emissions, which also show improving equity between North and South. This would be expected from the fact that all but one of these scenarios are Sustainable Development scenarios.

Chapter 3 of the SRES discusses the relationships between GHG emissions and a number of driving forces, including population, economic and social development (including equity), and technology. What is clear from that discussion, which is consistent with the evidence summarized in *Table 2.4*, is that the impacts on GHG emissions of changes in these underlying driving forces are complex.

These complex relationships suggest that the choice of future “world” is more fundamental than the choice of a few driving forces in determining GHG emissions. The wide range of emissions in the various SRES baseline scenarios also demonstrates this point. Choices about DES are crucial, not just for the underlying conditions which give rise to emissions, but also for the nature and severity of climate change impacts, and the success of particular mitigation and adaptation policies. This finding is consistent with the discussion in Chapter 1, which suggests the central importance of DES issues in any consideration of climate change.

It is important therefore that emission scenarios consider qualitative aspects that are potentially important for future GHG emissions and mitigation policies. One way to do this is to link these scenarios with the broader global futures scenarios. However, this will be difficult because there are few areas of overlap, as a result of the very different natures of the two kinds of scenarios. Perhaps a more fruitful way of incorporating qualitative dimensions into quantitative scenarios, already pursued by the Global Scenarios Group and others, as well as in the SRES, is to develop quantitative estimates of key variables based on qualitative descriptions of future worlds.

2.4.5 Conclusions

A survey of the global futures literature has yielded a number of insights that are relevant to GHG emission scenarios and sustainable development. First, a wide range of future conditions has been identified by futurists, ranging from variants of sustainable development to collapse of social, economic, and environmental systems. Since future values of the underlying socio-economic drivers of emissions may vary widely, it is important that GHG emission scenarios in particular, and climate change analysis in general, not limit themselves to a narrow range of possible futures, but consider the implications for mitigation of quite different sets of future conditions. In turn, climate policies should be designed so that they are resilient against widely different future conditions.

Second, the global futures scenarios describe a wide range of worlds, from pessimistic to optimistic, that are consistent with rising GHG emissions and a smaller range of (generally optimistic) worlds that are consistent with falling emissions. Scenarios that show falling emissions tend to show improved governance, increased equity and political participation, reduced conflict, conditions supportive of lower birth rates, and improved environmental quality. Scenarios with rising emissions generally show reduced environmental quality and equity within nations and increased conflict, and are more mixed with respect to governance and international equity. Both types of scenarios generally indicate continued technological development. The Sustainable Development scenarios suggest that sustainable development approaches are feasible, and can lead to futures characterized by relatively low emissions. A key implication is that sustainable development policies, taken generally, can make a significant contribution to emission reduction.

Third, scenarios do not all show a positive relationship between emissions and economic and population growth, as is commonly assumed (see also the discussion of the Kaya identity in Section 2.3.2.1 of this chapter). This is largely because, in the scenarios with declining emissions and rising population and economic activity, policy, lifestyle choices, and technological development act to reduce emissions through efficiency improvements, energy conservation, shifts to alternative fuels, and shifts to post-industrial economic structures. This suggests that different combinations of driving forces are consistent with low emission scenarios, which agrees with the SRES findings. The implication of this would seem to be that it is important to consider the linkage between climate policy and other policies and conditions associated with the choice of future paths in a general sense. In other words, low emission futures are associated with a whole set of policies and actions that go beyond the development of climate policy itself.

In general, the global futures scenarios provide more comprehensive coverage of the issues relevant to sustainable development than the general mitigation scenarios described in section 2.3. They therefore represent an important complement to the quantitative emission scenarios. However, there are significant difficulties involved in trying to connect the mainly narrative-based scenarios discussed in this section with the more quantitatively oriented scenarios discussed earlier. In this connection, the work of the Global Scenarios Group, the SRES, and others in linking narrative scenarios addressing social, environmental, and economic elements of sustainable development with model "quantifications" appears to point the way to the type of work needed to better assess the implications of GHG mitigation for sustainable development and vice versa. Section 2.5 below discusses the SRES scenarios and process, as well as mitigation scenarios that were developed on the basis of the SRES baseline scenarios.

2.5 Special Report on Emissions Scenarios (SRES) and Post-SRES Mitigation Scenarios

This section reviews two scenario literatures. One is the SRES, which reports on the development of multiple GHG emissions baselines based on different future world views, and the other is the post-SRES literature, which involves the quantification of mitigation scenarios based on the new SRES baseline scenarios.

2.5.1 Special Report on Emissions Scenarios: Summary and Differences from TAR

2.5.1.1 IPCC Emissions Scenarios and the SRES Process

First, the reference scenarios are reviewed, namely the SRES GHG emissions scenarios. These are "reference" scenarios in the sense that they describe future emissions in the absence of specific new policies to mitigate climate change. The new scenarios are published as the Special Report on Emissions Scenarios (SRES) by the IPCC (Nakicenovic *et al*., 2000).

A key feature of the SRES process was that different methodological approaches and models were used to develop the scenarios. Another was that an "open process" was used to develop the scenarios through which researchers and other interest groups throughout the world could review and comment on the SRES scenarios as they were being developed. The SRES also aimed at improving the process of scenario development by extensively documenting the inputs and assumptions of the SRES scenarios; by formulating narrative scenario storylines; by encouraging a diversity of approaches and methods for deriving scenarios; by making the scenarios from different groups more comparable, and by assessing their differences and similarities; by expanding the range of economic-development pathways, including a narrowing of the income gap between developing and industrially developed countries; by incorporating the latest information on economic restructuring throughout the world; and by examining different trends in and rates of technological change.

2.5.1.2 SRES Approach to Scenario Development

The basic approach of the SRES writing team was to construct scenarios that were both qualitative and quantitative. The process involved first the formulation of the qualitative scenario characteristics in the form of narrative storylines and then their quantification by six different modelling approaches. The qualitative description gives background information about the global setting of the scenarios, which can be used to assess the capability of society to adapt to and mitigate climate change, and for linking the emission scenarios with DES issues. The quantitative description of emission scenarios can be used as input to models for computing the future extent of climate change, and for assessing strategies to reduce emissions.

The relation between qualitative and quantitative scenarios can be characterized in terms of *Figure 2.10*.

The SRES writing team developed four scenario "families" (see *Box 2.5* for an explanation of terminology used in the SRES), because an even number helps to avoid the impression that there is a "central" or "most likely" case. The scenarios cover a wide range – but not all possible futures. In particular, there are no "global disaster" scenarios. None of the scenarios include new explicit climate policies.

Each family has a unifying theme in the form of a "storyline" or narrative that describes future demographic, social, economic, technological, and policy trends. Four storylines were developed by the whole writing team that identified driving forces, key uncertainties, possible scenario families, and their logic. Six global modelling teams then quantified the storylines. The quantification consisted of first translating the storylines into a set of quantitative assumptions about the driving forces of emissions (for example, rates of change of population and size of the economy and rates of technological change). Next, these assumptions were input to six integrated, global models that computed the emissions of GHGs and sulphur dioxide (SO_2). As a result, a total of 40 scenarios were produced for the four storylines. The large number of alternative scenarios showed that a single storyline could lead to a large number of feasible emission pathways.

In all, six models were used to generate the 40 scenarios that comprise the four scenario families**.** Six of these scenarios,

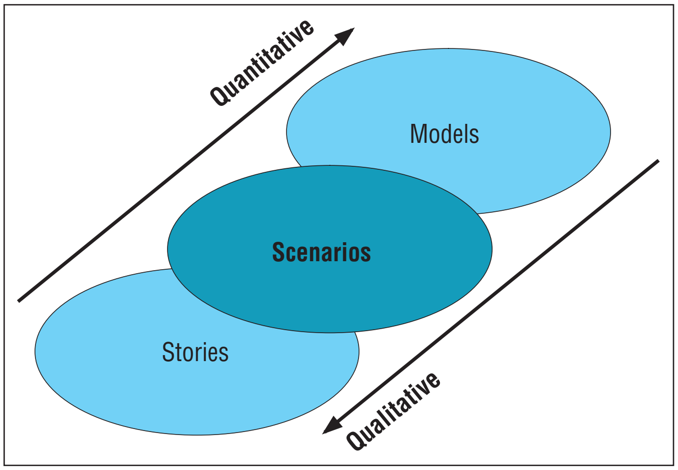

Figure 2.10: *Schematic illustration of alternative scenario formulations ranging from narrative storylines to quantitative formal models (source: Nakicenovic et al., 2000).*

Box 2.5. IPCC SRES Scenario Terminology (Source: Nakicenovic *et al.*, 2000)

Model: a formal representation of a system that allows quantification of relevant system variables.
Storyline: a narrative description of a scenario (or a family of scenarios) highlighting the main scenario characteristics, relationships between key driving forces, and the dynamics of the scenarios.
Scenario: a description of a potential future, based on a clear logic and a quantified storyline.
Family: scenarios that have a similar demographic, societal, economic, and technical-change storyline. Four scenario families comprise the SRES: A1, A2, B1, and B2.
Group: scenarios within a family that reflect a variation of the storyline. The A1 scenario family includes three groups designated by A1T, A1FI, and A1B that explore alternative structures of future energy systems. The other three scenario families consist of one group each.
Category: scenarios are grouped into four categories of cumulative CO_2 emissions between 1990 and 2100: low, medium–low, medium–high, and high emissions. Each category contains scenarios with a range of different driving forces yet similar cumulative emissions.
Marker: a scenario that was originally posted on the SRES website to represent a given scenario family. A marker is not necessarily the median or mean scenario.
Illustrative: a scenario that is illustrative for each of the six scenario groups reflected in the Summary for Policymakers of this report. They include four revised "scenario markers" for the scenario groups A1B, A2, B1, and B2, and two additional illustrative scenarios for the A1FI and AIT groups. See also "(Scenario) Groups" and "(Scenario) Markers".
Harmonized: harmonized scenarios within a family share common assumptions for global population and GDP while fully harmonized scenarios are within 5% of the population projections specified for the respective marker scenario, within 10% of the GDP and within 10% of the marker scenario's final energy consumption.
Standardized: emissions for 1990 and 2000 are indexed to have the same values.
Other scenarios: scenarios that are not harmonized.

which should be considered equally sound, were chosen to illustrate the whole set of scenarios. They span a wide range of uncertainty, as required by the SRES Terms of Reference. These encompass four combinations of demographic change, social and economic development, and broad technological developments, corresponding to the four families (A1, A2, B1, B2), each with an illustrative "marker" scenario. Two of the scenario groups of the A1 family (A1FI, A1T) explicitly explore energy technology developments, alternative to the "balanced" A1B group, holding the other driving forces constant, each with an illustrative scenario. Rapid growth leads to high capital turnover rates, which means that early small differences among scenarios can lead to a large divergence by 2100. Therefore, the A1 family, which has the highest rates of technological change and economic development, was selected to show this effect.

To provide a scientific foundation for the scenarios, the writing team extensively reviewed and evaluated over 400 published scenarios. Results of the review were published in the scientific literature (Alcamo and Nakicenovic, 1998), and made available to the scientific community in the form of an Internet scenario database. The background research by the six modelling teams for developing the 40 scenarios was also published in the scientific literature (Nakicenovic, 2000).

2.5.1.3 A Short Description of the SRES Scenarios

Since there is no agreement on how the future will unfold, the SRES tried to sharpen the view of alternatives by assuming that individual scenarios have diverging tendencies — one emphasizes stronger economic values, the other stronger environmental values; one assumes increasing globalization, the other increasing regionalization. Combining these choices yielded four different scenario families (*Figure 2.11*). This two-dimensional representation of the main SRES scenario characteristics is an oversimplification. It is shown just as an illustration. In fact, to be accurate, the space would need to be multi-dimensional, listing other scenario developments in many different social, economic, technological, environmental, and policy dimensions.

The titles of the four scenario storylines and families have been kept simple: A1, A2, B1, and B2. There is no particular order among the storylines; they are listed in alphabetical and numerical order:

- The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).[12]
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-

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[12] Balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies.

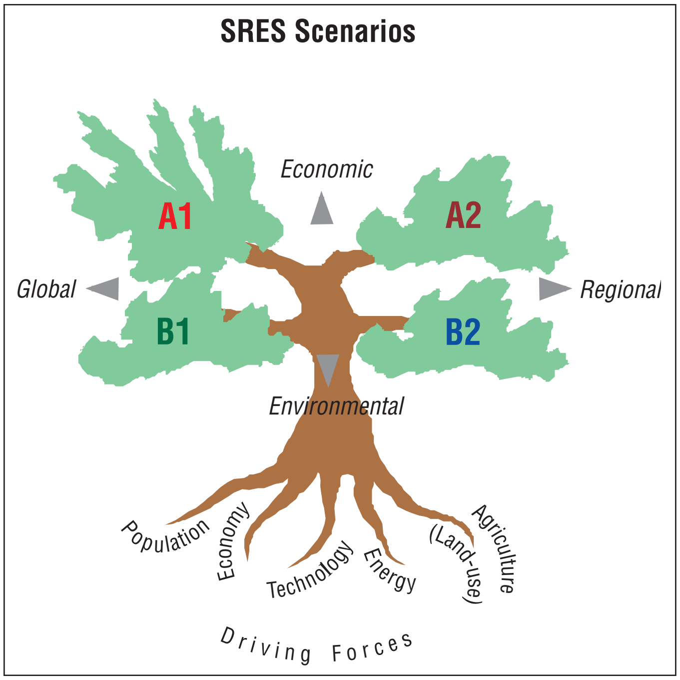

Figure 2.11. *Schematic illustration of SRES scenarios. The four scenario "families" are shown, very simplistically, for illustrative purposes, as branches of a two-dimensional tree. The two dimensions shown indicate global and regional scenario orientation, and development and environmental orientation, respectively. In reality, the four scenarios share a space of a much higher dimensionality given the numerous driving forces and other assumptions needed to define any given scenario in a particular modelling approach. The schematic diagram illustrates that the scenarios build on the main driving forces of GHG emissions. Each scenario family is based on a common specification of some of the main driving forces.*

reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

- The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures towards a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with a continuously increasing global population at a rate lower than in A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

In all, six models were used to generate the 40 scenarios that comprise the four scenario families. They are listed in *Table 2.5*. These six models are representative of emissions scenario modelling approaches and different integrated assessment frameworks in the literature, and include so-called top-down and bottom-up models.

Table 2.5: *Models used to generate the SRES scenarios*

Model	**Source**	**Reference**
Asian Pacific Integrated Model (AIM)	National Institute of Environmental Studies in Japan	Morita *et al.*, 1994 Kainuma *et al.*, 1998, 1999a, 1999b
Atmospheric Stabilization Framework Model (ASF)	ICF Consulting in the USA	EPA 1990; Pepper *et al.*, 1992
Integrated Model to Assess the Greenhouse Effect (IMAGE), used in connection with the WorldScan model	IMAGE: RIVM and WorldScan: CPB (Central Planning Bureau), The Netherlands	IMAGE: Alcamo 1994; Alcamo *et al.*,1998; de Vries *et al.*, 1999 WorldScan: CPB Netherlands, 1999
Multiregional Approach for Resource and Industry Allocation (MARIA)	Science University of Tokyo in Japan	Mori and Takahashi, 1998
Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE)	IIASA in Austria	Messner *et al.*, 1996; Riahi and Roehrl, 2000
The Mini Climate Assessment Model (MiniCAM)	PNNL in the USA	Edmonds *et al.*, 1996

2.5.1.4 Emissions and Other Results of the SRES Scenarios

Figure 2.12 illustrates the range of global energy-related and industrial CO_2 emissions for the 40 SRES scenarios against the background of all the 400 emissions scenarios from the literature documented in the SRES scenario database. The six scenario groups are represented by the six illustrative scenarios. *Figure 2.12* also shows a range of emissions of the six scenario groups next to each of the six illustrative scenarios.

Figure 2.12 shows that the four marker and two illustrative scenarios by themselves cover a large portion of the overall scenario distribution. This is one of the reasons that the SRES Writing Team recommended the use of all four marker and two illustrative scenarios in future assessments. Together, they cover most of the uncertainty of future emissions, both with respect to the scenarios in the literature and the full SRES scenario set. *Figure 2.12* also shows that they are not necessarily close to the median of the scenario family because of the nature of the selection process. For example, A2 and B1 are at the upper and lower bounds of their scenario families, respectively. The range of global energy-related and industrial CO_2 emissions for the six illustrative SRES scenarios is generally somewhat lower than the range of the IPCC IS92 scenarios (Leggett *et al*., 1992; Pepper *et al*., 1992). Adding the other 36 SRES scenarios increases the covered emissions range. Jointly, the SRES scenarios cover the relevant range of global emissions, from the 95th percentile at the high end of the distribution all the way down to very low emissions just above the 5th percentile of the distribution. Thus, they only exclude the most extreme emissions scenarios found in the literature – those situated out in the tails of the distribution. What is perhaps more important is that each of the four scenario families covers a sizable part of this distribution, implying that a similar quantification of driving forces can lead to a wide range of future emissions. More specifically, a given combination of the main driving forces is not sufficient to uniquely determine a future emission path. There are too many uncertainties. The fact that each of the scenario families covers a substantial part of the literature range also leads to an overlap in the emissions ranges of the four families. This implies that a given level of future emissions can arise from very different combinations of dri-

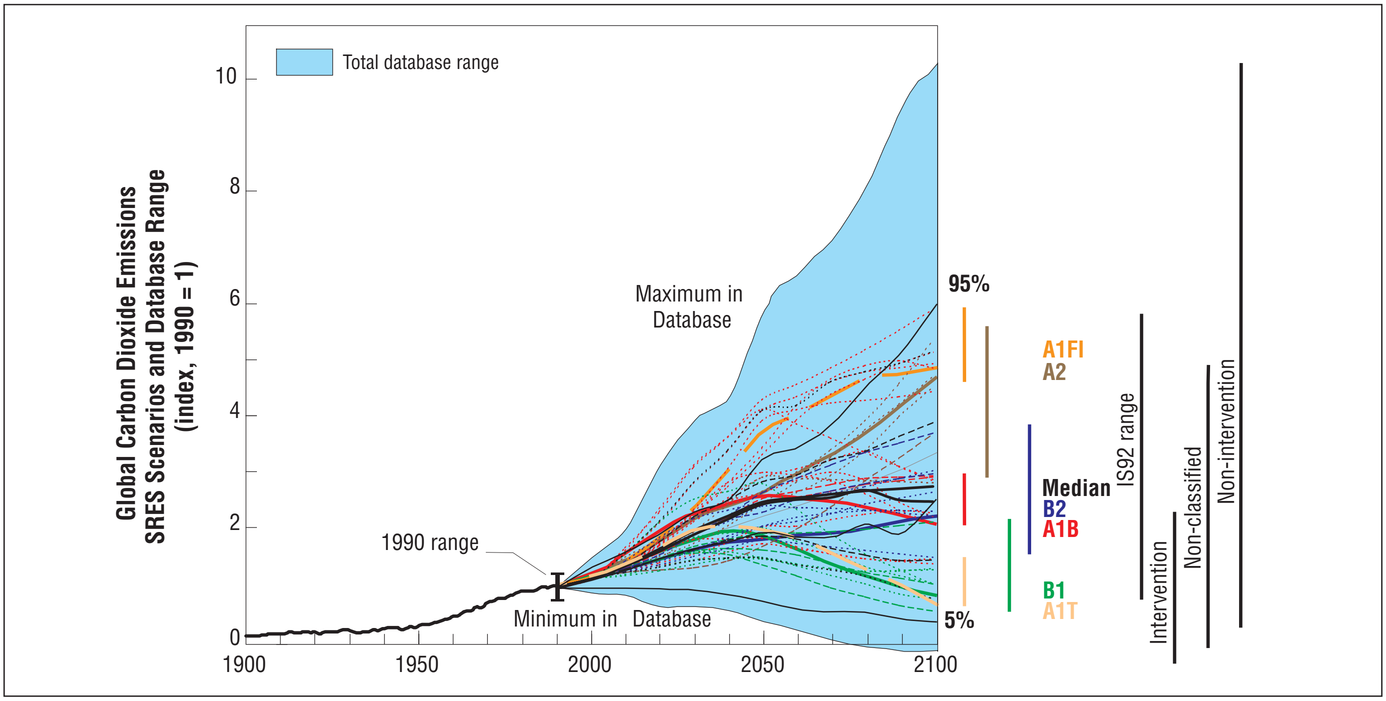

Figure 2.12: *Global CO_2 emissions from energy and industry, historical development from 1900 to 1990 and in 40 SRES scenarios from 1990 to 2100, shown as an index (1990 = 1). The range is large in the base year 1990, as indicated by an "error" bar, but is excluded from the indexed future emissions paths. The dashed time-paths depict individual SRES scenarios and the blue shaded area the range of scenarios from the literature (as documented in the SRES database). The median (50th), 5th, and 95th percentiles of the frequency distribution are shown. The statistics associated with the distribution of scenarios do not imply probability of occurrence (e.g., the frequency distribution of the scenarios in the literature may be influenced by the use of IS92a as a reference for many subsequent studies). The 40 SRES scenarios are classified into six groups. Jointly the scenarios span most of the range of the scenarios in the literature. The emissions profiles are dynamic, ranging from continuous increases to those that curve through a maximum and then decline. The coloured vertical bars indicate the range of the four SRES scenario families in 2100. Also shown as vertical bars on the right are the ranges of emissions in 2100 of IS92 scenarios, and of scenarios from the literature that apparently include additional climate initiatives (designated as "intervention" scenarios emissions range), those that do not ("non-intervention"), and those that cannot be assigned to either of these two categories ("non-classified").*

ving forces. This result is of fundamental importance for assessments of climate change impacts and possible mitigation and adaptation strategies.

An important feature of the SRES scenarios obtained using the SAR methodology is that their overall radiative forcing is higher than the IS92 range despite comparatively lower GHG emissions (Wigley and Raper, 1992; Wigley *et al*., 1994; Houghton *et al*., 1996; Wigley, 1999; Smith *et al*., 2000; IPCC, 2001). This results from the loss of sulphur-induced cooling during the second half of the 21st century. On one hand, the reduction in global sulphur emissions reduces the role of sulphate aerosols in determining future climate, and therefore reduces one aspect of uncertainty about future climate change (because the precise forcing effect of sulphate aerosols is highly uncertain). On the other hand, uncertainty increases because of the diversity in spatial patterns of SO_2 emissions in the scenarios. Future assessments of possible climate change need to account for these different spatial and temporal dynamics of GHG and sulphur emissions, and they need to cover the whole range of radiative forcing associated with the scenarios.

In summary, the SRES scenarios lead to the following findings:

- Alternative combinations of driving-force variables can lead to similar levels and structure of energy use and land-use patterns, as illustrated by the various scenario groups and scenarios. Hence, even for a given scenario outcome, for example, in terms of GHG emissions, there are alternative combinations and alternative pathways that could lead to that outcome. For instance, significant global changes could result from a scenario of high population growth, even if per capita incomes would rise only modestly, as well as from a scenario in which a rapid demographic transition (low population levels) coincides with high rates of income growth and affluence.
- Important possibilities for further bifurcations in future development trends exist within one scenario family, even when adopting certain values for important scenario driving force variables to illustrate a particular possible development path.
- Emissions profiles are dynamic across the range of SRES scenarios. They portray trend reversals and indicate possible emissions crossover among different scenarios. They do not represent mere extensions of a continuous increase of GHGs and sulphur emissions into the future. This more complex pattern of future emissions across the range of SRES scenarios reflects the recent scenario literature.
- Describing potential future developments involves inherent ambiguities and uncertainties. One and only one possible development path (as alluded to for instance in concepts such as "business-as-usual scenario") simply does not exist. And even for each alternative development path described by any given scenario, there are numerous combinations of driving forces and numerical values that can be consistent with a particular scenario description. This particularly applies to the A2 and B2 scenarios that imply a variety of regional development patterns that are wider than in the A1 and B1 scenarios. The numerical precision of any model result should not distract from the basic fact that uncertainty abounds. However, in the opinion of the SRES writing team, the multi-model approach increases the value of the SRES scenario set, since uncertainties in the choice of model input assumptions can be more explicitly separated from the specific model behaviour and related modelling uncertainties.
- Any scenario has subjective elements and is open to various interpretations. While the SRES writing team as a whole has no preference for any of the scenarios, and has no judgement about the probability or desirability of the scenarios, the open process and reactions to SRES scenarios have shown that individuals and interest groups do have such judgements. This will stimulate an open discussion in the political arena about potential futures and choices that can be made in the context of climate change response. For the scientific community, the SRES scenario exercise has led to the identification of a number of recommendations for future research that can further increase understanding about potential development of socio-economic driving forces and their interactions, and associated GHG emissions.

2.5.2 Review of Post-SRES Mitigation Scenarios

2.5.2.1 Background and Outline of Post-SRES Analysis

The review of general mitigation scenarios shows that mitigation scenarios and policies are strongly related to their baselines, and that there has been no systematic comparison of the relationship between baseline and mitigation scenarios. Modellers participating in the SRES process recognized the need to analyze and compare mitigation scenarios using as their baselines the new IPCC scenarios, which quantify a wide range of future worlds. Consequently, they participated (on a voluntary basis) in a special comparison programme to quantify SRES-based mitigation scenarios (Morita *et al*., 2000a; 2000b). These SRES-based scenarios are called "Post-SRES Mitigation Scenarios".

The process of the post-SRES analysis was started by a public invitation to modellers. A "Call for Scenarios" was sent to more than one hundred researchers in March 1999 by the Coordinating Lead Authors of this chapter and the SRES to facilitate an assessment of the potential implications of mitigation scenarios based on the SRES cases, which report was developed in support of the Third Assessment Report. Modellers from around the world were invited to prepare quantified stabilization scenarios for two or more concentrations of atmospheric CO_2, based on one or more of the six SRES scenarios. Concentration ceilings include 450, 550 (minimum require-

Table 2.6: *Post-SRES participants and quantified scenarios (indicated by CO_2 stabilization target in ppmv)*

Baseline scenarios	**A1B**	**A1FI**	**A1T**	**A2**	**B1**	**B2**
AIM (NIES and Kyoto University, Japan)	450, 550, 650	550		550	550	550
ASF (ICF Corporation, USA)				550, 750		
IMAGE (RIVM, Netherlands)	550				450	
LDNE (Tokyo University, Japan)	550	550	550	550	550	550
MARIA (Science University of Tokyo, Japan)	450, 550, 650		450, 550, 650		450, 550	450, 550, 650
MESSAGE-MACRO (IIASA, Austria)	450, 550, 650	450(*), 550(*) 650(*), 750(*)	450, 550	550, 750		550
MiniCAM (PNNL, USA)	550(*)	450, 550, 650, 750		550	450, 550	550 (*)
PETRO (Statistics Norway, Norway)	450, 550, 650, 750		450, 550 650, 750			
WorldScan (CPB, Netherlands)	450 (**), 550(**)			450, 550(**)	450(**), 550	450(**), 550

Notes: (*) High and low baselines were used; (**) An early action and a delayed response were quantified.

ment), 650, and 750ppmv, and harmonization with the SRES scenarios was required by tuning reference cases to SRES values for GDP, population, and final energy demand.

Nine modelling teams participated in the comparison programme, including six SRES modelling teams and three other teams: AIM team (Jiang *et al*., 2000), ASF team (Sankovski *et al*., 2000), IMAGE team, LDNE team (Yamaji *et al*., 2000), MESSAGE-MACRO team (Riahi & Roehrl, 2000), MARIA team (Mori, 2000), MiniCAM team (Pitcher, 2000), PETRO team (Kverndokk *et al.*, 2000) and WorldScan team (Bollen *et al*., 2000). *Table 2.6* shows all the modelling teams and the stabilized concentration levels which were adopted as stabilization targets by each one. Most of the modelling teams covered more than two SRES baseline scenarios, and half of them developed multiple stabilization cases for at least one baseline, so that a systematic review can be conducted to clarify the relationship between baseline scenarios and mitigation policies and/or technologies.

While all baselines were analyzed, the A1B baseline was most frequently used. Across baselines, the stabilization target of 550ppmv seemed to be the most popular. Because of time constraints involved in quantifying the stabilization scenarios, the modelling teams mostly focused their analyses on energy-related CO_2 emissions. However, about half of the modelling teams, notably the AIM, IMAGE, MARIA, and MiniCAM teams, have quantified mitigation scenarios in non-energy CO_2 emissions as well as in non-CO_2 emissions. The modelling teams that did not estimate non-energy CO_2 emissions introduced scenarios of them from outside of their models for estimating atmospheric concentrations of CO_2.

In order to check the performance of CO_2 concentration stabilization for each post-SRES mitigation scenario, a special "generator" (Matsuoka, 2000) was used by the modelling teams to convert the CO_2 emissions into CO_2 concentration trajectories. In addition, the generator was used by them to estimate the eventual level of atmospheric CO_2 concentration by 2300, based on the 1990 to 2100 CO_2 emissions trajectories from the scenarios. This generator is based on the Bern Carbon Cycle Model (Joos *et al*., 1996), which was used in the IPCC SAR (IPCC, 1996) and TAR (IPCC, 2001). Using this generator, each modelling team adjusted their mitigation scenarios so that the interpolated CO_2 concentration reached one of the alternative fixed target levels at the year 2150 within a 5% error. The year 2150 was selected based on Enting *et al*. (1994) who gave a basis for stabilization scenarios of the IPCC SAR (IPCC, 1996).[13] A further constraint imposed was that the

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[13] Enting *et al*. (1994) selected the timings to reach alternative target levels in 2100 year for 450ppmv, 2150 year for 550 ppmv, 2200 year for 650ppmv, and 2250 year for 750ppmv. Post-SRES modellers selected only the year 2150 for all the stabilization targets; this decision was a consequence of the tight time constraints the modelling teams faced for preparation of the scenarios. As a result, 450ppmv stabilization scenarios of post-SRES require slightly more reductions of CO_2 than those of IPCC (1995), while 650 and 750ppmv stabilization scenarios of post-SRES require slightly less reductions than those of IPCC (1995), both during the period from now to 2150.

interpolated emission curve should be smooth after 2100, the end of the time-horizon of the scenarios. This adjustment played an important role in the post-SRES analyses for harmonizing emissions concentrations levels across the stabilization scenarios. The key driving forces of emissions such as population, GDP, and final energy consumption were harmonized in baseline assumptions specified by the six SRES scenarios.

2.5.2.2 Storylines of Post-SRES Mitigation Scenarios

The procedure for creating post-SRES mitigation scenarios was similar to the SRES process, even though the period for the post-SRES work was much shorter than that for the SRES and, in contrast to the SRES process, the exercise was voluntary and not mandated by the IPCC. The storyline approach of SRES indicates that different future worlds will have different mitigative capacities (cf. Chapter 1). Hence, the first step of the post-SRES scenario work was to create storylines for the mitigation scenarios.

In general, mitigation scenarios are defined relative to a baseline scenario. If mitigation strategies are formulated and implemented in any of the future worlds as described within SRES, a variety of aspects of that world will determine the capacity to formulate and implement carbon reduction policies, for instance:

- The availability and dissemination of relevant knowledge on emissions and climate change;
- The institutional, legal, and financial infrastructure to implement mitigation policies and measures;
- Entrepreneurial and/or governmental policies for generating innovation and encouraging the penetration of new technologies; and
- The mechanisms by which consumers and entrepreneurs respond to changing prices and new products and processes.

In the post-SRES process, it was difficult for the modelling teams to consider all of these aspects with relation to the SRES future worlds, because of their inherent complexity and the amount of time available for the work. However, some aspects were considered by some modelling teams and these were reflected in the quantification assumptions. The rest of this section illustrates these major points in the form of storylines for each of the six SRES scenarios, which describe the relationship between the kind of future world on the one hand and the capacity for mitigation on the other.

The A1 world is well equipped to formulate and implement mitigation strategies in view of its high-tech, high-growth orientation and its willingness to co-operate at a global scale, provided the major actors acknowledge the need for mitigation. There will be good monitoring and reporting on emissions and climate change, and possible signs of climate change will be detected early and become part of the international agenda. Market-oriented policies and measures will be the preferred response. Least-cost options will be searched for and implemented through international negotiation and mechanisms with the support of governments and multinational companies. New emission reduction technologies from developed countries will enable developing countries to respond more rapidly and effectively if barriers to technology transfer can be overcome. In this high-growth world, the economic costs associated with the response to climate change are likely to be bearable. In the A1B scenario, where mitigation strategies may hit the limits of renewable energy supply, and in the A1FI scenario, carbon removal and storage as well as higher end-use energy efficiency will become major emission reduction options. In the A1T scenario, technology developments are such that mitigation policies and measures only require limited additional efforts.

Developing and implementing climate change mitigation measures and policies in the A2 world can be quite complicated. This is a result of several features embedded in the scenario storyline: rapid population growth, relatively slow GDP per capita growth, slow technological progress, and a regional and partially “isolationist” approach in national and international politics. Because of all these serious challenges, the abatement of GHG emissions in the A2 world becomes plausible only in the situation when the negative effects of climate change become imminent and the associated losses “outweigh” the costs of mitigation. The same features that make the A2 world “non-receptive” to worldwide mitigation policies may exacerbate the climate change effects and prompt nations to act. Measures such as a rapid shift towards high-tech renewable energy or deep-sea carbon storage will be highly improbable in the A2 world as a consequence of technology limitations. Instead, such relatively low-tech measures as limiting energy consumption, and capturing and using methane from natural gas systems, coal mining, and landfills better fit the A2 world’s economic and technological profile. The lack of global co-operation may cause rather large regional variations in the feasibility and cost of mitigation policies and measures.

The B1 world is also well equipped to formulate and implement mitigation strategies, in view of its high economic growth and willingness to co-operate at a global scale. In comparison with the A1 world, however, it will be confronted with higher marginal abatement costs, although total costs are much lower than in A1B or A1FI. This is because baseline carbon emissions are lower in the B1 world compared to the A1 world, a consequence of the emphasis on sustainable development in B1. There will be intense monitoring and reporting of emissions and climate change. The precautionary principle informs international agenda setting and policy formulation, with governments taking responsibility for climate change-related preventive and adaptive action. Tightening international standards generates incentives for further innovation towards energy-efficiency and low- and zero-carbon options. Educational campaigns are another important instrument. Developed regions support the less developed regions in a variety of ways, including transfer of energy-efficiency and renewable-energy related technologies. Carbon taxes are introduced; an elaborate phase-in mechanism for less developed regions is negotiated and implemented. A part of the carbon tax revenue is used to compensate some fossil-fuel exporters and for a fund to compensate those affected by climate change.

In the B2 scenario actions to reduce GHG emissions are taken mainly at a local or regional scale in response to climate change impacts. Environmentally aware citizens of the B2 world will increasingly attribute damages to human-induced climate change. High-income countries, which are generally less vulnerable to climate change impacts, will increasingly see the need for climate policy action as a consequence of cost-benefit analyses. With increasing costs of damage, countermeasures challenge existing energy sector policies and institutional frameworks. Generally high educational levels promote both development and environmental protection. Resource availability, economic development, and technical change are uneven over regions. In relative terms, R&D expenditures are expected to stay constant, but they will be more targeted towards cleaner and less carbon-intensive energy technologies. Existing bilateral trade links will foster bilateral technology transfer from OECD countries to some developing countries. This is because rapidly increasing energy and, in particular, electricity demand in developing countries present business opportunities no longer available in OECD countries. Therefore, there exist a number of incentives for bilateral environmental policy co-operation between R&D intensive countries in the North and developing countries of the South. Energy trade links, first for oil and later for natural gas and methanol, will play an important seed role for new environmental bilateral co-operation, leading to a regionally heterogeneous approach to GHG reduction.

2.5.2.3 *Comparison of Quantified Stabilization Scenarios*

Based on the storylines, 76 stabilization scenarios were quantified as shown in *Table 2.6*. The assessment of the post-SRES work in this section is restricted to the analysis of CO_2 emissions and energy use in the different model runs. The detailed comparison of macroeconomic costs of reducing CO_2 emissions costs is not dealt with here: Chapter 8 addresses this aspect of stabilization.

Figure 2.13 shows the CO_2 emission trajectories of the 76 post-SRES mitigation scenarios along with the ranges of SRES and

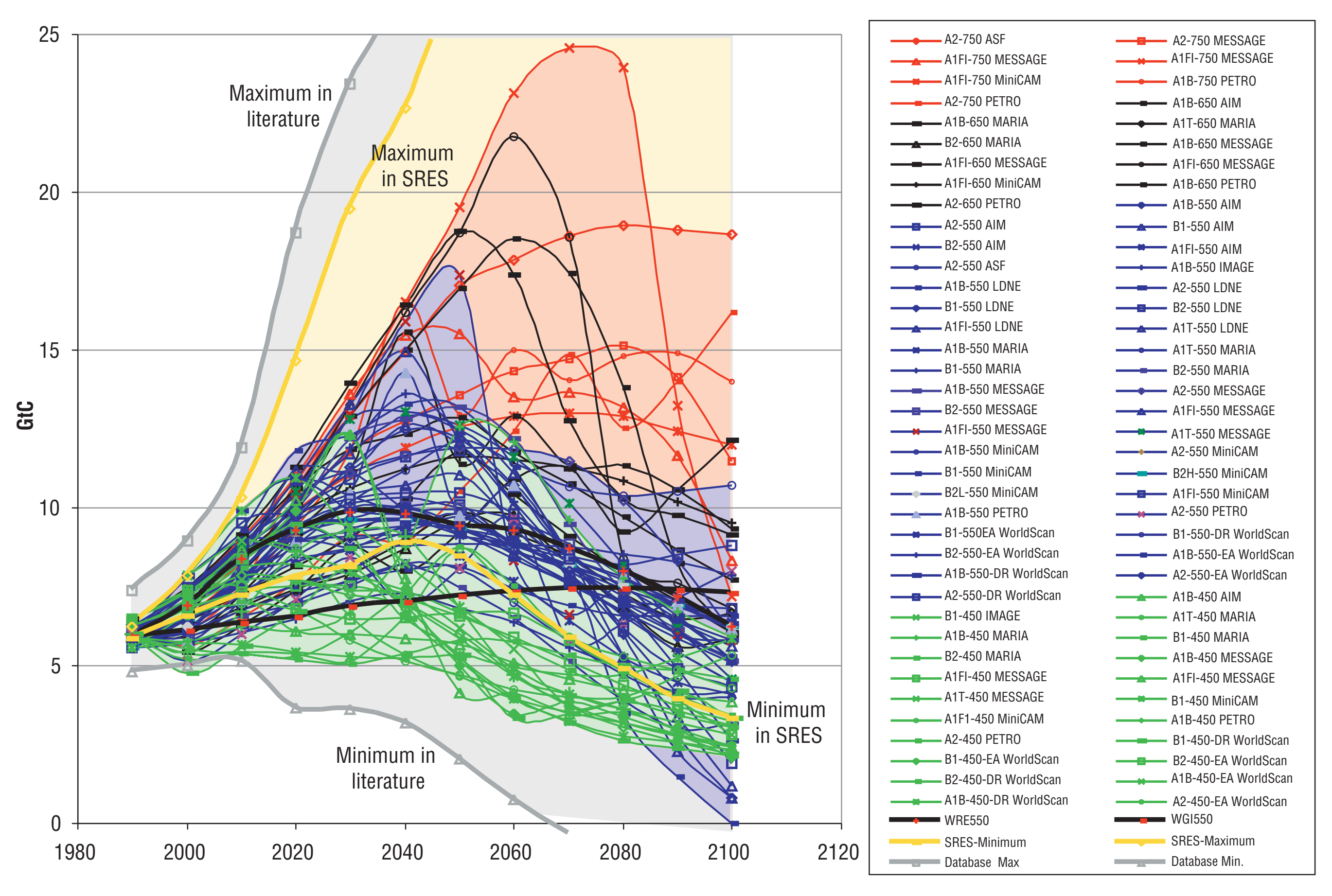

Figure 2.13: *The 76 post-SRES stabilization scenarios of world fossil fuel CO_2 emissions. Different stabilization levels are indicated by colour, with 750ppmv in red, 650ppmv in black, 550ppmv in blue, and 450ppmv in green. For comparison, the minimum and maximum of the ranges of scenarios from the literature (grey) and the SRES (yellow) as well as the WRI and WRE 550ppmv stabilization scenarios (bold black) are also shown.*

other published scenarios. Quantifications differ with respect to the baseline scenario including assumed storyline, the stabilization target, and the model that was used. As shown in *Figure 2.13*, the post-SRES scenarios cover a very wide range of emission trajectories, but the range is relatively below the SRES range, and they are apparently classified into groups according to the different stabilization targets. The figure shows the WRE late-response scenario and WGI early-action scenario for 550ppmv stabilization to compare with post-SRES scenarios, and it shows that the post-SRES range covers a much wider range than that between WRE and WGI.

Figure 2.14 shows the comparison of SRES and post-SRES scenario ranges in total global CO_2 emissions. The post-SRES ranges are estimated based on the selected scenarios quantified by SRES participants in order to compare the formal SRES ranges in Nakicenovic *et al*. (2000). It is shown clearly in the figure that concentration stabilization requires much more reduction of CO_2 emissions under development paths with high emissions such as A1FI and A2 than under development paths such as B1 and B2. These differences in reduction requirements result in selection of different technology and/or policy measures and, as a consequence, different costs to stabilize concentrations even at the same level. In the A1 scenario family, with its different scenarios in technological development (A1B, A1FI, and A1T), technological change is also a key component in bringing down the costs of mitigation options and their contribution to the emissions reduction. The A1FI stabilization scenarios, which are based on the highest baseline emissions, require much larger emission reductions than the A1T stabilization scenarios. The role of technology has been found to be crucial in the A1 scenario variants.

Morita *et al.* (2000a) compared all the stabilization variants in detail and found several common characteristics among these scenarios. These findings are as follows:

- Comparing the CO_2 emissions reductions from SRES baselines, the models have many points in common, but there are also some clear differences. All models show an increase in CO_2 reduction over time. This reflects the strong constraint of atmospheric CO_2 concentration. There is a considerable range in reductions among models in early years. However, most models achieve a similar proportional reduction from the baseline over the observation period.
- For achieving stabilization at 550ppmv, the highest reductions in CO_2 emissions compared to the baseline are observed in the A2 family. B1 shows the lowest reductions. CO_2 reduction at the end of the 21st century ranges in A2 between 75% and 80%, A1B between 50% and 75%, B2 between 40% and 70%, and B1 between 5% and 40%.

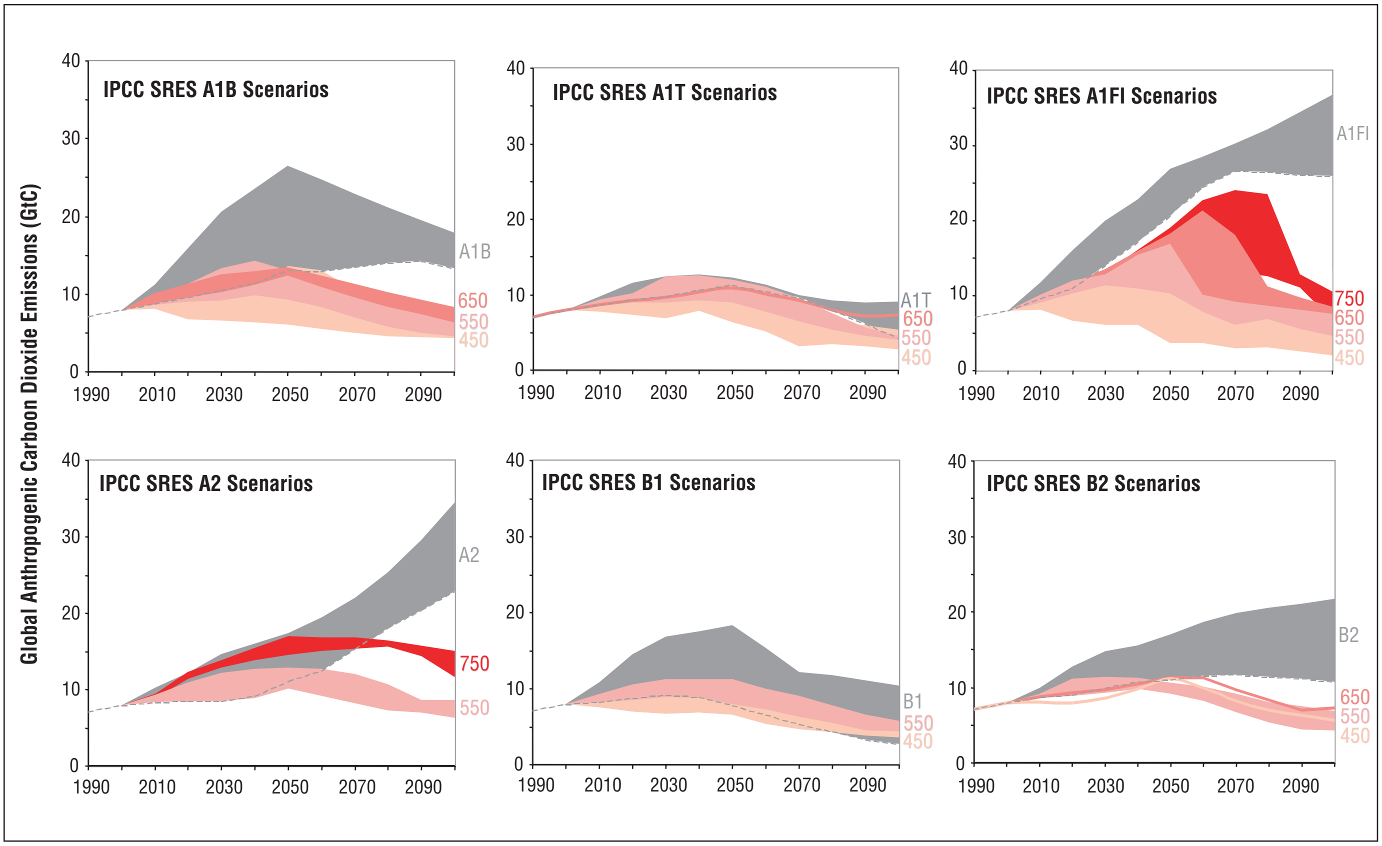

Figure 2.14: *Comparison of SRES and post-SRES scenario ranges in total global CO_2 emissions. The post-SRES ranges are estimated based on the selected scenarios quantified by SRES participants in order to compare SRES ranges.*

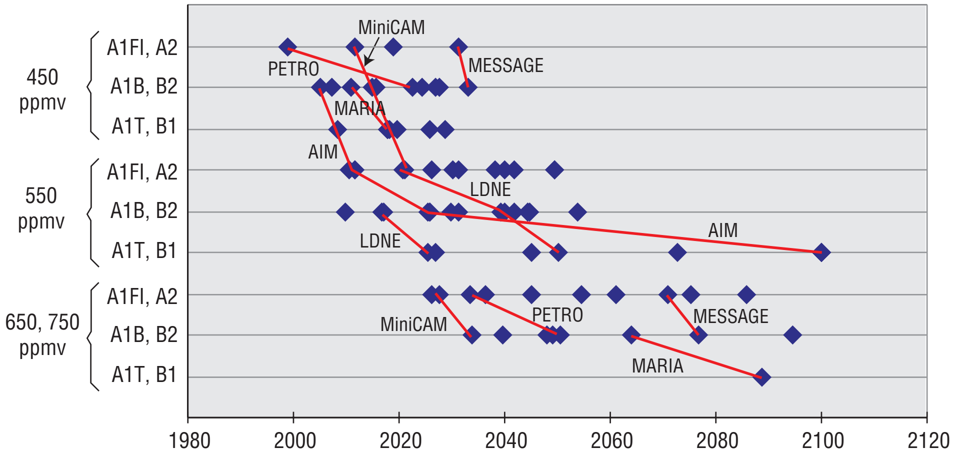

Figure 2.15: *Timing when the stabilization scenarios achieve a reduction of 20% of global energy-related CO_2 baseline emissions, compared across stabilization targets as well as baselines. Slanted lines join scenarios quantified by the same model.*

- The target stabilization level also significantly affects the CO_2 reduction, even when based on the same baseline scenario. In the 450ppmv stabilization case, the reduction reaches 70% to 100%[14] of A1B baseline emissions at the end of the 21st century.
- Energy consumption reductions are more complicated among models. There is no strong relationship between the level of energy consumption and the stabilization level.
- Different baselines lead to different macroeconomic costs in order to reach a stabilization target. In spite of the wide range among models, A2 would be the most expensive case while B1 would require the lowest cost for stabilization at 550ppmv. The GDP loss in B1 would be less than one-tenth that in the A1B case, and less than one-twentieth that in the A2 case.
- The CO_2 reduction and macroeconomic costs are also significantly affected by the target stabilization level, even when based on the same baseline scenario. The economic cost for 450ppmv stabilization would be around three times that for 550ppmv, and six to eight times that for 650ppmv. These relationships can be observed at both the global and regional levels.
- Different stabilization targets also require different timing for the introduction of reduction policies. The 450ppmv stabilization case requires drastic emission reductions that occur earlier than under the 650ppmv case. Very rapid increases in emission reduction over 20 to 30 years are also observed in the 450ppmv stabilization case.

In order to compare the scenarios in further detail, several indices were calculated for this review.

First, a CO_2 reduction index was compared among stabilization levels as well as among SRES worlds. This index is calculated by subtracting baseline emissions from mitigation scenario emissions. In general, the lower the stabilization level that is required, as well as the higher the level of baseline emissions caused by the selected development path, the larger the CO_2 divergence from the baseline that is needed in all the regions. However, it does not simply follow from the larger divergence in emissions that there is an earlier divergence from the baseline.

The impact on the timing of emission reduction of both the stabilization level and the baseline level of emissions is further elaborated in *Figure 2.15*. This figure shows when the reduction in energy-related CO_2 emissions in each stabilization scenario would reach 20% of baseline emissions. This figure indicates that more stringent stabilization targets require earlier emission reductions from baseline levels. Higher emission worlds such as A1F1 and A2 also require earlier reduction than lower emission worlds such as A1T and B1.

A key policy question is what kind of emission reductions would be needed in the medium term, after the commitment period of the Kyoto Protocol (assuming that it will be implemented). *Figure 2.16* shows the percent reduction in energy-related CO_2 emissions in Annex I countries from 1990 for the various stabilization cases. Since the first commitment period of the Kyoto Protocol ends in 2012, this can give some indication of the extent to which emission reduction commitments after 2012 would be needed to achieve the various stabilization levels. It should be noted that about two thirds of the scenarios assume that developing countries have already diverged from their baseline emission trajectories in 2020. Another point is that the post-SRES scenarios were not developed specifically to include the Kyoto targets, so there is a range of Annex I emission reductions (from 1990 levels) in 2010, 2020 and 2030. The mid-course scenarios are indicated in *Figure 2.16* as

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[14] The 100% reduction scenario based on LDNE assumes the large scale introduction of carbon sequestration technologies.

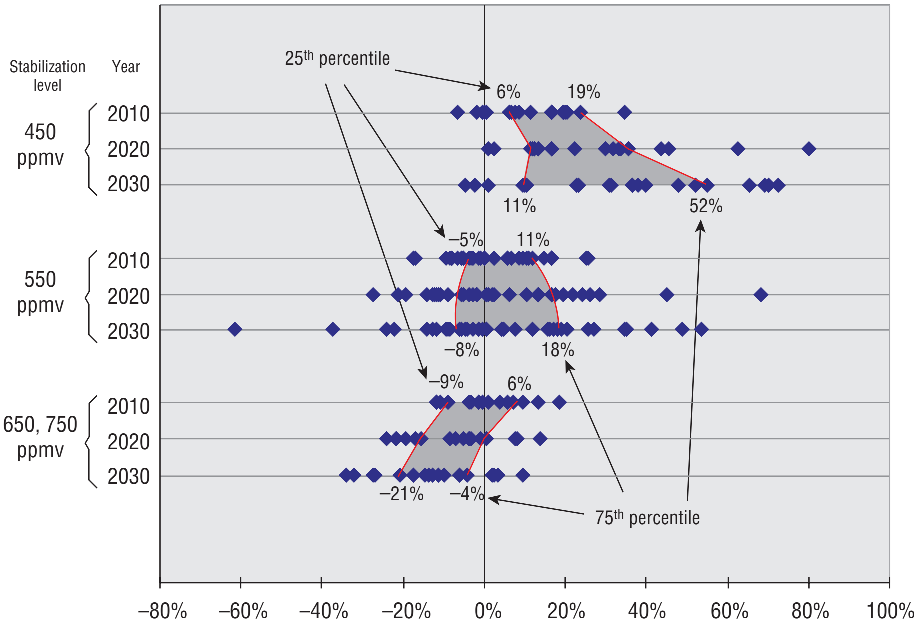

Figure 2.16: *The reduction of energy-related* CO_2 *emissions from 1990 levels in Annex I countries for stabilization at 450ppmv, 550ppmv, and 650–750ppmv. For each stabilization level, emission reductions are shown for the years 2010 (upper lines), 2020 (middle lines), and 2030 (lower lines). Shaded areas show the range between the 25th and 75th percentiles of the frequency distribution of the scenarios.*

the range between the 25th and 75th percentiles of the frequency distribution of the scenarios.

Figure 2.16 shows that:

- In the 450ppmv stabilization scenarios, the middle range (between the 25th and 75th percentiles) of Annex I emissions in 2010 lies between the Kyoto target and a 19% reduction from 1990 levels. This range increases after 2010, as does the decrease in Annex I emissions that would be needed to achieve stabilization at 450 ppmv. The percent reduction from 1990 levels in the middle range of scenarios is 13%–34% in 2020 and 11%–52% in 2030;
- In the 550ppmv stabilization scenarios, the middle range of Annex I emissions in 2010 is around the Kyoto target (from an 11% decrease to a 5% increase from 1990 levels); in 2020, the middle range of emissions lies between a 17% decrease and an 8% increase from 1990 levels; and in 2030, it lies between an 18% decrease and an 8% increase from 1990 levels. The average level of emissions slightly decreases after 2010; and
- The 650 or 750ppmv stabilization scenarios show similar changes in emission levels in 2010 compared to 1990, and few of them show any additional reduction in Annex I emissions after 2010. The middle range of emissions lies between an increase of 1%–17% from 1990 levels in 2020, and an increase of 4%–21% from 1990 levels in 2030.

This suggests that achievement of stabilization at 450ppmv will require emissions reductions in Annex I countries by 2020 that go significantly beyond their Kyoto Protocol commitments for 2008 to 2012.[15] It also suggests that it would not be necessary to go much beyond the Kyoto commitments for Annex I countries (assuming as indicated that developing countries diverge from their baselines by 2020) to achieve stabilization at 550ppmv or higher. However, it should be recognized that several scenarios do indicate the need for significant emission reductions by 2020 in order to achieve these stabilization levels. These findings should be interpreted in light of the facts that CO_2 concentrations are assumed to reach one of the alternative fixed target levels in the year 2150, and unlike “emission corridor” analyses, these scenarios do not introduce other conditions such as a constraint on the rate of temperature increase.

Another important policy question concerns the participation of developing countries in emission mitigation. As a first step in addressing this question, the post-SRES scenarios were evaluated according to when per capita CO_2 emissions in Annex I countries would fall below per capita emissions in non-Annex I countries, assuming that all CO_2 emission reduction necessary for stabilization would occur in Annex I countries and that non-Annex I countries would emit CO_2 without

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[15] It should be noted, however, that a few scenarios show the possibility of achieving 450ppmv stabilization even if the initial Kyoto commitments are not met, provided that emissions decline sufficiently by 2020.

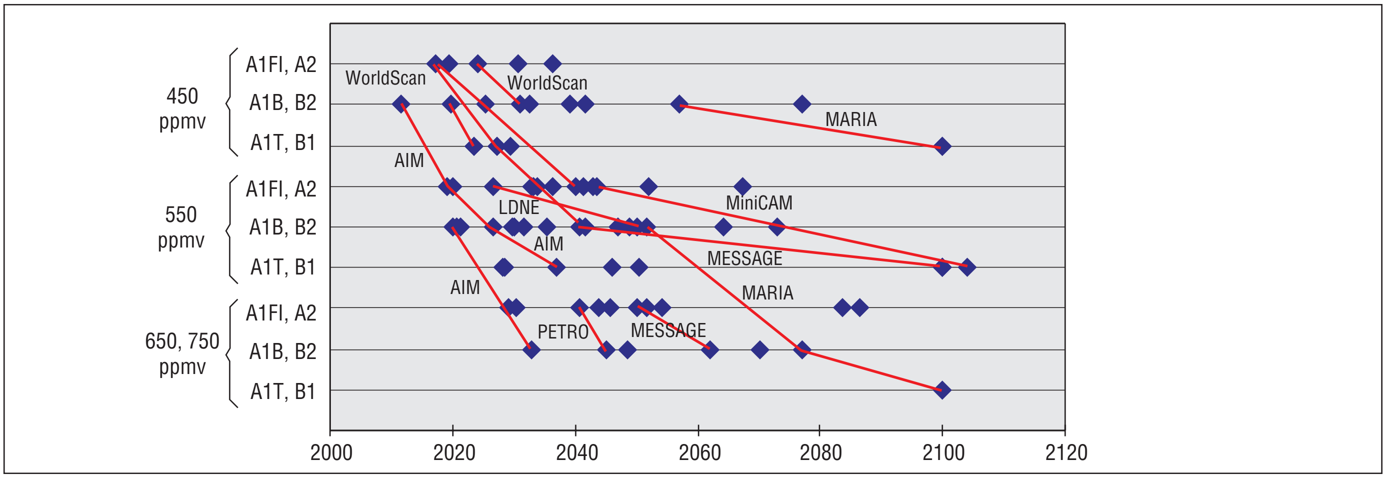

Figure 2.17: *Timing of when per capita CO_2 emissions in Annex I countries would fall below per capita CO_2 emissions in non-Annex I countries, assuming that all CO_2 emission reduction necessary for stabilization would occur in Annex I countries and that non-Annex I countries would emit CO_2 without any controls.*

any controls. This hypothetical assumption permits the analysis of one of the determinants of when non-Annex I emissions might begin to diverge from baseline levels. The results are shown in *Figure 2.17* for each stabilization level and for three groups of SRES baselines.

Figure 2.17 shows that:

- Assuming that all the CO_2 reductions for concentration stabilization are undertaken in Annex I countries, most of the post-SRES scenarios indicate that per capita Annex I emissions would fall below per capita non-Annex I emissions in the 21st century. This situation occurs before 2050 in two-thirds of the scenarios. Only in the A1T or B1 worlds would per capita CO_2 emissions in developing countries remain below those of developed countries in the 21st century.
- These timings are significantly affected by the time series of emission reductions in the scenarios, and consequently they diverge in the scenarios. However, comparison within individual models suggests that the lower the stabilization level, the earlier that Annex I per capita emissions fall below non-Annex I per capita emissions. Stabilization scenarios based on higher emission worlds such as A1FI and A2 also tend to show earlier timing for Annex I to fall below non-Annex I per capita emissions compared to scenarios based on the lower emission worlds of B1 or A1T. This suggests that the stabilization target and the baseline emission level are both important determinants of the timing when developing countries' emissions might need to diverge from their baseline emissions.

In order to assess priority setting in energy intensity reduction or in carbon intensity reduction, a "response index" was calculated for all stabilization variants of post-SRES scenarios for the years 2020, 2050, and 2100, as shown in *Figure 2.18*. This index relates the impact on CO_2 emission reduction of switching towards low-carbon or carbon free energy to the impact of energy intensity reduction. The response index is the ratio of the change in carbon intensity to the change in primary energy intensity[16].

When energy intensity reduction is relatively larger than carbon intensity reduction, the index shows more than 1.0, and less than 1.0 in the opposite case.

It is clear from *Figure 2.18* that the priority of response to reduce CO_2 emissions would change over time. Energy intensity reduction would be relatively larger than carbon intensity reduction in the beginning of 21st century, but these would be of equal weight by the middle of the century. The impact of energy intensity reduction would be saturated towards the end of the 21st century, and the use of low-carbon or carbon-free energy sources would become relatively much larger. This pattern is generally consistent across the stabilization levels. The lower the stabilization target, the higher the relative importance of energy intensity reduction in the beginning of the 21st century, and the higher the relative importance of low-carbon or carbon free energy towards the end of the 21st century.

These trends are important, but it is necessary at the same time to understand the model assumptions behind them. Most of the models do not accommodate very well structural and consumption-pattern-related efficiency measures (e.g., advanced dematerialization, major structural change, and changes in consumption patterns and lifestyles). A few cases which incorpo-

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[16]
$$R = \frac{(Ci_{t,MS} / CI_{t,BS})}{(EI_{t,Ms} / EI_{t,BS})}$$
In this expression, CI denotes carbon intensity and EI energy intensity. The indices BS and MS refer to the baseline and mitigation scenario, respectively; the time is given by t.

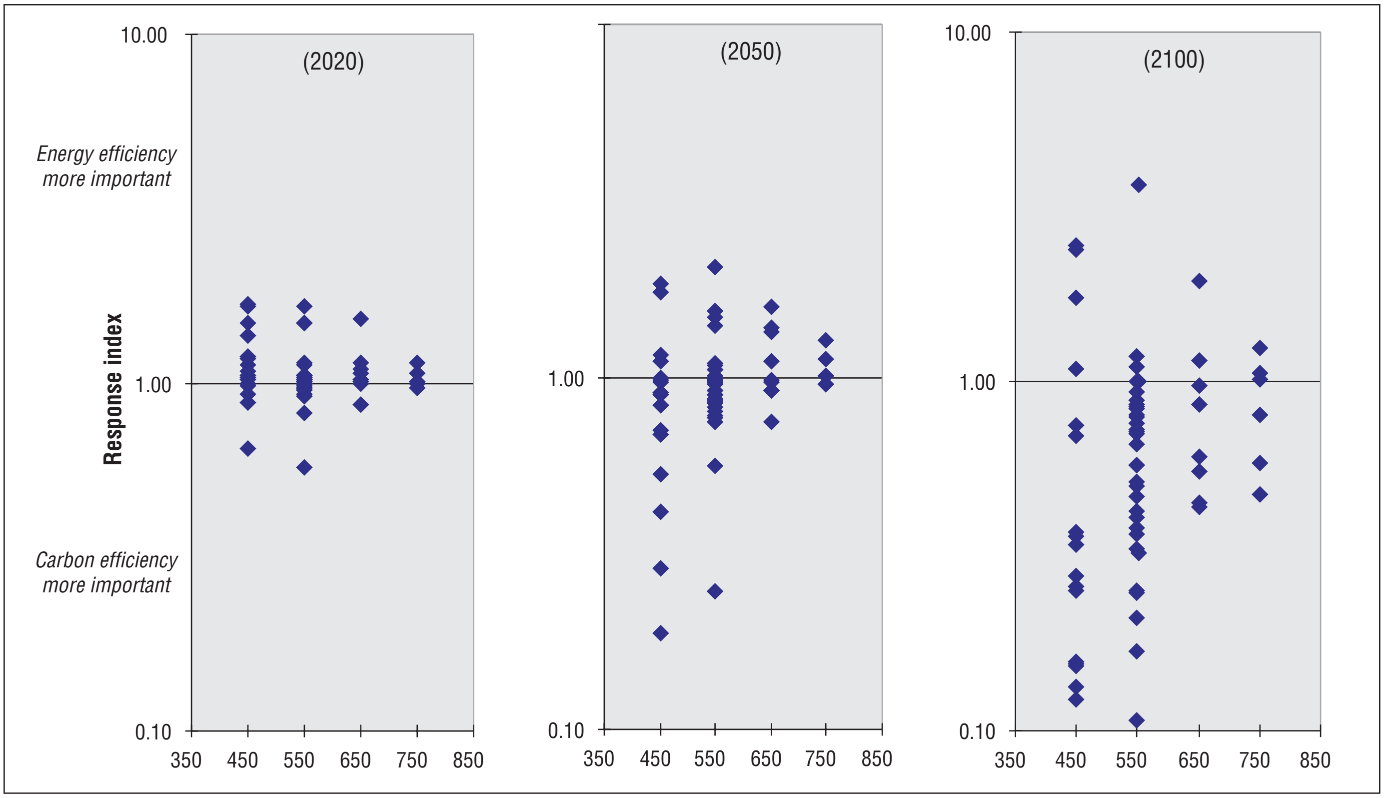

Figure 2.18: *Response index to assess priority setting in energy intensity reduction (more than 1.0) or in carbon intensity reduction (less than 1.0) for all stabilization variants of post-SRES scenarios in 2020, 2050, and 2100.*

rate drastic changes in social structure (e.g., some of the scenarios based on AIM and WorldScan) give relatively high priority to energy efficiency improvement even in the latter half of 21st century.

A per capita final energy index was calculated in order to analyze equity between North and South. Since one of the weak points of quantified scenario analysis concerns equity or "burden sharing", the comparison of this kind of index is very important. Even though the per capita income is the most popular index to analyze equity, this index was not estimated by all the modelling teams. Therefore, final energy consumption per person in each region was adopted as an appropriate index for the equity analysis, because this index is closely related to per capita economic welfare. *Figure 2.19* shows this index (in GJ/capita) among the OECD, EFSU, ASIA and ALM regions[17] for all post-SRES and SRES variants over the period 1990 to 2100.

As shown in this figure, some interesting trends can be observed:

- In the development-emphasized worlds (A1B and A2) climate policy would reduce per capita final energy in both the Annex I and non-Annex I countries, while in the environment-emphasized worlds (B1 and B2) climate policy would have little effect on energy use. These impacts would slightly improve equity in per capita final energy use between the Annex I and non-Annex I countries, because the reduction in energy use caused by climate policies would be larger in Annex I than in non-Annex I.
- However, the impact of climate policies on equity in per capita final energy use would be much smaller than that of the future development path. The differences among the various SRES baseline conditions have the largest impact upon whether per capita energy use values converge between Annex I and non-Annex I countries, with the highest degree of convergence occurring in the A1B and B1 worlds. This can be seen in *Figure 2.19* by comparing the (smaller) change in energy use between regions within each of the four columns (i.e., between the baseline and the 55ppmv stabilization scenario for each world) with the (much larger) change between regions across each of the two rows (i.e., across the baseline or across the 550ppmv stabilization scenario).

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[17] These regional aggregations were defined by Nakicenovic *et al*. (2000). OECD: OECD member countries as of 1990; EFSU: the East and Central European countries and Former Soviet Union; ASIA: all non-Annex I countries in Asia (excluding the Middle East); ALM: Africa, Latin America, and the Middle East, and the rest of the world.

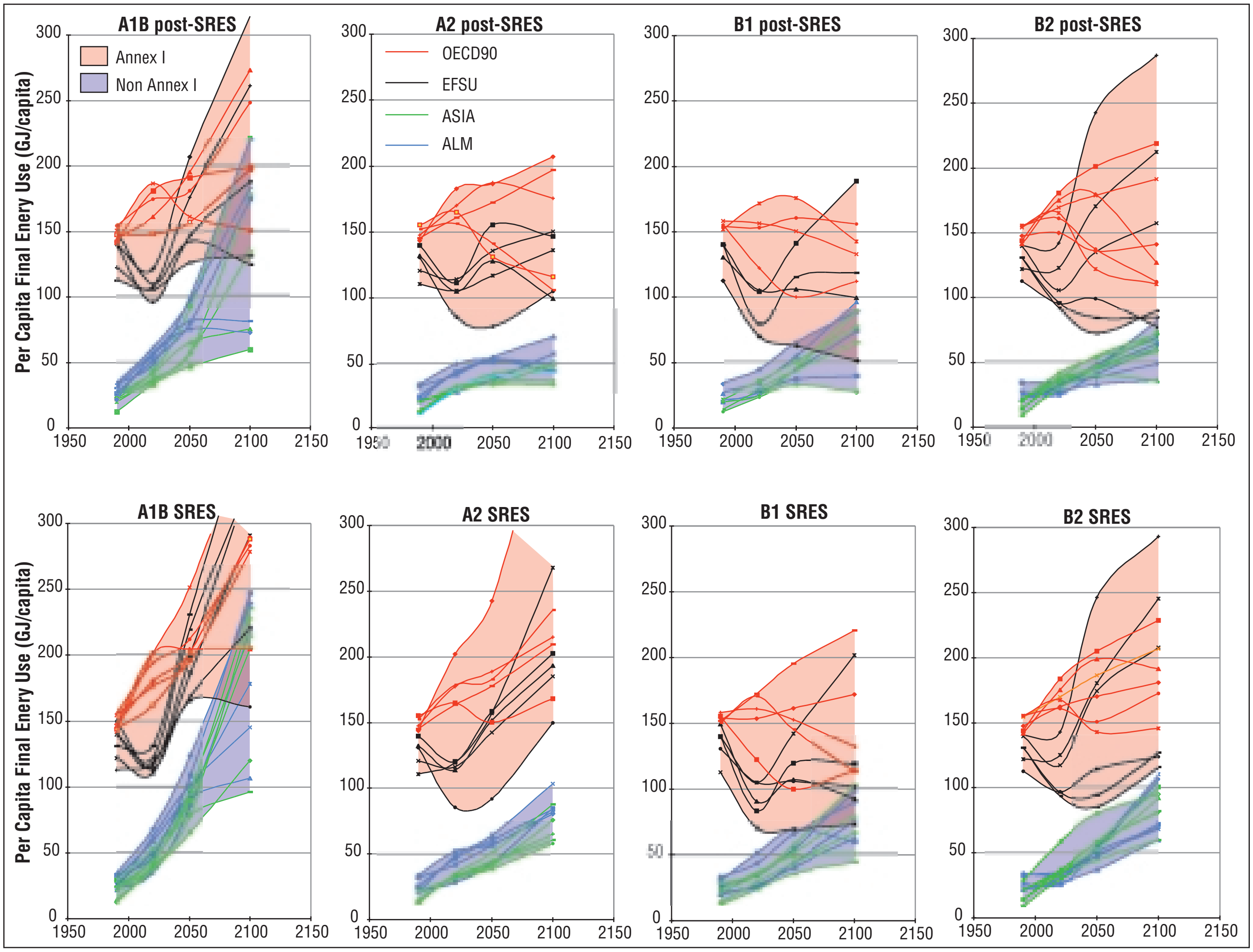

Figure 2.19: *An equity index to compare per capita final energy use (GJ/capita) between the Annex I (pink) and non-Annex I (blue) countries for all post-SRES (550ppmv stabilization) and SRES (baseline) variants from 1990 to 2100. Climate policy has a much smaller impact on equity in energy use than does choice of development path. This can be seen by comparing the change in energy use within each of the four worlds (i.e., between the baseline and the 550ppmv stabilization for each world) with the change among the worlds (i.e., across the baselines or across the 550ppmv stabilization).*

Though the analyses described above mainly focus on CO_2 emissions from energy consumption, it is also important to consider non-CO_2 emissions as well as non-energy-related CO_2 emissions. However, very few scenarios that include these emissions have been quantified and therefore it was not possible to include this additional review in this report. Some of the nine modelling approaches used here do include other radiatively active gases. However, the mitigation and/or stabilization scenarios include explicit limitations only on CO_2 emissions, and hence the reductions in other gases are indirect results (or ancillary benefits) of the CO_2 reduction measures.

2.5.2.4 Comparison of Technology and/or Policy Measures and Assessment of Robustness

Assumed technology and/or policy options differ among models (Morita *et al.*, 2000a). These differences are strongly dependent on the model structure. MESSAGE-MACRO, LDNE, and MARIA are dynamic optimization-type models that incorporate detailed supply-side technologies; once a constraint on CO_2 emission or concentration is imposed, the optimal set of technology and/or policy measures (focusing on energy supply) is automatically selected in the model. AIM and IMAGE are recursive simulation-type models which integrate physical and land-use modules rather than focus on energy demand, so that highly detailed technology and/or policy measures are assumed for each region and time as exogenous scenarios. ASF, MiniCAM, PETRO, and WorldScan are other types of integrated models focusing on the economics of energy systems. In these models, only a carbon tax is used for the post-SRES analyses.

In order to reduce CO_2 and other GHG emissions, each modelling team assumed specific technology and/or policy measures

Table 2.7: *Sources of emissions reduction for 550ppmv stabilization across the nine post-SRES models. Minimum-maximum and (median) at 2100 (GtC)*

	A1B	**A1FI**	**A1T**	**A2**	**B1**	B2
Substitution among fossil fuels	-0.1 – 2.2 (0.97)	0.2 – 11.8 (1.82)	0.1 – 0.1 (0.09)	2.4 – 5.4 (2.95)	0.0 – 0.2 (0.09)	0.6 – 2.7 (1.35)
Switch to nuclear	0.3 – 6.4 (0.55)	-2.4 – 1.9 (1.20)	0.0 – 2.0 (1.03)	0.3 – 1.7 (1.18)	0.0 – 3.1 (0.02)	-0.2 – 5.1 (2.28)
Switch to biomass	-0.8 – 1.5 (1.03)	-0.2 – 5.5 (2.50)	-0.2 – 0.3 (0.07)	1.1 – 3.8 (1.84)	0.0 – 4.3 (0.04)	-1.9 – 1.5 (0.63)
Switch to other renewables	0.1 – 2.5 (1.51)	0.6 – 15.1 (2.70)	-0.1 – 0.0 (-0.05)	2.2 – 6.7 (3.33)	0.1 – 0.3 (0.28)	0.1 – 3.2 (2.07)
CO_2 scrubbing and removal	0.0 – 4.7 (0.00)	0.0 – 23.8 (0.39)	0.5 – 1.6 (1.06)	0.0 – 5.8 (0.00)	0.0 – 1.1 (0.00)	0.0 – 3.0 (0.63)
Demand reduction	0.5 – 6.6 (0.94)	1.9 – 17.7 (10.4)	0.0 – 0.2 (0.11)	5.2 – 15.6 (10.21)	0.1 – 0.3 (0.08)	0.7 – 3.5 (1.64)
TOTAL reduction	*7.1 – 11.9* *(9.16)*	*21.7 – 30.5* *(21.1)*	*0.3 – 4.4* *(2.31)*	*21.7 – 26.9* *(22.81)*	*0.2 –9.6* *(0.39)*	*6.0 – 10.6* *(8.14)*

Note: Emission reductions are estimated by subtracting the mitigation value (in GtC) from the baseline value (in GtC) of each scenario.

for its scenario quantification. The main reduction measures are:

- demand reductions and/or efficiency improvements;
- substitution among fossil fuels;
- switch to nuclear energy;
- switch to biomass;
- switch to other renewables;
- CO_2 scrubbing and removal; and
- afforestation.

Table 2.7 summarizes the contribution of these emission mitigation options and/or measures for the post-SRES scenarios. The table shows the emission reduction (in GtC) between the baseline and the mitigation and/or stabilization cases, corresponding to the first six points of the list above. For simplicity, the total ranges as well as the median value in 2100 are shown only for the 550ppmv stabilization case. As shown in *Table 2.7*, no single source will be sufficient to stabilize atmospheric CO_2 concentrations. Across the scenarios, the contributions of demand reduction, substitution among fossil fuels, and switching to renewable energy are all relatively large. The contributions of nuclear energy, of CO_2 scrubbing and removal differ significantly among the models and also across the post-SRES scenarios.

With respect to the role of biofuels, it should be noted that the models assume trade in biofuels across regions; hence, biomass produced in Africa and/or South America can satisfy the fuel needs of Asia. In all mitigation scenarios, the additional role of biomass, as a mitigation option, is limited and the world supply never exceeds 400EJ/yr; this is possible because the other options (solar and/or wind, nuclear, and CO_2 removal and storage) also play a key role in mitigation strategies. *Table 2.8* shows the ranges in primary biomass use in 2050 in the post-SRES scenarios.

Table 2.8: *Ranges of primary use of biomass in 2050 in the post-SRES scenarios (EJ)*

Stabilization target	**A1B**	**A1FI**	**A1T**	**A2**	**B1**	**B2**
450ppmv	246 - 328	226 - 246	137 - 246	128	96 - 186	127 - 189
550ppmv	76 - 228	78 - 217	74 - 217	22 - 232	36 - 176	27 - 157
650ppmv	0 -180	143 -184	133	(*)		121
750ppmv	(*)	131		25 - 63		

Note: As the PETRO model does not separate biomass energy from primary energy, no number is filled in (*).

To contribute to a synthesis of findings, each modelling team was asked to respond to the following questions about the policy implications of the scenarios:

- How do technology and/or policy measures vary among different baselines for a given stabilization level?
- How does the stabilization level affect the technology and/or policy measures used in the scenarios?
- What packages of technology and/or policy measures are robust enough to beeffected in the different baseline worlds?

As shown in *Table 2.7*, high emission worlds such as A1FI, A2, and A1B require a larger introduction of energy demand reduction, switching to renewable energy, and substitution among fossil fuels, in comparison to other SRES worlds. The contribution of CO_2 scrubbing and removal is largest in the A1FI stabilization scenarios, while mitigation measures in the A1T world depend mainly on a switch to nuclear power as well as carbon scrubbing and removal. Biomass energy steadily contributes across the SRES worlds and also across stabilization targets.

The following summarizes more detailed differences in technology and/or policy measures across the regions as well as the different SRES worlds:

- The timing and the pace of the emissions reduction are particularly influenced by the region's resource availability. Regions with large amounts of cheap fossil fuel reserves and resources (ASIA: coal; EFSU: natural gas) rely comparatively longer on fossil fuel-based power generation. In the long run the emissions mitigation measures are predominantly the result of the technology assumptions consistent with the scenario storylines. In the fossil-intensive A2 scenario, emissions reduction for 2100 in ASIA and EFSU are mainly a result of shifts to advanced fossil technologies in combination with carbon scrubbing and/or removal and increasing shares of solar-photovoltaic, and advanced nuclear technologies. For the B2 scenario, the shift towards non-fossil fuels in ASIA and EFSU is more complete, and hence, scrubbing plays a less important role. In A2 and B2, synthetic fuel production from biomass plays a key role in the ALM region. In both scenarios the emissions mitigation in the OECD region is because of shifts to wind, solar-photovoltaic, biomass, and nuclear technologies. In the OECD, fossil fuels contribute roughly 30% to the power generation, which comes predominantly from fuel cells (MESSAGE-MACRO team: Riahi and Roehrl, 2000).
- In the 550ppmv cases, the composition of primary energy is diversified, with increased shares of various renewable energy sources, nuclear power, and natural gas. Among the renewable energy sources, photovoltaics (PV) seem to be the most promising abatement measure in the A1 and A2 scenarios, where the final energy demands grow quite substantially, while CO_2 recovery and disposal measures play a very important role in the B1 and B2 scenarios. In the case of A1B and A2, PV would increase rapidly especially in the Middle East and North Africa (ALM) where PV panels could be set in wide desert areas. For the entire SRES world, methanol would be made from hydrogen (H_2) and carbon monoxide (CO) through gas splitting mainly in the Former Soviet Union and Eastern Europe (EFSU) where there are plenty of natural gas resources. Wind energy production would play an important role in North America (LDNE team: Yamaji *et al.*, 2000).
- In the A1B and A1T worlds, expansion of biomass utilization is the major strategy, rather than nuclear power, for carbon emission control in OECD and EFSU. In the latter, biomass mainly substitutes for natural gas in public and other sectors, and a shift from coal to natural gas in the industry sector is also observed. Nuclear power is mainly used in the Asia-Pacific and ALM regions. In contrast, the B1 scenarios give very similar figures among regions, except for a small increase of biomass in the OECD region. Carbon sequestration is implemented in all regions for the purpose of carbon emission control. B2 scenarios are basically similar to those of the A1 family, except that nuclear energy and biomass are introduced in the OECD region (MARIA team: Mori, 2000).
- In the A1 and B1 families, technology transfer to developing countries would occur with respect to renewable energy production, unconventional oil and gas exploitation, and nuclear power generation. In these worlds, there would be a large increase in biomass use in the Asia and ALM regions. Coal is mainly produced in the Asia-Pacific region. Nuclear technology is widely used in developing regions. In the A2 and B2 worlds, energy supply and use heavily depend on local energy resources because of international trade barriers. The Asia-Pacific region will rely on nuclear energy and coal, while ALM may use much renewable energy. The OECD region makes much use of advanced end-use technology and modern renewable energy technologies. Large gas resources in the EFSU region can satisfy much of the energy demand in that region (AIM team: Jiang *et al.*, 2000).
- The allocation of carbon "taxes" across regions based on their per capita GDP levels leads to substantial differences in levels of CO_2 reductions relative to the baseline. The largest relative reductions are implemented in regions with relatively high per capita GDP growth (e.g., OECD) and regions with a relatively low cost of renewable energy (Latin America). The lowest relative reductions are achieved in regions with low per capita GDP and a relatively high cost of renewable energy (e.g., Africa) (ASF team: Sankovski *et al.*, 2000).
- Assuming that there are no constraints on fuel trade, the Middle East and later the Commonwealth of Independent States (CIS) will still be major fossil fuel exporters; their revenues may decline significantly by

the middle of the 21st century as a consequence of carbon mitigation measures. Parts of Africa and South America may develop into important biofuel exporters. High-income regions with limited fossil fuel resources, such as Europe and the USA, will probably be among the first to introduce high-efficiency and non-carbon technologies. This results over time in sizeable cost reductions, enabling less industrialized regions to replace their indigenous coal use by these relatively capital-intensive supply side options.

One of the major results of the post-SRES analyses is the identification of "robust climate policy options" across the different SRES worlds as well as across different stabilization targets. Most of the modelling teams have identified several such options based on their simulations. The following list summarizes the major findings:

- Robust policies include technological efficiency improvements for both energy use technology and energy supply technology, social efficiency improvements such as public transport introduction, dematerialization promoted by lifestyle changes and the introduction of recycling systems, and renewable energy incentives through the introduction of energy price incentives such as a carbon tax (AIM, IMAGE, MARIA, MiniCAM (Pitcher, 2000), PETRO (Kverndokk *et al.,* 2000), and WorldScan teams);
- It would be reasonable to start with energy conservation and reforestation to cope with global warming. However, innovative supply-side technologies will eventually be required to achieve stabilization of atmospheric CO_2 concentration (AIM, ASF, IMAGE, and LDNE teams);
- Robust options across the SRES worlds are natural gas and the use of biomass resources. Innovative transitional strategies of using natural gas as a "bridge" towards a carbon-free hydrogen economy (including CO_2 sequestration) are at a premium in a possible future world with low emissions (MESSAGE-MACRO, AIM, MARIA, and MiniCAM teams);
- In all mitigation scenarios, gas combined-cycle technology bridges the transition to more advanced fossil (fuel) and zero-carbon technologies. The future electricity sector is not dominated by any single dominant technology, however, hydrogen fuel cells are assumed to be the most promising technology among all stabilization cases (MESSAGE-MACRO, IMAGE, and MiniCAM teams);
- Climate stabilization requires the introduction of natural gas and biomass energy in the first half of the 21ST century, and either nuclear energy or carbon removal and storage in the latter half of the century as the cost effective pathways. Carbon removal and storage has a role to play in high emission worlds such as A1FI and A1B for the serious or moderate targets (LDNE, MiniCAM, and MARIA teams);
- Even in the B1 world there are very difficult decisions to be made and these may well imply the need to significantly further redirect the energy system (MiniCAM and WorldScan teams); and
- Energy systems would still be dependent on fossil fuels at more than 20% of total primary energy over the next century, even with the stabilization of CO_2 concentration (LDNE and WorldScan teams).

The post-SRES analyses supplied several other findings from individual model simulations. The AIM and the MESSAGE-MACRO teams as well as other teams found that technological progress plays a very important role in stabilization, and that knowledge transfer to developing countries is a key issue in facilitating their participation in early CO_2 emission reduction. With respect to policy integration, the AIM team found that integration between climate policies and domestic policies could effectively reduce GHGs in developing regions from their baselines, especially for the next two or three decades. On the other hand, the MESSAGE-MACRO team estimated that regional air pollution control with respect to sulphur emissions tends to: (1) amplify global climate change in the medium-term perspective, and (2) accelerate the shift towards less carbon (and sulphur) intensive fuels such as renewables. The MiniCAM team concluded that agriculture and land use and energy system controls need to be linked, and that failure to do this can lead to much larger than necessary costs.

The above results are found with robust technology and/or policy measures across the SRES worlds and across different stabilization targets, and many of them are common among different modelling teams. A part of these common results can be tested by more detailed analyses of emission reduction sources, shown in *Table 2.7*. This table as well as time series analyses of the contribution of sources clearly show that:

- Large and continuous energy efficiency improvements are common features of mitigation scenarios in all the different SRES worlds;
- Introduction of low-carbon energy is also a common feature of all scenarios, especially biomass energy introduction over the next one hundred years and natural gas introduction in the first half of the 21st century;
- Solar energy and other renewable energy sources could play an important role in climate stabilization in the latter half of the 21st century, especially for higher emission baselines or lower stabilization levels; and
- Mitigation scenarios with reduced fossil fuel use will further decrease regional sulphur emissions and hence open up the possibility of earlier and larger climate change effects.

2.5.2.5 Summary of Post-SRES Scenario Review

A new type of policy assessment has been conducted by the post-SRES activities, with nine modelling teams quantifying various simulation cases. Even though stabilization scenarios show a range among the models, several common trends and characteristics can be observed.

The different SRES baseline worlds require different technology and/or policy measures to stabilize at the same level. The A1F1, A1B, and A2 worlds require a wider range of stronger technology and/or policy measures than A1T, B1, and B2. For example, energy efficiency improvements in all sectors, the introduction of low-carbon energy, and afforestation would all be required in the A1F1, A1B, and A2 worlds in the first half of the 21st century, with the additional introduction of advanced technologies in renewable energy and other energy sources in the second half of the 21st century. The level of technology and/or policy measures in the beginning of this century would be significantly affected by the choice of development path over the next one hundred years. Higher emission worlds such as A1F1 and A2 require earlier reduction than low emission worlds such as A1T and B1.

The stabilization level chosen also significantly affects technology and/or policy measures and the timing of their introduction. More stringent stabilization targets require earlier emission reductions from baseline levels. The post-SRES scenario analysis suggests that stabilization at 450ppmv will require emissions reductions in Annex I countries that go significantly beyond the Kyoto Protocol commitments. It also suggests that maintaining emissions at the level of the Kyoto commitments may be adequate for achieving stabilization at 550ppmv or higher, although it should be recognized that several scenarios do indicate the need for significant emission reductions by 2020 in order to achieve these stabilization levels.

With respect to the important policy question of the role of developing countries in GHG emission mitigation, a preliminary finding of the post-SRES scenario analysis is that, assuming that the CO_2 emission reduction needed for stabilization occurs in Annex I countries only, per capita CO_2 emissions in Annex I countries would fall below per capita emissions in non-Annex I countries during the 21st century except in some of A1T and B1 stabilization scenarios, and this occurs before 2050 in two-thirds of the scenarios. This suggests that, especially for more stringent stabilization targets and/or worlds with relatively high baseline emissions, there is a need for emissions to diverge from baseline levels in developing countries. The stabilization target and the baseline emission level were both important determinants of the timing when developing countries emissions might need to diverge from their baseline emissions.

No single measure will be sufficient for the timely development, adoption, and diffusion of mitigation options to stabilize atmospheric GHGs. Rather, a portfolio based on technological change, economic incentives, and institutional frameworks might be adopted. Large and continuous energy efficiency improvements and afforestation are common features of mitigation scenarios in all the different SRES worlds. Introduction of low-carbon energy is also a common feature of all scenarios, especially biomass energy introduction over the next one hundred years, as well as natural gas introduction in the first half of the 21st century. Reductions in the carbon intensity of energy have a greater mitigation potential than reductions in the energy intensity of GDP in the latter half of the 21st century, while energy intensity reduction is greater than carbon intensity reduction in the beginning of the century. This result appears to be robust across the storylines and stabilization levels, if drastic social changes are not assumed for energy efficiency improvement. In an A1B or A2 world, either nuclear power or carbon sequestration would become increasingly important for GHG concentration stabilization, the more so if stabilization targets are lower. Solar energy could play an important role in climate stabilization in the latter half of the 21st century, especially for a higher emission baseline or lower stabilization levels.

Robust policy and/or technological options include technological efficiency improvements for energy supply and use, social efficiency improvements, renewable energy incentives, and the introduction of energy price incentives such as a carbon tax. Energy conservation and reforestation are reasonable first steps, but innovative supply-side technologies will eventually be required to achieve stabilization of atmospheric CO_2 concentration. Possibilities include using natural gas and combined-cycle technology to bridge the transition to more advanced fossil (fuel) and zero-carbon technologies such as hydrogen fuel cells. However, even with emissions control, some modellers found that energy systems would still be dependent on fossil fuels over the next century.

Integration between global climate policies and domestic air pollution abatement policies could effectively reduce GHG emissions in developing regions for the next two or three decades. However, control of sulphur emissions could amplify possible climate change, and partial trade-offs are likely to persist for environmental policies in the medium term.

Policies governing agriculture and land use and energy systems need to be linked for climate change mitigation. Failure to do this can lead to much larger than necessary costs. At tight levels of control, even some ability to acquire additional emissions capacity from land sequestration can have major cost-reducing impacts. Moreover, a high potential supply of biomass energy would ameliorate the burden of carbon emission reductions.

2.6 Recommendations for Future Research

- Rigorous techno-economic analysis of multiple mitigation measures for each baseline and mitigation target;
- More explicit analysis of policy instruments leading to mitigation;
- Inclusion of other GHGs in addition to CO_2;
- Analysis of the feasibility and costs of stabilizing atmospheric concentrations at levels other than 550ppmv CO_2;
- Explicit cost-benefit analysis of the impacts of timing and burden sharing on mitigation costs and targets;

- Quantitative analysis of linkages between DES targets (e.g., international equity) and climate change mitigation costs and benefits;
- More extensive attempts to link qualitative narrative-based scenarios analysis with quantitative modelling work; and
- Capacity building for scenario analyses in developing countries.

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Chapter 2 Appendix

Appendix 2.1: Details of scenarios from IPCC-SRES database in legends of *Figures 2.2, 2.3, 2.4, 2.6,* and *2.7*

Legend Key	Baseline scenario name	Stabilzation scenario name	Legend key name	Baseline scenario name	Stabilzation scenario name
AIM (1)	Standard Ref	Stblz ppm/STD	PEF (25)	Modeler's Ref	Stblz ppm/MOD
AIM96 (2)	Standard Scenario	Scenario_3	PEF (26)	Standard Ref	Stblz ppm/STD
CETA (3)	Modeler's Ref	Stblz ppm/MOD	RICE (27)	Modeler's Ref	Stblz ppm/MOD
CETA (4)	Standard Ref	Stblz ppm/STD	SGM97 (28)	Reference	MID550 (full trade)
CRPS (5)	Standard Ref	Stblz ppm/STD	SGM97 (28a)	--	MID550 (partial trading)
DICE (6)	Modeler's Ref	Stblz ppm/MOD	SGM97 (28b)	--	WGI550 (trade)
DNE21/98 (7)	Ref	550ppmv	SGM97 (28c)	--	WRE550 (trade)
HCRA (9)	Standard Ref	Stblz ppm/STD	WEC (29)	--	C
ICAM2 (10)	Modeler's Ref	Stblz ppm/MOD	YOHE (30)	Modeler's Ref	Stblz ppm/MOD
ICAM2 (11)	Standard Ref	Stblz ppm/STD	AIM97 (31)	--	Stblz ppm/MOD
IIASA (12)	Modeler's Ref	Stblz ppm/MOD	AIM97 (31a)	--	MID550 (full trade)
IIASA (13)	Standard Ref	Stblz ppm/STD	AIM97 (31b)	--	MID550 (no trade)
IIASA/WEC98 (14)	--	C1	AIM97 (31c)	--	WRE550 (full trade)
IIASAWEC (15)	--	C1	AIM97 (31d)	--	WRE550 (no trade)
IMAGE2.1 (16)	Baseline-A	Stab 550 All	AIM97 (31e)	--	WGI550 (no trade)
MARIA (17)	Standard Ref	Stblz ppm/STD	CETA (32)	--	550_stab
MARIA95 (18)	--	A	FUND (33)	Modeler's Reference	Kyoto+Min.Cost 550ppm
MERGE (19)	Standard Ref	Stblz ppm/STD	FUND (33a)	--	Min. Cost 550ppm
MINICAM (20)	Standard Ref	Stblz ppm/STD	G-CUBED (34)	Modeler's Reference	Stblz ppm
MIT (21)	Modeler's Ref	Stblz ppm/MOD	GRAPE (35)	--	Stblz ppm
MIT (22)	Standard Ref	Stblz ppm/STD	RICE (40)	Modeler's Reference	Min. Cost 550ppm
NWEAR21 (23)	--	Stblz ppm/MOD	SGM (41)	--	WRE550 (trade)
PAGE (24)	Standard Ref	Stblz ppm/STD			

Note: The scenario names are taken from the IPCC scenario database (Morita & Lee, 1998a)