12. Additional Calculations

In addition to the calculations specified in Appendix A, a number of additional calculations were contributed. In this section we discuss a number of these. The GWP-reference calculation in Section 9 is another special case. Appendix F gives the complete list of the 'non-standard' calculations.

12a. WEC Energy Use Scenarios

Since the initial specifications for the calculations (as reproduced in Appendix A) were produced, a new set of emission scenarios have been constructed by the World Energy Council (WEC, 1993). In order to convert these to total industrial carbon releases, as used in the present analyses, a number of modifications have been required. The main changes are the inclusion of 'non-energy' contributions from cement production and gas-flaring. The task of converting the WEC energy-related CO_2 emissions into the total industrial releases listed in Table 12.1 was undertaken by Gregg Marland.

Table 12.1 gives the specification of the scenarios where linear interpolation is used for the intermediate times. Figure 12.1 shows these modified emission functions for the three cases. Cases A, B and C correspond respectively to 'weak' and 'strong' emission reductions and an 'ecological' scenario.

Figure 12.2 shows the calculated concentrations using Model W.

Year	A	B	C
1990	6.10	6.10	6.10
1995	6.79	6.45	6.15
2000	7.57	6.83	6.21
2005	8.43	7.22	6.27
2010	9.40	7.85	6.34
2015	10.49	8.09	6.41
2020	11.70	8.57	6.49
2025	12.05	9.04	6.64
2050	15.06	12.39	7.48
2075	14.95	11.82	4.71
2100	16.50	11.68	2.57

Table 12.1. Specification of the World Energy Council scenarios, modified to correspond to the definition of industrial emissions used in the present calculations. Releases are in Gt C y^{-1}, linearly interpolated between the specified years.

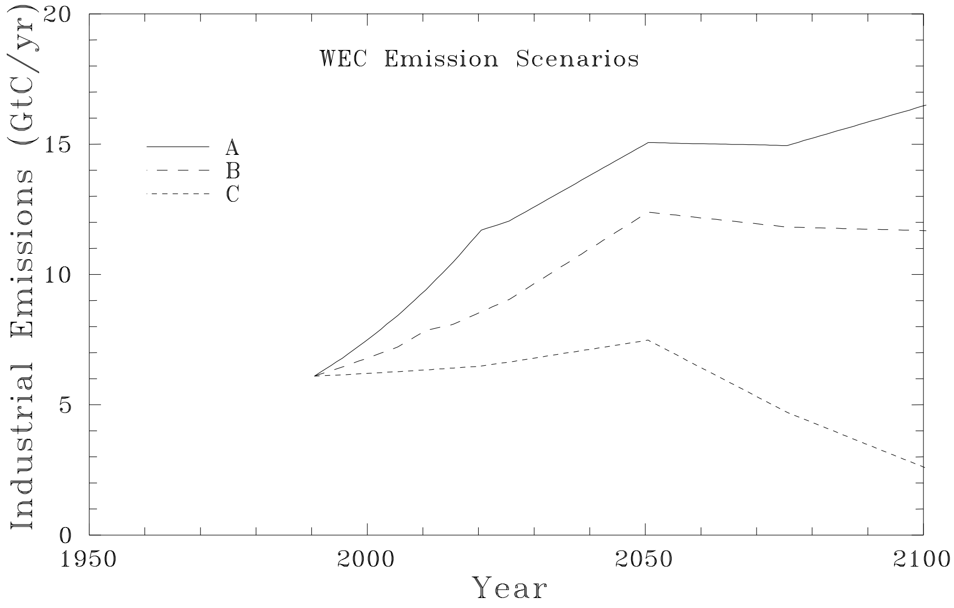

Figure 12.1 World Energy Council CO_2 emission scenarios, converted to total industrial emissions by including cement production and gas flaring.

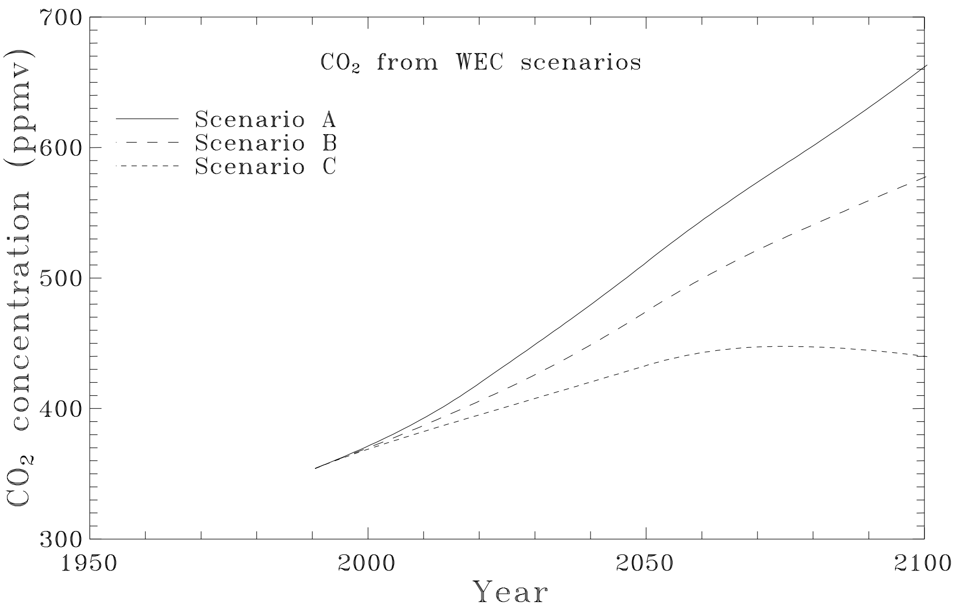

Figure 12.2 CO_2 concentrations calculated using the WEC emission scenarios in Model W.

12b Climate sensitivity

The standard specifications in Appendix A require an absence of any feedback between CO_2 and climate. This restriction does not exclude calculations with a 'CO_2-fertilisation' response which is sometimes referred to as a feedback (e.g. Wigley and Raper, 1992). Enting (1994) proposed the terminology 'carbon-cycle feedback' for discussing fertilisation in feedback terms and 'CO_2-climate' feedback for those processes where the carbon cycle is affected by climate change. In these terms, this section deals with CO_2-climate feedback.

The IPCC reports (IPCC 1990, 1992, 1994) list a variety of potential mechanisms for CO_2-climate feedback. Most of the oceanic feedbacks generally involve changes in ocean circulation. Of the models considered here, only the ocean GCMs could address this question and only if run in 'on-line' mode (as opposed to using previously calculated transport fields). Feedbacks in the terrestrial component can be represented with a range of simple parameterisations. However, because a very large number of processes are of potential importance (e.g. Harvey, 1989b), and because many systems involve sets of competing effects, there are serious difficulties in trying to validate such models.

Many of the terrestrial models included the capability of representing the effects of climate change. However in most such models, this capability was disabled in order to comply with the specifications in Appendix A. The cases in which it was included were the forward runs with IMAGE-2 (denoted R^*, c.f. Model R without feedbacks) and all runs with Model T. The various results quoted in the preceding sections indicate that these feedbacks would not play a large role in the future carbon budget. None of the models used here considered the role of climatic change in changing ocean circulation.

12c. Terrestrial modelling

The instructions in Appendix A provide that the effects of land-use change shall be specified in terms of the net flux. Thus, modelling the carbon changes associated with changes in land use is regarded as being external to the model calculations required here. We are specifying the use of a single model for the flux from land-use change: essentially the model of Houghton et al. (1983).

The specification of net fluxes is appropriate for the objectives of the IPCC exercise, since it is the net flux that is the anthropogenic forcing. However in spite of its simplicity, the net flux may not be the most natural description in terms of model representations. As noted in Appendix A, models with a first-order loss rate in carbon reservoirs will tend to 'recover' from prescribed perturbations so that the perturbing flux is not identical to the net flux (see also Enting and Lassey, 1993).

In the various versions of Model B, the processes of land-use change were modelled internally in terms of a prescribed harvesting rate which was adjusted to approximately reproduce the prescribed net fluxes. The significance of this difference can not be readily assessed because of the other significant difference in the various versions of Model B — the non-zero residual flux extrapolated into the future as a constant.

Model R (and R*) also included internal modelling of terrestrial changes associated with land-use change, even though (in Model R) no climatic feedbacks were included after 1990. The model predicted flux variations through the 21st century that translated into irregular variations in the industrial emissions that were deduced from atmospheric balance when following the prescribed smooth concentration profiles. In particular there were two periods of significant regrowth —around 2050 and 2100.

Refined terrestrial modelling is likely to be an important part of future model development. A more flexible approach to the modelling of the flux from land-use change should allow a more incisive assessment of the uncertainties inherent in this component of the carbon budget. As well as a need for more sophisticated modelling, there is a need for standardised descriptions so that different modelling approaches can be meaningfully compared.

12d. Pathways to stabilisation

In order to be able to compare the results from the different models, the stabilisation calculations specified a prescribed set of concentration profiles (Figure 8.1) defining the way in which stabilisation was to be achieved. The main principle guiding the choice of these profiles is that the implied emissions should not be required to change too abruptly, and certainly not discontinuously. This implies that the specified concentration profiles should have continuous first derivatives.

This still leaves considerable ambiguity in how the profiles should be defined. As emphasised in the introduction, it is not the role of the IPCC Working Group 1, (and certainly not the role of this report) to recommend specific policy options. However, there are a few general points that can be made:

- Delaying reductions in emissions does not greatly change the total emissions that are consistent with achieving stabilisation of CO_2 concentrations.
- The main penalties for delay are firstly, the need to make reductions more rapidly at some time in the future and secondly, the fact that the reductions will be relative to the 'low-emission' situation required towards the end of next century. Increased costs are to be expected for both more rapid reductions and a greater marginal cost when decreasing emissions from a low level as compared to decreasing them from a high level.
- The requirements of the Framework Convention on Climate Change impose a complex set of criteria on pathways to stabilisation:
  - A restriction on climate change, presumably implying a stabilisation of concentrations;

– A restriction on rate of climate change, presumably related in part to rates of change of greenhouse gas concentrations;
– A need to avoid adverse economic consequences of low emission requirements;
– A need to avoid adverse economic consequences of rapid decreases in emission rates.

Several of the model calculations contributed did not follow the specified profiles. These have been noted earlier; see also Appendix F.

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