3 RESULTS

3.1 General Results

Twenty three replies were received to the 34 questionnaires sent by facsimile to modelling experts. Of those who responded, 14 were able to provide data and information that could be used directly in the review.

This material was used in several ways.

It was used to update the model information in the literature review (Appendix 1). This review now contains information on over 70 models (arranged alphabetically by model developer) most of which have been used at the global level, but some of which are only applicable at the regional level. The level of detail also varies quite considerably: from models known only by their name and a reference; to those that could be described qualitatively, but for which no quantitative data could be obtained; to those with detailed quantitative and qualitative information, taken from the questionnaire and recent references.

It was also used to update a database of global CO2 emission scenarios. This database contains model forecasts of global CO2 emissions of fossil fuel origin, as well as model assumptions concerning population and economic growth. The database is included as Appendix 3.

The information in the questionnaire and database was then used to prepare a series of graphs that include the latest forecasts of CO2 emissions based on "Business as Usual" cases, as well as the IPCC (1992) forecasts.

3.2 Emission Scenarios

Many quantitative estimates of CO2 emissions from fossil fuel consumption have been prepared since the problem of global warming began to be studied. Figure 1 presents the estimates of future CO2 emissions from fossil fuel sources prepared before 1985. Figure 2 presents the most recent estimates of future CO2 emissions from fossil fuel sources, including those of the IPCC Supplement Report scenarios, which are labelled as IS92 (Houghton et al., 1992).

Of those estimates prepared before 1985, the lowest estimate of emissions for

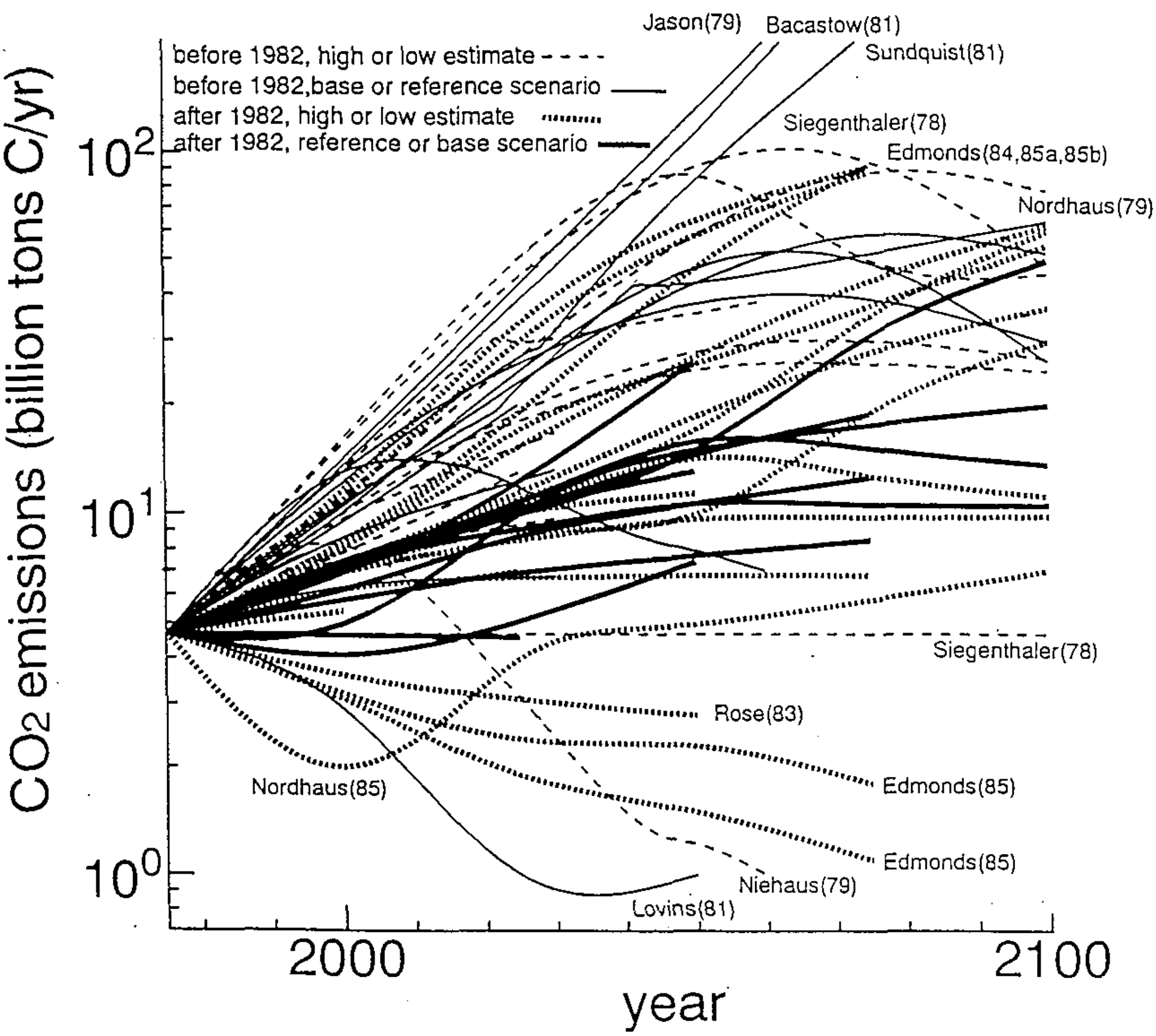

Figure 1 Fossil Fuel CO2 Emission Scenarios (Estimated before 1985)

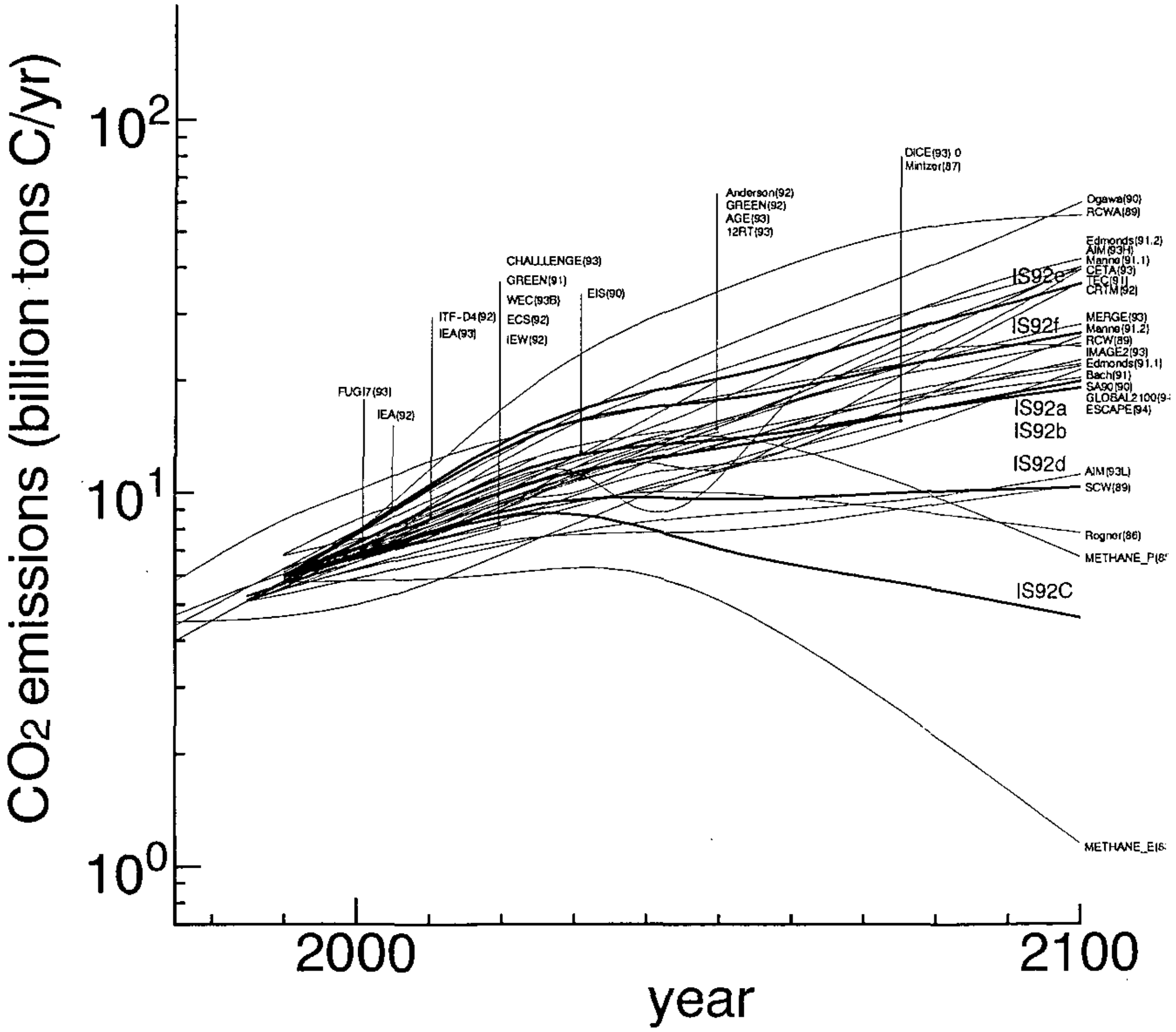

Figure 2 Fossil Fuel CO2 Emission Scenarios (Recent Estimates)

the year 2000 is 1 billion tonnes of carbon (tC) per year, while the highest is 100 billion tC per year, 100 times greater than the lowest value. The thin lines are the reference scenarios, while the bold lines represent the values published between 1983 and 1985. The results calculated after 1983 are more consistent and lower than those calculated before that time. This is considered to be related to the increased awareness of energy conservation resulting from the second oil crisis during 1979 and 1980.

The most recent estimates - those prepared since 1986 and shown in Figure 2 - have become even more consistent as information about global warming became more widespread, and the relationships between likely causes and impacts became better understood.

A comparison between the IPCC reference scenarios and the other recent scenarios illustrates several important features.

Over the short term - to 2030 - most of the scenarios are grouped in a general band, which at the year 2030 is bounded by IS92e and IS92c, as the upper and lower limits respectively. At this time, the band extends from approximately 9 to 19 billion tonnes of carbon per year, and includes the other four IS92 reference scenarios (IS92a, b, d, and f). IS92a and IS92b are roughly in the center of this band, while IS92e and IS92f are at the upper end and IS92d and IS92c are at the lower end.

Over the longer term - to 2100 - most of the scenarios fit into a band ranging from approximately 20 to 40 Giga tonnes of carbon per year. Thus, as would be expected for very long-term scenarios, as the uncertainty of time increases, so the variation between them grows. Nevertheless, it is notable that most are within this band. These scenarios are presented on a log graph, so this dispersion is not readily apparent.

At 2100, the scenario of Edmonds (91.2) forms the upper limit of this band, while IS92b forms the lower limit. IS92e and IS92f, which were among the higher values at 2030, have moved to relatively lower positions amongst the other scenarios.

Scenarios IS92c and IS92d, which were at the lower boundary of the general band at 2030, have moved well below the lower limit by 2100.

The range between the high and low standard scenarios of the AIM estimates (Matsuoka et al., 1993) covers most of the scenarios over the whole time period.

3.3 Population Growth

Figure 3 presents those estimates of future world population used as assumptions in previous emission scenarios.

Beginning in 1990, with the world's population at about 5.3 billion, it can be seen that estimates for 2100 range widely from 3.6 billion (World 3 model; Meadows et al., 1992) to 109.4 billion (UN, 1992).

The United Nations estimates (UN, 1992) which are extraordinarily high, were calculated assuming that the total fertility rate (TFR: the average number of children per woman) in the early 21st century would remain as it now. Mesarovic's (1974) high level, which is the second highest estimate, was calculated assuming that the current rate of increase would not change in the future. It is considered that they should be regarded merely as calculated values, rather than rationale estimates. The scenario with a population of 3.6 billion at 2100 was calculated by Meadows et al.(1992), and assumes that the death rate would increase because of environmental pollution. This scenario is also considered to be extremely unlikely and is rejected.

With these exclusions, the estimates of population at 2100 range from 5.66 billion (Nordhaus and Yohe, 1983) to 19.16 billion (UN, 1992). The highest estimate was calculated using a cohort model which assumes that the final value of the TFR was 2.5 and the lowest 1.7. These figures are equal to Japan's reproductive rates during the periods 1947-1950 and 1975-1985, and so might be considered to be within the realm of future possibility. However, if the higher estimates prevailed, world population would grow to 28 billion by 2150. The likelihood of this is also questionable.

Population policies that produce a considerable decrease in population, such as the lower scenarios, are likely to strike social problems, for example from an aging society. These estimates are also considered to be unfeasible. As a result, the most practical and useful range is considered to extend from the 1990 estimates of the World Bank (WB, 1990; Bulatao, 1990), which estimated that the TFR will become 2.1 (population replacement) at a comparatively early stage, to the 1987 estimate of the U.S. Bureau of Census which estimated that time is reached later. The values of both these forecasts are very close until the beginning of the next century, at which time they separate. WB (1990) assumes that the world's reproductive rate, including developing countries, becomes 1 by around 2040, while USBC (1987) assumes this will occur in the century after next. WB (1990) estimates the population at 2100 to be 11.3 billion, while USBC (1987) estimates it to

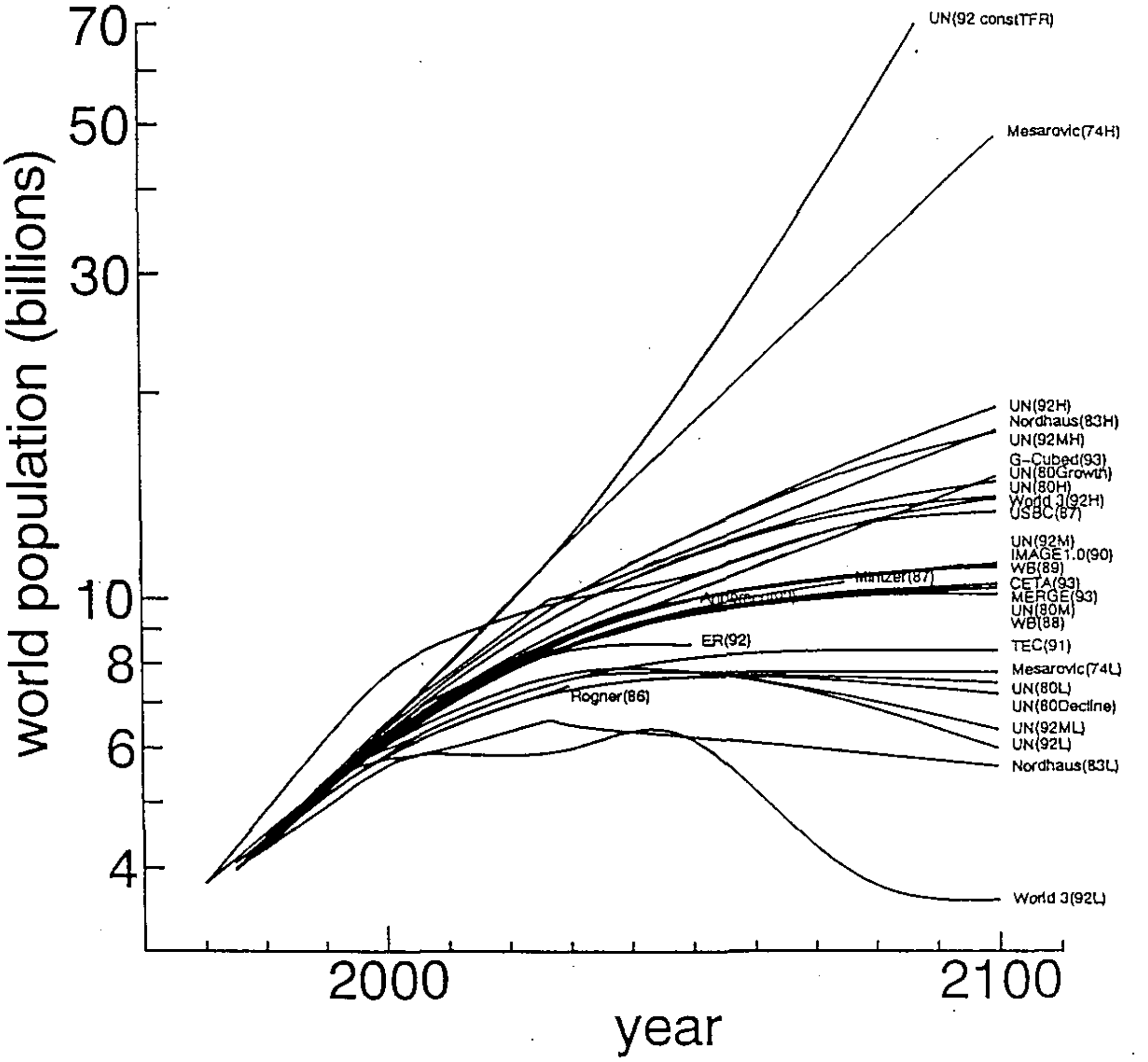

Figure 3 Future World Population Assumptions

be 13.5 billion.

3.4 Economic Growth

Figure 4 presents future economic growth assumptions (per capita GDP) used in various emission scenarios.

The total value of economic activities is determined by population size X per capita GNP, so CO2 emission estimates are very sensitive to assumptions about per capita GNP.

In this figure, the upper group of thin lines are the per capita GDP values of OECD nations, while the lower group of thin lines are those for South and East Asian nations excluding Japan. The bold lines are global estimates.

As can be readily seen, the assumptions are widely dispersed.

The per capita GDP assumptions for the developed regions increase by between about 4 and 9 times from now to the end of the 21st century. Those for the South and East Asian countries increase from 10 to 40 times, and in some cases reach, or exceed, the assumptions for developed regions at 2100. All but two of these assumptions exceed the OECD countries current per capita GDP by 2050. These two end before 2050, but their extrapolation for just a few years would result in them reaching this level before that time.

The global assumptions in particular, are very wide ranging. In general, the more recent ones show a lower level of growth. If they contain estimates of per capita GDP for OECD nations and countries in South and East Asia that are similar to those in this graph, then they must also include an expectation that the prospects for economic growth in other developing nations will remain very low. Also they may reflect the poor economic conditions at the time the forecast was prepared, such as recently seen in Eastern European countries and those that comprised the former Soviet Union.

However, it is considered that many of the population growth assumptions are inconsistent with the economic growth assumptions. This problem will be explained in the following section.

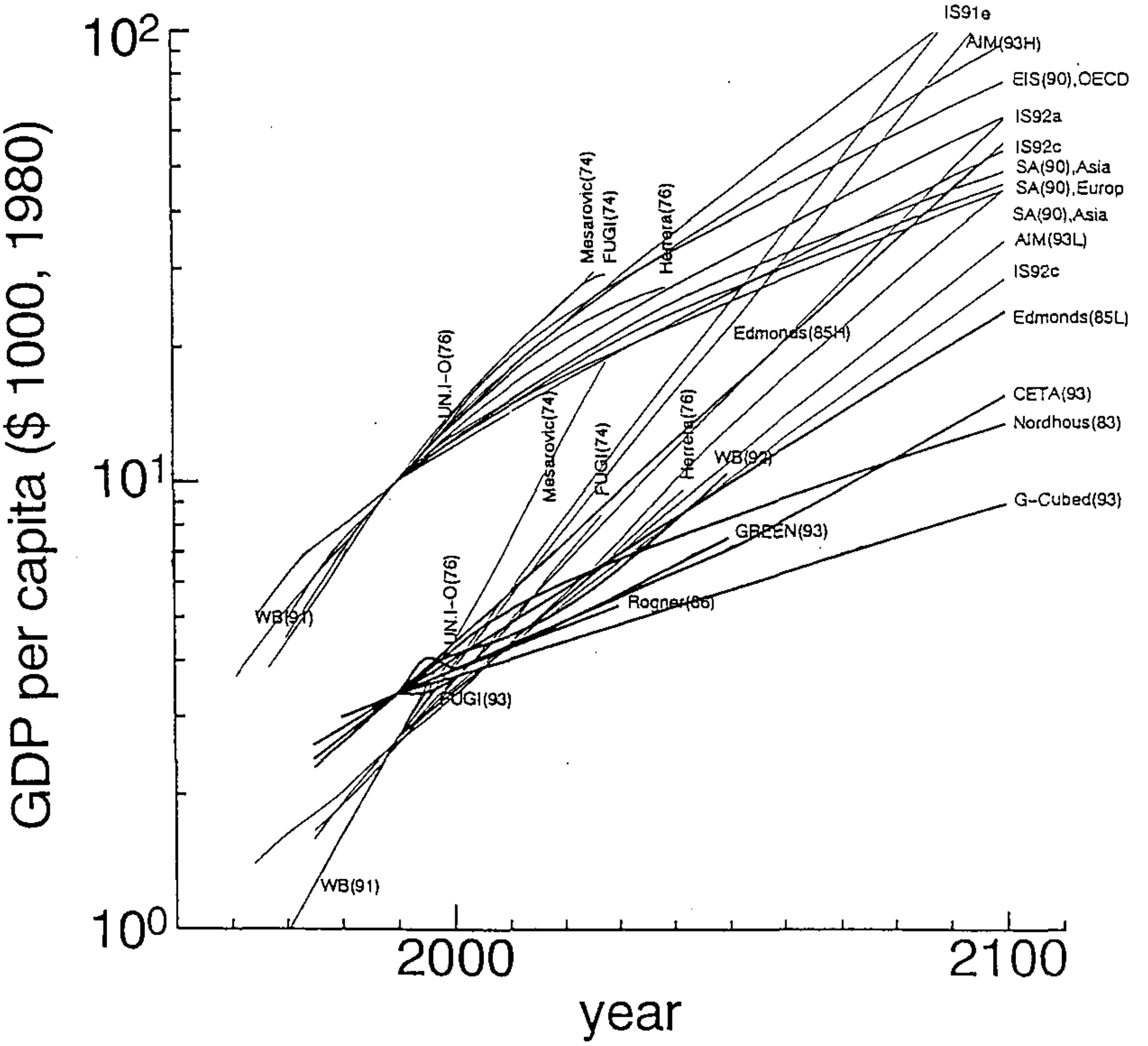

Figure 4 Future Economic Growth Assumptions

(The upper lines are OECD countries, while the lower lines are South Eastern countries excluding Japan.
The thick lines are global estimates.)

3.5 The Relationship between Population Growth and Economic Growth

When determining population and economic growth assumptions, their correlativity must be considered. A decrease in population growth rates of developing regions, and especially fertility rates, increases the potential for saving and promotes the formation of capital. As a result, productivity is able to increase and economies develop. Countries in southern Asia are currently very interested in the impact of this mechanism for the construction of development strategies, so are directing much effort into creating predictive models and preparing scenarios (Bilsborrow, 1989).

The relationship between the global Total Fertility Rate (TFR) and per capita GNP can be explained by the following equation:

$$\Delta TFR = -\alpha \Delta ln\,[\text{per capita GNP}]$$

The parameter α was estimated statistically to be 1.3 by Matsuoka et al. (1993).

This value can then be incorporated into calculations of future estimates of world population using a cohort population projection model, as is shown in Figure 5. From the calculated estimates of future population growth under different GNP growth rates, it can be seen that the median estimate of the UN/WB projections is equivalent to a GNP growth rate of around 3% per year.

IS92a and many other scenarios assume that the world's population will be around 11.3 billion at 2100, corresponding to the estimates of the World Bank (1990) and United Nations (1992). IS92a also assumes that the economic growth rate will be about 2.3% per year, which implies a per capita GNP growth rate of about 1.7%. Clearly, this is incompatible with the value calculated above.

Matsuoka et al. (1993) illustrate that even when the per capita economic growth rate is assumed to be zero, population growth will produce an increase in world GNP of more than 2.5% per year. It would appear that a global population of 11 billion and an economic growth rate of 2.3% at the turn of the next century could only be achieved with very strict population control.

In these circumstances, the use of a model such as is described by Matsuoka et al. (1993) can help provide planners and policy makers with more consistent future scenarios.

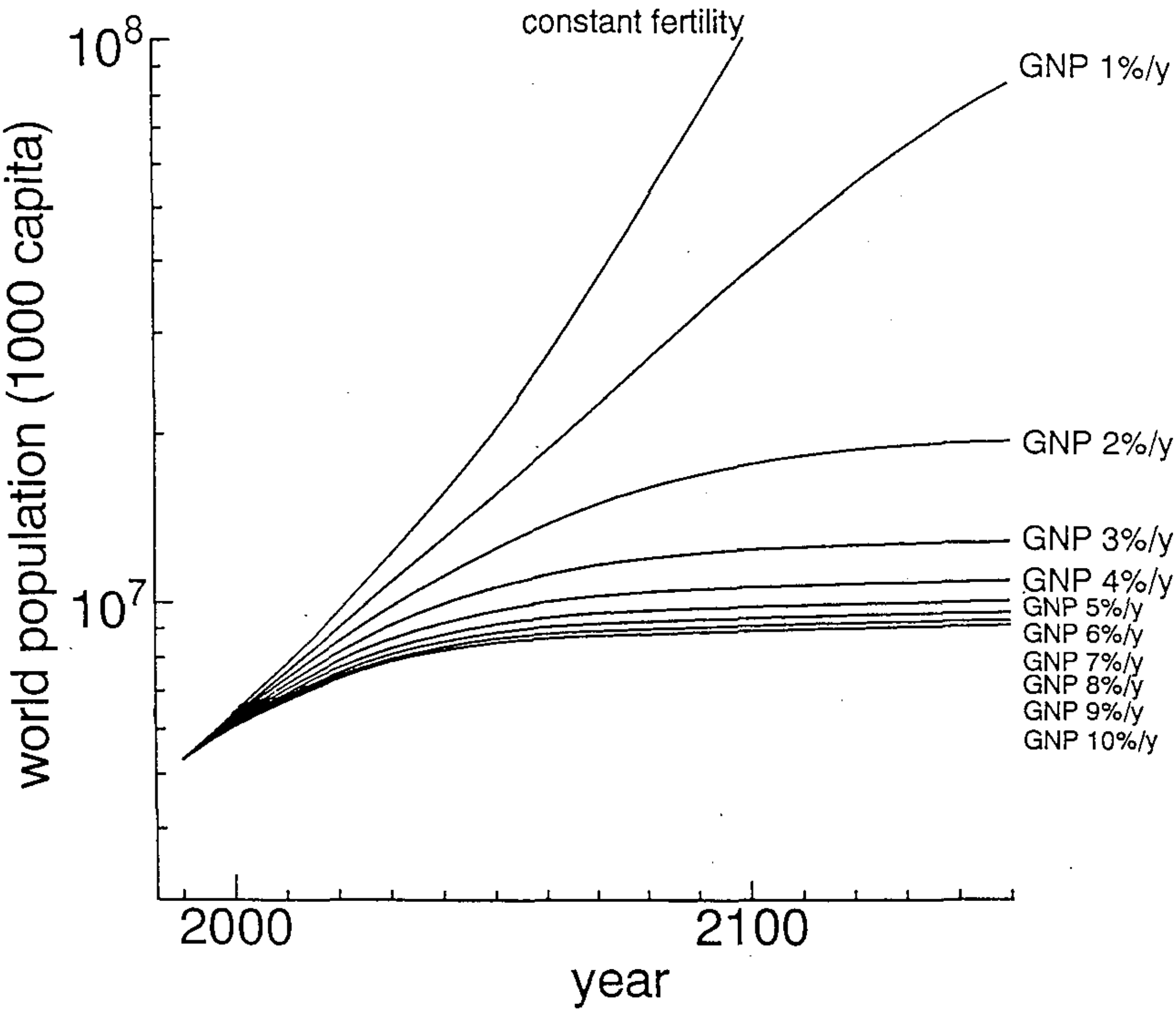

Figure 5 World Population Forecasts under Different Scenarios of Per Capita GNP

3.6 Technology

Table 1 presents AEEI (Autonomous Energy Efficiency Improvements) values of some typical recent emission models. Where there is no great attention paid to saving energy, the annual improvement rate is between 0% and 0.5%, while if great savings are assumed, it rises to 1.0%.

The implications of some normative energy saving scenarios can be examined. For example, in the scenario of Lovins et al. (1981), between 1975 and 2080, per capita consumption of primary energy is reduced to 22% in developed regions, and to 50% in developing regions. The scenario of Goldemberg et al. (1988) assumes that between 1980 and 2020, per capita energy consumption in developed regions is reduced to 50%, while in developing regions it is restricted to 110%. When these values are converted to annual rates using energy prices during the forecast periods and per capita GDP growth rates, values of about 1.1 to 2.9% are obtained.

In the Goldemberg scenario, the planning period is a comparatively short 40 years. It is considered that it will be much more difficult to save energy after this period, so there is little hope for maintaining a 2% annual rate over the long term. Accordingly, this high figure is excluded, and the AEEI annual rate is assumed to range between 0 and 1.5%. However, it is also recognized that the AEEI will differ greatly between different energy consumers and regions.

3.7 The Driving Force of CO2 Emissions

In general, the level of CO2 emissions from the combustion of fossil fuels can be explained by assumptions about population, per capita GNP, energy efficiency improvements and fuel carbon intensity. In order to confirm the main factors in this relationship, the annual rate of CO2 increase calculated by each model was plotted against their assumed annual economic growth rate minus the assumed AEEI.

This relationship is shown in Figure 6, which illustrates that for these scenarios the annual economic growth rate minus the AEEI can explain most of the CO2 emission changes. However, the dispersion indicates that some other important factors are also playing a role.

In order to assess the CO2 emission scenarios more deeply, it is considered that quite detailed analyses need to be conducted of the elasticities of price-induced en-

Table 1 AEEI of Major Global GHG Emission Models

MODELERS	AEEI (%/annum)
Global energy models	
Manne and Richels (1994)	0.7
Goulder (1994)	0
Nordhous (1993)	0 - 1.25
Mckibbin and Wilcoxen (1993)	0
Peck and Teisberg (1993)	0.25
Manne et al. (1993)	0.5
Anderson and Bird (1992)	1
Edmonds and Reilly (1991)	0.5 - 1
IEA (1991)	1.1 (OECD)
GREEN (1991)	1
Manne and Richels (1990)	0 - 1
IPCC (1990) (*)	0.16 (low growth) 0.46 (high growth) (USA)
Feasibility studies of energy efficient scenarios	
Lovins (1981) (*)	1.12 (Developed) 1.53 (Developing)
Goldemberg (1988) (*)	2.85 (Developed) 1.40 (Developing)

(*) Estimated

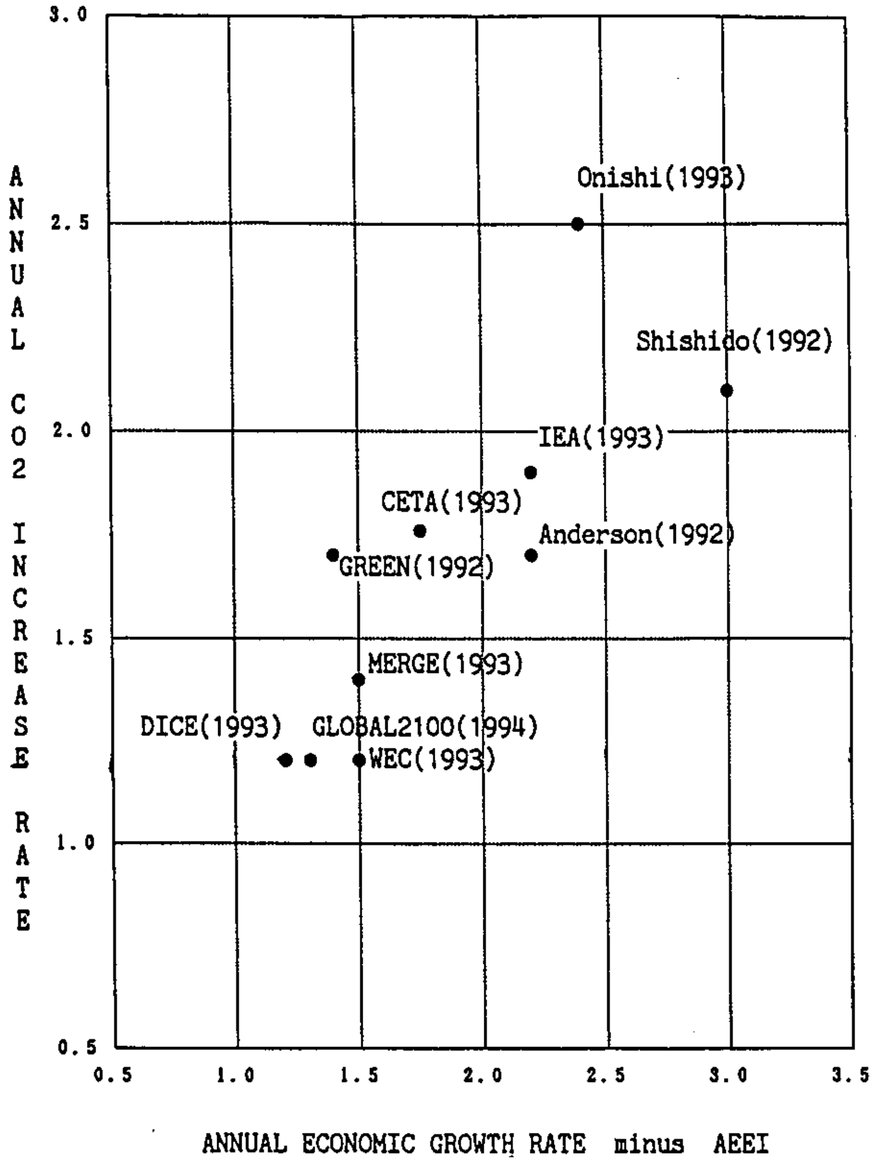

Figure 6 Relationship Between Economic/Technological Assumptions and CO2 Emissions Scenarios

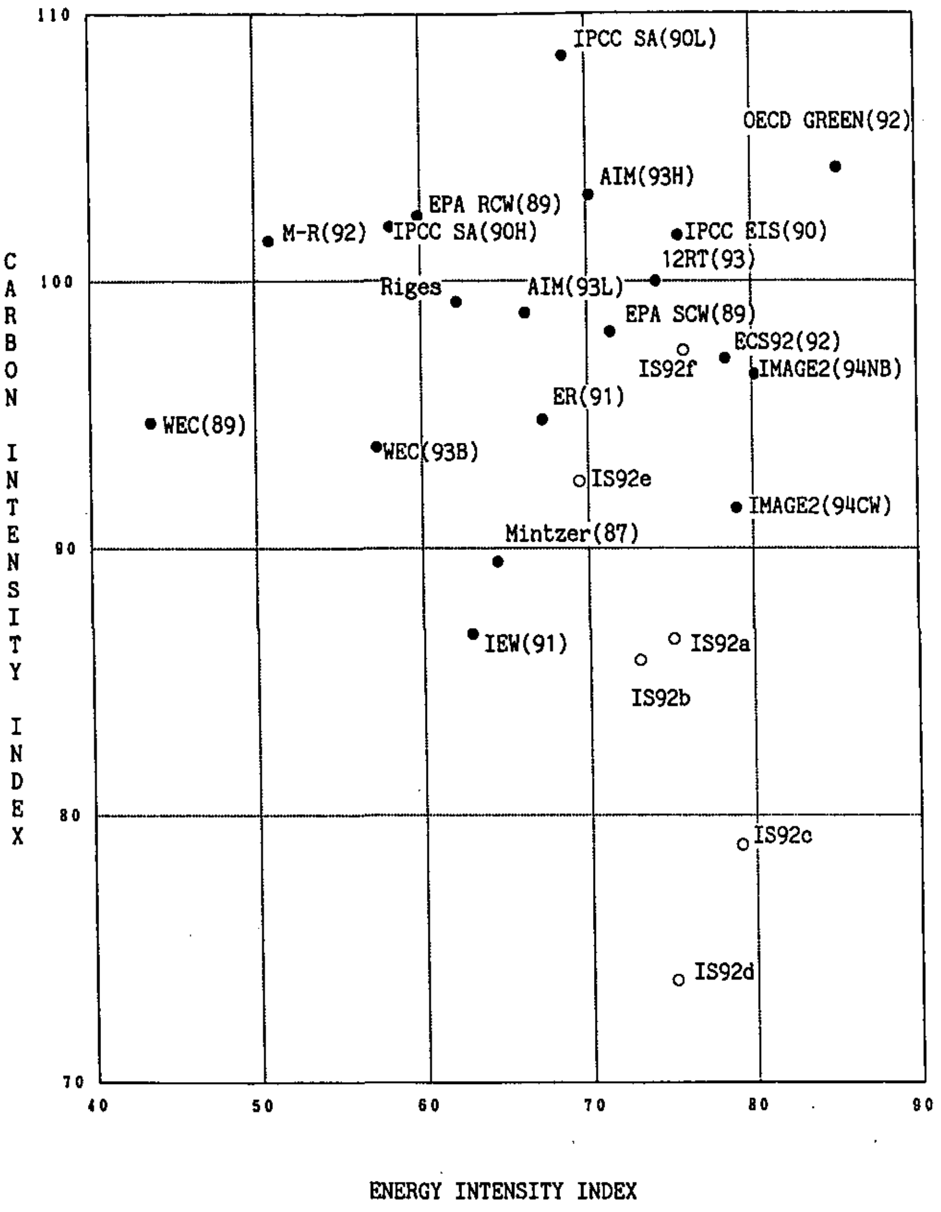

Figure 7 Energy and Carbon Intensities in 2025 of Various Emission Scenarios (Index : 1990 = 100)'