A3

Emissions Scenarios for the IPCC: an Update

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EXECUTIVE SUMMARY

Scenarios of net greenhouse gas and aerosol precursor emissions for the next 100 years or more are necessary to support study of potential anthropogenic impacts on the climate system. The scenarios both provide inputs to climate models and also assist in assessing the relative importance of relevant trace gases and aerosol precursors in changing atmospheric composition and hence climate. Scenarios can also help to improve the understanding of key relationships among factors that drive future emissions.

Scenarios are not predictions of the future and should not be used as such. This becomes increasingly true as the time horizon increases, because the basis for the underlying assumptions becomes increasingly speculative. Considerable uncertainties surround the evolution of the types and levels of human activities (including economic growth and structure), technological advances, and human responses to possible environmental, economic and institutional constraints.

Since completion of the 1990 Scenario A (SA90), events and new information have emerged which relate to that scenario's underlying assumptions. These developments include: the London Amendments to the Montreal Protocol; revision of population forecasts by the World Bank and the United Nations; publication of the IPCC Energy and Industry Sub-group scenario of greenhouse gas emissions to AD 2025; political events and economic changes in the former USSR, Eastern Europe and the Middle East; re-estimation of sources and sinks of greenhouse gases (reviewed in this Assessment); revision of preliminary FAO data on tropical deforestation; and new scientific studies on forest biomass.

These factors have led to an update of SA90, the current exercise providing an interim view and laying a basis for a more complete study of future emissions. Six alternative IPCC scenarios (IS92a-f) now embody a wide array of assumptions affecting how future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted. The different worlds which the new scenarios imply, in terms of economic, social and environmental conditions, vary widely and the resulting range of possible greenhouse gas futures spans almost an order of magnitude. Overall, the scenarios indicate that greenhouse gas emissions could rise substantially over the coming century in the absence of new and explicit control measures. IS92a is closer to SA90 due to modest and largely offsetting changes in the underlying assumptions. The highest greenhouse gas levels result from IS92e which combines, among other assumptions, moderate population growth, high economic growth, high fossil fuel availability and eventual hypothetical phase-out of nuclear power. At the other extreme, IS92c has a CO_2 emission path which eventually falls below its 1990 starting level. It assumes that population grows, then declines by the middle of the next century, that economic growth is low, and that there are severe constraints on fossil fuel supplies. IS92b, a modification of IS92a, suggests that current commitments by many OECD Member countries to stabilize or reduce CO_2 might have a small impact on greenhouse gas emissions over the next few decades, but would not offset the substantial growth in the rest of the world. IS92b does not take into account the possibility that such commitments could accelerate development and diffusion of low greenhouse gas technologies, nor possible resulting shifts in industrial mix.

Population and economic growth, structural changes in economies, energy prices, technological advance, fossil fuel supplies, nuclear and renewable energy availability are among the factors which could exert a major influence on future levels of CO_2 emissions. Developments such as those in the republics of the former Soviet Union and in Eastern Europe, now incorporated into all the scenarios, have important implications for future fossil fuel carbon emissions, by affecting the levels of economic activities and the efficiency of energy production and use. Biotic carbon emissions in the early decades of the scenarios are higher than SA90, reflecting higher preliminary FAO estimates of current rates of tropical deforestation in many - though not all - parts of the world, and higher estimates of forest biomass.

The revised scenarios for CFCs and other substances which deplete stratospheric ozone are much lower than in SA90. This is consistent with wide participation in controls under the 1990 London Amendments to the Montreal Protocol. However, the future production and composition of CFC substitutes (HCFCs and HFCs) could significantly affect the levels of radiative forcing from these compounds.

The distribution of CH_4 and N_2O emissions from their respective sources has changed from the SA90 case. CH_4 emissions from rice paddies are lower, and emissions from animal waste and biomass burning have also been revised downwards. Adipic and nitric acid production have been included as additional sources of N_2O. Preliminary analysis of the emissions of volatile organic compounds and sulphur dioxide suggests that the global emissions of these substances are likely to grow substantially in the coming century.

A3.1 Introduction and Background

In January 1989, the Response Strategies Working Group (RSWG) of the Intergovernmental Panel on Climate Change (IPCC) requested a United States/Netherlands expert group to prepare a set of scenarios of global emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halocarbons and the tropospheric ozone precursors nitrogen oxide (NO_x) and carbon monoxide (CO) (IPCC, 1991a). These scenarios were completed in December 1989 for use by the IPCC Science Working Group (WGI) in its assessment of future climate change (IPCC, 1990a and b). New information has become available since the development of the original scenarios. Consequently, in March 1991, the IPCC requested an update of the existing scenarios in light of recent developments and newly adopted policies. The new IPCC mandate explicitly excluded development of new climate policy scenarios (Swart *et al.*, 1991).

This Section first briefly compares the major assumptions on population and economic growth with historical data or other published forecasts. It then summarizes how the original no-climate-policy Scenario A (SA90) has been updated with information which has become available in 1990 and 1991. This produces the new IPCC Scenarios "IS92a" and "IS92b". Because of substantial uncertainty in how the future will evolve, this Section also includes a preliminary assessment of a range of additional no-climate-policy scenarios, as well as comparisons with other published greenhouse gas scenarios. The updated scenarios are set against two studies of the probability distributions of possible CO_2 scenarios, and then are compared to other published "central tendency" scenarios that extend past the year 2000 and up to the year 2100. Finally, we present sector-by-sector discussions of the particular methods and assumptions in the update, along with additional sectoral scenarios. Detailed documentation of the scenarios is available in a supporting document which also provides tabulations of key variables including population, GNP, primary energy consumption, and emissions (Pepper *et al.*, 1992).

A3.2 New Aspects of this Update

The following changes have occurred since the original IPCC scenarios were developed:

- revised World Bank and United Nations (UN) population forecasts;
- a new greenhouse gas scenario from the IPCC Energy and Industry Sub-Group (EIS);
- important political reforms in the USSR, Eastern Europe and other countries, and a war in the Persian Gulf;
- more optimistic assessments of the economical availability of renewable energy resources;
- revised estimates of current sources and sinks of greenhouse gases, reported in Section A1 of this report;
- revised Food and Agriculture Organization (FAO) data on rates of tropical deforestation and several new studies on forest biomass content; and
- the London Amendments to the Montreal Protocol as well as developments in participation and compliance with the Protocol entered into force.

For completeness, several small sources of greenhouse gases are added to this assessment which were not included in the 1990 IPCC Assessment Report. These include N_2O from the production of nitric acid and adipic acid, and CH_4 from animal wastes and domestic sewage (see Sections A1.3 and A1.4). In addition, scientific evidence described in Section A2 underscores the need to consider the full range of gases which influence climate, directly or indirectly. Cognizant of the importance of a comprehensive approach, this Section also provides preliminary estimates of present and future emissions of volatile organic compounds (VOC) and sulphur oxides (SO_x). Their indirect influences on radiative forcing are more uncertain than those of the direct greenhouse gases and it is not yet possible to quantify on an equivalent basis all the direct and indirect forcing. Improved information with which both to estimate the emissions of these gases and to summarize their effects is needed for future assessments.

The reader should be cautioned, however, that none of the scenarios depicted in this section predicts the future. Long-term scenarios provide inputs to climate models and assist in the examination of the relative importance of relevant trace gases, aerosols, and precursors in changing atmospheric composition and climate. Scenarios can also help improve understanding of key relationships among factors that drive future emissions. Scenarios illustrate the emissions which could be associated with an array of possible assumptions regarding demographics, economics, and technological advance. They can help policymakers to consider the directions in which future emissions may evolve in the absence of new greenhouse gas reduction efforts, and the types of change in important parameters which could or would have to occur in order to significantly change future emission paths.

The results of scenarios can vary considerably from actual outcomes even over short time horizons. Confidence in scenario outputs decreases as the time horizon increases, because the basis for the underlying assumptions becomes increasingly speculative. Uncertainties are of two types:

(i) large uncertainty associated with the evolution of future patterns of human activity, such as economic growth and structure, technological advances, or responses to environmental, economic, or institutional constraints; and

(ii) inadequacy of scientific knowledge concerning physical parameters, such as emission factors, and their relationships.

We have addressed some of these uncertainties in the updated IS92a and b in four ways. The first is through the creation of new scenarios (c through f explained in Table A3.1) using modified key parameters; the second compares some of the new IPCC scenarios with two studies which have mapped probability distributions of future CO_2 emissions; the third compares the range of new IPCC scenarios with other published studies of "central tendencies"; and the fourth analyses sensitivity of results in different sectors to key parameters. The current exercise lays a basis for more complete analysis of the credible range and probabilities of alternative scenarios.

A possibly important limitation of this analysis is that it does not assess the effects that climate change may have on agricultural production, energy demand, and terrestrial ecosystems. Nor does it make assumptions about growth of vegetation if CO_2 increases fertilization, or about losses of the forest uptake of CO_2 if deforestation continues. There could also be positive feedbacks on CO_2 and methane emissions through increased respiration of vegetation and degradation of organic soils. Also, as discussed in Section A2 of this report, we do not yet have an adequate method for summarizing on an equivalent basis the effects on climate of all the greenhouse gases.

A3.3 The Analytical Tool: The "Atmospheric Stabilization Framework"

The Atmospheric Stabilization Framework (ASF), developed by the US Environmental Protection Agency (EPA, 1990), was used as the primary tool for integrating the assumptions and estimating future emissions of greenhouse gases. The ASF is a framework which combines emission modules for various sectors including modules for energy, industry, agriculture, forests and land conversion, as well as a number of small sources. Each module combines assumptions concerning population, economic growth, structural change, resource availability, and emission coefficients to estimate emissions in future time periods. The ASF estimates emissions for CO_2, CH_4, N_2O, chlorofluorocarbons (CFCs) and substitutes, CO, NO_x, VOCs, and SO_x. The energy module uses energy prices to equilibriate supply from the different energy supply sources with demand in four energy end-use sectors. Increased energy prices encourage additional energy supply and increases in energy efficiency but have only a small feedback on economic growth. The agriculture module combines assumptions on population growth, economic growth, improved yields, and other factors to estimate future production and consumption of agricultural products, land use, and fertilizer use along with emissions of greenhouse gases from these activities. The CFC module estimates future emissions of CFCs, HCFCs, carbon tetrachloride (CCl_4), methyl chloroform, and HFCs under different policy objectives and compliance scenarios, derived with assumptions on the estimated growth in demand for CFCs. The tropical forest section combines assumptions including population, demand for agricultural land, method of forest clearing, and the amount of biomass stored in the vegetation and soils to estimate the clearing of tropical forests and the fate of the cleared land (e.g., forests may be cleared and then allowed to lie fallow in which case they can start to re-accumulate carbon).

A3.4 General Assumptions

The assumptions for the scenarios in this report come mostly from the published forecasts of major international organizations or from published expert analyses. Most of these have been subject to extensive review. The premises for the 1992 IPCC Scenarios a and b ("IS92a" and "IS92b") most closely update the SA90 scenario from IPCC (1990) There exist a wide variety of other plausible assumptions, some of which are used in the range of new scenarios presented here. Table A3.1 summarizes the different assumptions used in the six scenarios. These assumptions are documented in detail in a supporting report (Pepper *et al.*, 1992).

New information since the SA90 has raised the assumed population and economic growth rates compared to those in the earlier assessment. The forecast of future population growth in the SA90 came from the World Bank (Zachariah and Vu, 1988), which the World Bank has since revised (Bulatao *et al*, 1989). The UN has also published new population estimates (UN, 1990; UN Population Division, 1992). The UN medium case is very close to the World Bank's update; the UN medium-low and medium-high cases are used in the alternative scenarios presented here. Most of the variance between the medium-high and medium-low cases is in the developing countries. The updated World Bank population assumptions are close to 10% higher than the assumptions in the SA90: global population increases from 4.84 billion in 1985, to 8.42 billion in 2025, and to 11.33 billion in 2100, with about 94% of the growth occurring in the developing countries. The UN medium forecast of future population estimates that global population may reach 8.51 billion in 2025, 1% higher than the World Bank estimate. Their recent medium extension of this suggests world population of 11.18 billion in 2100 (UN Population Division, 1992), or about 1% lower than the World Bank's. The UN medium-low

Table A3.1: *Summary of assumptions in the six IPCC 1992 alternative scenarios.*

Scenario	Population	Economic Growth		Energy Supplies	Other	CFCs
IS92a	World Bank 1991 11.3 B by 2100	1990-2025: 1990-2100:	2.9% 2.3%	12,000 EJ Conventional Oil 13,000 EJ Natural Gas Solar costs fall to \$0.075/kWh 191 EJ of biofuels available at \$70/barrel †	Legally enacted and internationally agreed controls on SO_x, NO_x and NMVOC emissions. Efforts to reduce emissions of SO_x, NO_x and CO in developing countries by middle of next century.	Partial compliance with Montreal Protocol. Technological transfer results in gradual phase out of CFCs in non-signatory countries by 2075.
IS92b	World Bank 1991 11.3 B by 2100	1990-2025 1990-2100	2.9% 2.3%	Same as "a"	Same as "a" plus commitments by many OECD countries to stabilize or reduce CO_2 emissions.	Global compliance with scheduled phase out of Montreal Protocol.
IS92c	UN Medium-Low Case 6.4 B by 2100	1990-2025 1990-2100	2.0% 1.2%	8,000 EJ Conventional Oil 7,300 EJ Natural Gas Nuclear costs decline by 0.4% annually	Same as "a"	Same as "a"
IS92d	UN Medium-Low Case 6.4 B by 2100	1990-2025 1990-2100	2.7% 2.0%	Oil and gas same as "c" Solar costs fall to \$0.065/kWh 272 EJ of biofuels available at \$50/barrel	Emission controls extended worldwide for CO, NO_x, NMVOC and SO_x. Halt deforestation. Capture and use of emissions from coal mining and gas production and use.	CFC production phase out by 1997 for industrialized countries. Phase out of HCFCs.
IS92e	World Bank 1991 11.3 B by 2100	1990-2025 1990-2100	3.5% 3.0%	18,400 EJ conventional oil Gas same as "a" Phase out nuclear by 2075	Emission controls which increase fossil energy costs by 30%.	Same as "d"
IS92f	UN Medium-High Case 17.6 B by 2100	1990-2025: 1990-2100:	2.9% 2.3%	Oil and gas same as "e" Solar costs fall to \$0.083/kWh Nuclear costs increase to \$0.09/kWh	Same as "a"	Same as "a"

† - Approximate conversion factor: 1 barrel = 6GJ.

Table A3.2: *Population assumptions (in millions).*

Region	World Bank (1991) IS92a, b & e 1990	2025	2100	UN Med-Low IS92c & d 2025	2100 †	UN Med-High IS92f 2025	2100 †
OECD	838	939	903	865	503	1,039	1,359
USSR & E.-Europe	428	496	513	475	337	540	856
China & CP Asia ††	1,218	1,721	1,924	1,526	935	1,881	2,385
Middle East	128	327	603	272	223	349	693
Africa	648	1,587	2,962	1,375	1,668	1,807	4,651
Latin America	440	708	869	682	770	832	1,662
South & East Asia	1,553	2,636	3,538	2,395	1,979	2,999	5,987
Total	5,252	8,414	11,312	7,591	6,415	9,445	17,592

† Regional breakout of data for 2100 reported here was derived from UN Population Division (1992) which used different regions from this IPCC analysis and did not provide country-specific estimates.
†† CP = Centrally planned economies.

Table A3.3: *GNP growth assumptions (average annual rate)*

	.... World Bank†			IS92c		IS92a		IS92e	
		Low††	High††						
	1965 1989	1990 2000	1990 2000	1990 2025	1990 2100	1990 2025	1990 2100	1990 2025	1990 2100
OECD	3.2%	2.4%	3.1%	1.8%	0.6%	2.5%	1.7%	3.0%	2.2%
USSR/E.Europe†††	1.3%	3.2%	3.6%	1.5%	0.5%	2.4%	1.6%	3.2%	2.4%
China & CP¥ Asia	7.6%	5.6%	6.7%	4.2%	2.5%	5.3%	3.9%	6.1%	4.7%
Other	4.7%	3.8%	4.5%	3.0%	2.1%	4.1%	3.3%	4.8%	4.1%
Global	-	-	-	2.0%	1.2%	2.9%	2.3%	3.5%	3.0%

† Source: World Bank (1991).
†† Estimated using projections of regional growth in GDP/capita and country estimates of GDP, population and population growth from 1990 to 2000.
††† World Bank data only include several countries in Eastern Europe.
¥ CP = Centrally planned economies.

and medium-high cases reach 6.4 billion and 17.6 billion, respectively, in 2100. Table A3.2 summarizes the population assumptions by region.

Future economic growth assumptions are summarized in Table A3.3. Growth rates assumed in this update are based in part on the reference scenario to 2025 of the Energy and Industry Sub-Group (EIS) of the RSWG (IPCC, 1991b). However, we have adjusted them downward in the near and medium terms in Eastern Europe, the (former) USSR, and the Persian Gulf due to the likely impacts of recent political events. Overall, the economic growth assumptions in IS92a and IS92b are higher than those used in the SA90, especially in Africa, China and Southeast Asia. However, the IS92a and b assumptions for 1990 to 2000 are generally below or at the low end of the ranges forecast by the World Bank (1991), with the exceptions of the US, OECD (Organization of Economic Cooperation and Development) Pacific and the Middle East. Table A3.3 compares the ranges of GNP assumptions in the new IPCC Scenarios with historical data and the near term projections from the World Bank (World Bank, 1991). The GNP growth rate assumptions for the initial 35 years of IS92a and b, from 1990 to 2025, are substantially below those experienced by most world regions in the past 34 years, from 1955 to 1989. The exceptions are Africa; and Eastern Europe and the USSR, where we assume substantial

***Table A3.4:** GDP per capita growth † from 1955 to 1989 (average annual rate)*

OECD Members	2.9%
Eastern Europe	2.5%
Europe, Middle East, & North Africa	2.6%
Sub-Saharan Africa	1.0%
Latin America	1.6%
Asia	4.6%

† Source: World Bank (1991), rates of growth re-estimated.

***Table A3.5:** GNP per capita growth assumptions from 1990 to 2025 (average annual rate)*

	IS92c	IS92a	IS92e
OECD	1.7%	2.2%	2.7%
USSR/E.-Europe	1.2%	2.0%	2.7%
China & CP Asia	3.5%	4.3%	5.1%
Mid-East	0.5%	1.2%	2.0%
Africa	0.9%	1.7%	2.5%
Latin America	1.2%	1.9%	2.7%
Rest of Asia	2.3%	3.0%	3.8%

structural adjustment would boost growth in the medium term. Over the long-term, GNP tends to slow due to an expected slowing of population growth.

Income per capita is assumed to rise most rapidly in the developing world throughout the next century, but in 2100 it remains well below levels in the developed economies. Table A3.4 provides historical data from the World Bank on growth of GDP/capita in the past 34 years, for comparison with Table A3.5 showing the range of IS92 assumptions for 1990 to 2025.

It is important to note that the emission results provided in this paper are highly sensitive to both the population and economic growth assumptions. These parameters would most likely be negatively correlated, however. The economic growth assumptions in IS92a and b fall below historical rates. It is uncertain whether ambitious growth can be realized and maintained in all regions, especially considering possible capital and resource constraints and the presently volatile circumstances in a number of nations. On the other hand, the relatively low GNP per capita in developing countries even at the end of the period suggest that the IS92a and b assumptions fall well below the aspirations of many countries.

All the scenarios presented here include the changes in government policies aimed at mitigating climate change which have been adopted (as of December 1991). The expert group used a rule for IS92a to incorporate only those emission controls internationally agreed upon and national policies enacted into law, such as the London Amendments to the Montreal Protocol, the amended US Clean Air Act, and the SO_x, NO_x, and VOC Protocols of the Convention on Long Range Transboundary Air Pollution (LRTAP).[1] It does not include the CO_2 emissions targets that have been proposed but not enacted by many OECD countries nor broad policy proposals to cut back on deforestation.

Another scenario, IS92b, shows some of the uncertainty surrounding these policies. IS92b enlarges the interpretation of current policies to include stated policies beyond those legally adopted. All CO_2 commitments of OECD countries, for example, are included, along with an assumption of worldwide ratification and compliance with the amended Montreal Protocol. Since we assume that the CO_2 stabilization commitments would be achieved through improvements in energy efficiency and switching from fossil fuels to nuclear or renewable energy, this reduces simultaneously some of the other greenhouse gases emitted by fossil fuels. We assume that after the target years, emissions would be kept level.

Four additional scenarios have been constructed to examine the sensitivity of future greenhouse gas emissions to a wider range of alternative input assumptions for key variables. Full documentation is available in Pepper *et al.* (1992). The scenarios suggest very different pictures of the future.

IS92c, the lowest scenario, assumes the UN medium-low population forecast, in which population declines in the twenty-first century. It also assumes lower growth in GNP per capita than IS92a and b, as well as low oil and gas resource availability, resulting in higher prices and promoting expansion of nuclear and renewable energy. Deforestation would be slower with lower population growth. IS92d represents another low but more optimistic scenario. It extrapolates some possible trends towards increasing environmental protection, but includes only actions that could be taken due to concern about local or regional air pollution, waste disposal, etc. Population growth assumes the UN medium-low forecast and would be associated with lower natality, falling below the replacement rate late in the twenty-first century, due for example to improvement in per capita income or increased

1 - In addition, since there is a trend toward increasing control of local air pollution in many countries, all scenarios assumed a slow penetration of low-cost technologies which reduce SO_x and NO_x emissions from very large installations and, in the case of NO_x and CO, from motor vehicles.

Table A3.6: *Selected results of six 1992 IPCC greenhouse gas scenarios.*

Scenario	Years	Decline in TPER/GNP (AARC)	Decline in C Intensity (AARC)	Cumulative Net Fossil C Emissions (GtC)	Tropical Deforestation: Total Forest Cleared (million hectares)	Tropical Deforestation: Cumulative Net C Emissions (GtC)	Year	Emissions Per Year: CO_2 (GtC)	CH_4 (Tg)	N_2O (TgN)	CFCs (kt)	HCFCs (kt)	HFCs (kt)	Other halo-carbons (kt)	SO_x (TgS)
IS92a	1990-2025	0.8%	0.4%	285	678	42	1990	7.4	506	12.9	827	143	0	864	98
	1990-2100	1.0%	0.2%	1386	1447	77	2025	12.2	659	15.8	217	824	511	121	141
							2100	20.3	917	17.0	3	1074	1823	0	169
IS92b	1990-2025	0.9%	0.4%	275	678	42	2025	11.8	659	15.7	36	847	533	3	140
	1990-2100	1.0%	0.2%	1316	1447	77	2100	19.1	917	16.9	0	1075	1823	0	164
IS92c	1990-2025	0.6%	0.7%	228	675	42	2025	8.8	589	15.0	217	824	511	121	115
	1990-2100	0.7%	0.6%	672	1343	70	2100	4.6	546	13.7	3	1074	1823	0	77
IS92d	1990-2025	0.8%	0.9%	249	420	25	2025	9.3	584	15.1	24	316	1064	3	104
	1990-2100	0.8%	0.7%	908	651	30	2100	10.3	567	14.5	0	0	2764	0	87
IS92e	1990-2025	1.0%	0.2%	330	678	42	2025	15.1	692	16.3	24	316	1064	3	163
	1990-2100	1.1%	0.2%	2050	1447	77	2100	35.8	1072	19.1	0	0	2764	0	254
IS92f	1990-2025	0.8%	0.1%	311	725	46	2025	14.4	697	16.2	217	824	511	121	151
	1990-2100	1.0%	0.1%	1690	1686	93	2100	26.6	1168	19.0	3	1074	1823	0	204

TPER = Total Primary Energy Requirement
Carbon (C) intensity is defined as units of carbon per unit of TPER
AARC = Average annual rate of change
CFCs include CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115
Other halocarbons include carbon tetrachloride, methyl chloroform, Halon 1211 and Halon 1301

family planning. Like IS92c, low fossil resource availability gives rise to greater market penetration of renewable energy and safe nuclear power. The costs of more stringent local pollution controls are incorporated into IS92d through a 30% environmental surcharge on fossil energy use. Greater well-being is assumed to lead to voluntary actions to halt deforestation, to adopt CFC substitutes with no radiative or other adverse effects, and to recover and efficiently use the CH_4 from coal mines and landfills.

IS92e, the case with the highest estimated CO_2 emissions, assumes the World Bank (moderate) population forecast but a more rapid improvement in GNP per capita. Fossil resources are plentiful, but, due to assumed improvement in living standards, environmental surcharges are imposed on their use. Nuclear energy is phased out by 2075. CFC substitute assumptions are like those in IS92d, but plentiful fossil resources discourage the additional use of coal mine methane for energy supply as assumed in IS92d. Deforestation proceeds at the same pace as in IS92a. IS92f falls below IS92e, using the high UN population growth forecasts but the lower assumptions of improvement in GNP per capita than IS92a. Other assumptions are high fossil resource availability, increasing costs of nuclear power, and less improvement in renewable energy technologies and costs. Table A3.6 summarizes key results of the scenarios for all gases and Figure A3.1 illustrates the scenarios for CO_2 emissions only. Table A3.7 summarizes net emissions of CO_2, and anthropogenic emissions of CH_4, and N_2O by region for IS92a.

A3.5 Comparisons with Other Studies

No systematic analysis has been conducted in this exercise of the likelihood of any of the outcomes illustrated in the six new IPCC Scenarios described above. However, the probabilities of these emission paths has been considered in part by comparison with other studies of probabilities

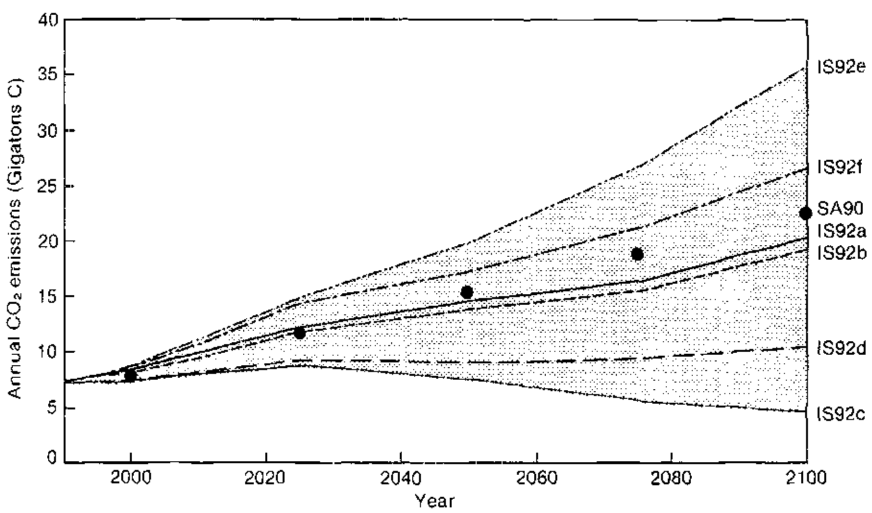

Figure A3.1: Annual CO_2 emissions from energy, cement production and tropical deforestation for the six IPCC 1992 scenarios (IS92a-f) and for the 1990 IPCC Scenario A (SA90).

Table A3.7: *Net emissions of CO_2 and anthropogenic emissions of CH_4 and N_2O under IS92a.*

	CO_2 (GtC)			Anthropogenic N_2O (TgN)			Anthropogenic CH_4† (Tg)		
	1990	2025	2100	1990	2025	2100	1900	2025	2100
OECD	2.8	3.5	4.3	1.4	2.0	1.7	74	90	143
USSR & Eastern Europe	1.7	2.4	2.5	0.8	1.0	0.9	70	62	113
China and CP Asia††	0.6	1.6	4.2	0.5	0.8	0.9	37	53	73
Other	0.9	3.2	8.8	1.9	3.7	5.1	146	260	380
Total	6.0	10.7	19.8	4.6	7.5	8.7	326	465	709

† Excludes CH_4 from domestic sewage which was not estimated on a regional basis.
†† CP = Centrally planned economies.

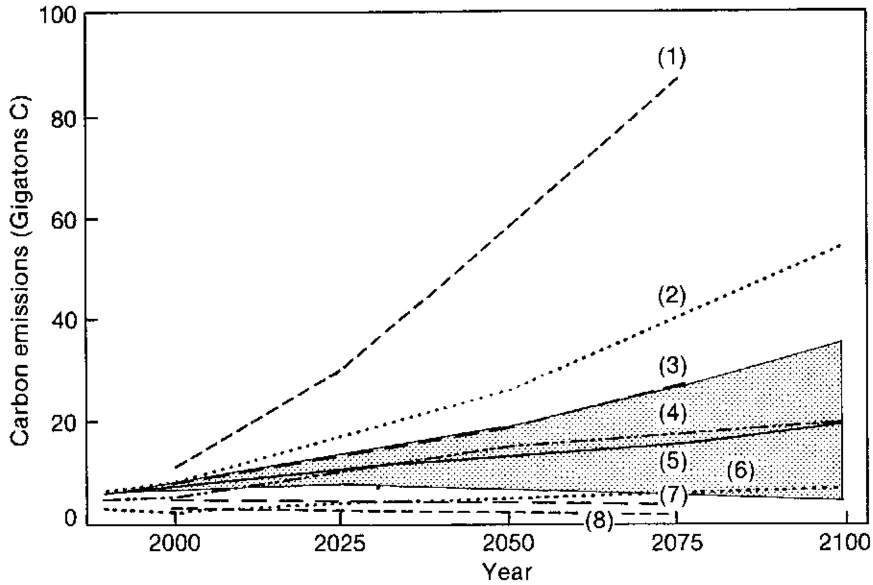

Figure A3.2: Uncertainty analyses for carbon emissions from fossil fuel. The following studies are represented: Edmonds - (1) 95th percentile, (3) 75th percentile, (7) 25th percentile, and (8) 5th percentile; Nordhaus and Yohe - (2) 95th percentile, (4) 50th percentile, and (6) 5th percentile; also (5) IS92a. The shaded area indicates the range of the IS92 scenarios.

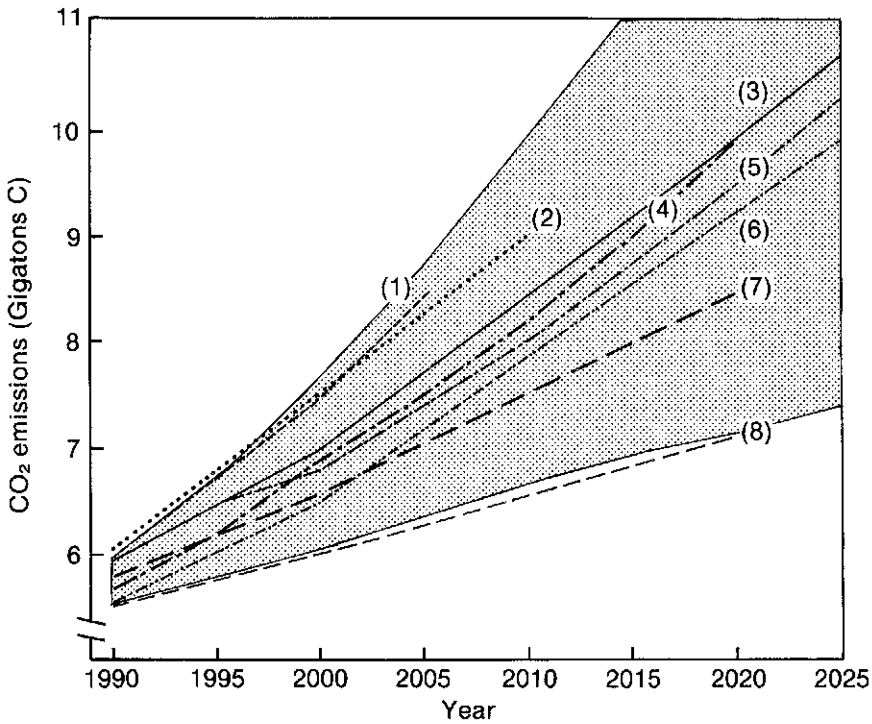

Figure A3.3: Comparison of CO_2 emissions from fossil fuels out to AD 2025 according to: (1) IEA; (2) CEC; (3) IS92a; (4) OECD; (5) IS92b; (6) SA90; (7) the World Energy Conference (WEC) "moderate" and (8) "low" scenarios. The shaded area indicates the range of the IS92 scenarios.

and "best guess" scenarios. Two studies, Edmonds *et al.* (1986) and Nordhaus and Yohe (1983) explicitly examined the issue of uncertainty by estimating the probabilities associated with the various critical input assumptions and the correlation among them, in order to calculate probability distributions of future CO_2 trends. Figure A3.2 shows their results, against a shaded area representing the range of the new IPCC Scenarios. Both the Edmonds *et al.* and the Nordhaus and Yohe teams found a very wide variation in potential future emissions in the absence of policies to limit this growth. The IS92a falls slightly below the 50th percentile values from Nordhaus and Yohe in the 2050 to 2100 time period until they coincide near 2100. IS92b is slightly lower. The IS92a and b lie between the

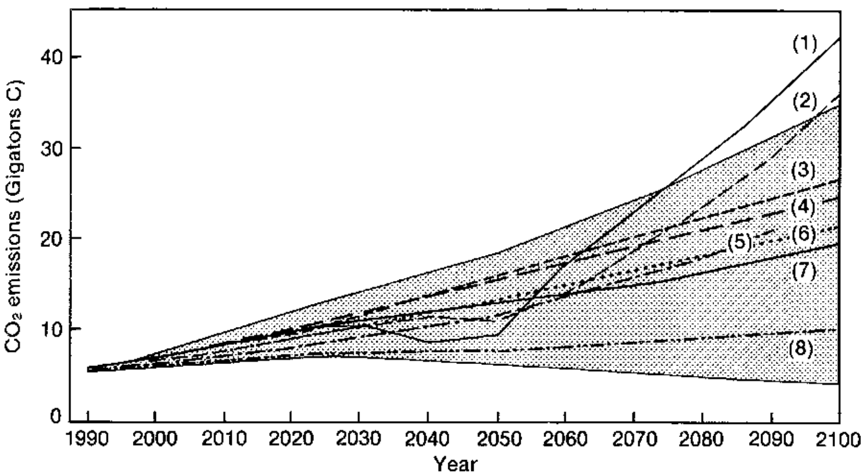

Figure A3.4: Comparison of CO_2 emissions from fossil fuels according to longer-range scenarios: (1) CETA; (2) CRTM-RD; (3) Manne & Richels; (4) EPA (RCW); (5) Edmonds/Reilly; (6) SA90; (7) IS92a, and (8) EPA (SCW). The shaded area indicates the range of the IS92 scenarios.

50th and 75th percentiles in the Edmonds analysis. The highest, new IPCC Scenario is very close to Edmonds 75th percentile, while the lowest is higher than Edmonds 25th percentile. These results from Edmonds *et al.* and Nordhaus and Yohe reinforce the conclusion that emission trajectories are extremely sensitive to a number of key parameters including population growth, economic growth, improvements in energy efficiency and structural change in the economy, as well as the future costs of fossil energy and alternative energy supplies.

Figure A3.3 compares CO_2 emissions from the range of IS92 scenarios in the period 1990 to 2025 to emissions adapted from scenarios of future energy use developed by the International Energy Agency (IEA, 1991), the Commission of the European Communities (CEC, 1989), the World Energy Conference (WEC, 1989), Burniaux *et al.* (1991), and SA90. Emissions in the IEA and CEC Scenarios are from 5% to 12% higher than the emissions in the IS92a through to 2010, the end point of their scenarios. Burniaux *et al.* (1991), using the OECD-GREEN model, suggest CO_2 emissions that are 4% lower than the IS92a in the early years but increase to the same levels by 2020. Emissions in the WEC moderate scenario are 24% lower than IS92a in 2020. Figure A3.4 examines longer-term scenarios, comparing the new IPCC Scenarios with 7 others, including the SA90 Scenario, two scenarios (Slowly Changing World, SCW, and Rapidly Changing World, RCW) developed by the US EPA (1990), scenarios from Manne and Richels (1990), and several studies underway within the Stanford University Energy Modeling Forum. The modellers include Edmonds and Barnes, Peck and Teisberg (using CETA), and Rutherford (using CRTM) (Weyant, 1991: studies to be published in mid-1992). The range of the new IPCC Scenarios is broader than the "central tendency" studies presented in Figures A3.3 and A3.4. This is especially true by 2100, due to the range of population and economic growth assumptions used in the scenarios. Edmonds *et al.* (1992) provides a more detailed comparison of these scenarios.

A3.6 Energy

Future levels of greenhouse gas emissions from the energy sector are a function primarily of population, incomes, the structure and efficiency of economies, and the relative costs and availability of different sources of energy. The population and economic assumptions in this update of the IPCC scenarios have already been discussed. To 2025, the estimates of energy demand by region and sector are based primarily on the EIS reference scenario. After 2025, energy demand is a function of the economic assumptions and the factors discussed in this Section, and modelled by the ASF (EPA, 1990). Associated emissions of greenhouse gases are estimated using coefficients from the OECD (1991).

The exogenous assumptions of improvements in the intensity of energy end-use are critical parameters counterweighing the upward push on CO_2 emissions from population and economic growth. The assumptions used within IS92a and b result in a global decrease in energy intensity of 0.8% annually in the period to 2025, and 1.0% annually from 2025 to 2100. The decrease in energy per unit of GNP is assumed to be particularly strong in China through to 2100 and in Eastern Europe and the former republics of the Soviet Union in the period 2000 to 2025 as IS92a and b assume substantial structural change. This reflects a complex mix of factors, including market-oriented reforms, a tendency to increase energy demand per capita with increased standards of living (though GNP growth is substantially reduced in Eastern Europe and the republics of the former Soviet Union in the early part of this period), and a tendency toward consumption of less energy intensive goods and services as economies develop. Long-term rates of decrease of exogenous end-use intensity are plausible in the range of 0.8% to 1.0% per year. Edmonds and Reilly (1985) explored the historical rate of change of the energy to GNP ratio in a wide range of OECD countries over extended periods of up to 100 years. The United Kingdom averaged a rate of decline in the energy to GNP ratio of 0.8% annually from 1880 to 1975, while the United States averaged 1.0% from 1920 to 1975. Rates of change over a 50 year period (1925 through 1975) for 13 other OECD nations ranged from 0.45% per year (Germany) to 1.33% per year (Italy). For three centrally planned economies (the former USSR, Czechoslovakia and Yugoslavia) the rate of change was 1.1% per year over the same 50 year period. The range of experience is significantly broader over shorter periods of time. Globally, according to World Bank data, the ratio of primary energy to GDP declined at an average rate of 0.4% in the 24 year period from 1965 to 1989 (World Bank, 1991).

The shares of different primary energy supplies change dramatically in all of the scenarios due to assumed limitations in fossil resources, expected advances in energy technologies, as well as calculated increases in energy prices. In IS92a and b, assumptions regarding available conventional oil, natural gas liquids (NGL), and gas resources are based on Masters *et al.* (1991). At oil and gas prices of $23 per barrel ($/bbl) and $2 per gigajoule ($/GJ), respectively, the available resource equals the Masters *et al.* mean resource estimates. Additional conventional resources, up to the Masters *et al.* 90% bounding values, are available at prices rising to $35/bbl for oil and $8/GJ for gas. As a result, in these scenarios, conventional oil and gas production is gradually replaced by unconventional fossil sources, by synthetic fuels from coal, and non-fossil energy supplies. World oil prices increase to $55/bbl by 2025 and up to $70/bbl by 2100. Up to 760 billion barrels of unconventional liquids including heavy oils, bitumen, and enhanced oil recovery are assumed to become available at oil prices of $35 to $70/bbl. As conventional oil and gas are replaced with coal and unconventional supplies, the production and conversion losses tend to result in significant increases in the rate of CO_2 emissions in IS92a. Large resources of shale oil are assumed to be available at prices over $70/bbl. For the high fossil resource assumptions in IS92e and f, we incorporated estimates of oil resources from Grossling and Nielson (1985).

Simultaneously, the costs of non-fossil energy supplies are assumed to fall significantly over the next hundred years. For example, solar electricity prices are assumed to fall to US$ 0.075 kilowatt per hour ($/kWh) in the IS92a, and to US$ 0.065/kWh in the more optimistic IS92d. They are assumed to fall only to $0.083/kWh in IS92f. Overall, while renewables are not significantly competitive with fossil energy in 1990, their market penetration speeds as unit costs fall and fossil fuel prices increase rapidly around 2025. By 2100, nuclear, solar, hydropower and biofuels represent 43% of total global primary energy supply in IS92a and b. Overall, the six new IPCC Scenarios represent a global energy system which continues to be dependent on fossil fuels, notably coal, and which shows only moderate gains in energy efficiency and technological development of non-fossil energy sources.

Global energy use rises steadily until 2100 in IS92a, reflecting increases in population and income. Commercial primary energy use which is 344 exajoules (EJ) in 1990, grows to 708 EJ by 2025 and to 1453 EJ by 2100.[1] Primary fossil energy use represents over 85% of primary energy use until 2025. After 2025, the fossil share of primary energy declines to 57% by 2100 despite a nearly three-fold increase in fossil energy production and use. Energy sources such as nuclear, hydropower, solar, and commercial biofuels play a much more important role after 2025 than before in all scenarios, although the mix varies among scenarios.

CO_2 emissions from energy use increase with primary energy use but at a slightly slower rate due to increased use of non-carbon energy sources. CO_2 emissions in the IS92a increase from 6.0 billion tons of carbon (GtC) in 1990 to 10.7 GtC in 2025 and 19.8 GtC in 2100.[2] Compared to the original SA90, this represents faster growth before 2025 but slower growth afterwards. The higher path until 2025 reflects the assumptions in IS92a and b of more rapid population and economic growth, combined with less optimistic assumptions concerning improvements in energy efficiency, based on the EIS reference scenario assumptions. After 2025, IS92a relies more heavily on non-fossil energy sources than SA90 thereby reducing the rate of growth in CO_2 emissions.

While global CO_2 emissions from energy use in IS92a and b grow fairly constantly at a rate of 1.1% and 1.0% annually, respectively, from 1990 to 2100 (see Figure A3.4), the pattern of growth differs considerably among regions. CO_2 emissions from the developed economies grow at an average annual rate of 0.8% until 2025. After 2025 in the developed economies, lower economic growth combined with stabilized population levels and increasing

1 - Primary energy use in SA90 was 473 to 657 EJ in 2025 and 728 to 1682 EJ in 2100, the range reflecting alternative economic growth projections.

2 - Average CO_2 emissions from energy in SA90 were 9.9 GtC in 2025 and 21.7 GtC in 2100.

use of non-fossil energy sources yield reductions in this growth to an annual average of 0.2%. Emissions from developing economies continue to rise due to increases in population and economic growth. In the period, 1990 to 2100, CO_2 emissions per capita from energy use grow at an average annual rate of only 0.2% to 0.3% in the OECD, Eastern Europe, and the republics of the former Soviet Union, while averaging 1.0% for the rest of the world. CO_2 emissions per capita in developing countries remain on average one quarter to one half those of developed countries by 2100. Conversely, CO_2 emissions per dollar GNP (per $GNP) in the OECD are two thirds the global average, one half those of Eastern Europe and the former Soviet Union, and one fifth those of China. Global average CO_2 emissions per $GNP decline at an average annual rate of 1.2% from 1990 to 2100. Regionally, the highest rate of decline is in China where CO_2 emissions per $GNP are over four times higher than the global average in 1990.

IS92b incorporates the stabilization goal for fossil carbon dioxide emissions for the year 2000, proposed by many OECD Member countries. If countries achieve these commitments and sustain them through 2100 (which is likely to require programmes beyond those already planned) and the rest of the world does not adopt similar measures, global emissions in 2025 of fossil carbon would be 0.4 GtC lower than in the IS92a. This reduction represents a reduction of 11% in emissions of CO_2 from the OECD from IS92a but only a 4% reduction of global emissions. These results reflect the long-term contribution of the economies of developing countries, the republics of the former Soviet Union, and Eastern Europe to CO_2 emissions.

A3.7 Halocarbons

Halocarbons, including chlorofluorocarbons (CFCs), their substitutes, and other compounds which deplete stratospheric ozone, may have important implications for climate change. Many of these compounds exert a much more powerful direct radiative forcing than CO_2 per molecule. Recently, it has been discovered that the loss of lower-stratospheric ozone can reduce the radiative forcing of the troposphere/surface system, particularly at high latitudes. Hence, ozone depleting molecules can have both positive (direct) and negative (indirect) contributions to radiative forcing. However, the net effect of such halocarbons on globally averaged temperatures or, more broadly, on climate is uncertain at present. As a result, the comparisons of scenarios for these gases are summarized using the kilotons (kt) of the compounds, not the index of direct "Global Warming Potential" (GWP), as calculated in Section A2 of this report.

An important event since the development of the scenarios for the first IPCC assessment is the agreement to adjust and amend the Montreal Protocol in London in 1990 (the "London Amendments"). Most key nations have either now signed the agreement or have pronounced the intention to do so. In IS92a, 70% of the developing world is assumed to ratify and comply with the London Amendments. This percentage is based on the GNP of countries that have signed and/or ratified as of December 1, 1991 (e.g., China has signed while India has not). We further assume in IS92a that if most of the world develops and uses CFC substitutes, then the need to trade in global markets and "technology transfer" will lead to a gradual phase-out of all CFC use (we assume gradually from 2025 to 2075) even without worldwide ratification. We have also included the voluntary reductions ahead of schedule achieved by many countries. IS92b assumes global compliance with the Montreal Protocol.

The London Amendments contain a recommendation only to use halocarbon substitutes for a transition period. There are no international agreements for eventually phasing down the production of all substitute compounds. Some substitutes may not deplete stratospheric ozone but may still contribute to climate change. Therefore, in the scenarios, we assume that the production of substitutes would mimic the growth rate of the underlying controlled compounds which they replace under the phase-out, adjusted for market reductions due to non-chemical substitution and increased use of recycling and other emission control programmes. Accordingly, all of the cases assume that the demand for CFCs grows by 2.5% annually until 2050 then remains flat. HCFCs and HFCs are assumed to replace approximately 21 to 42% (depending on the scenario) of phased-out CFCs. Substitution is weighted much more towards HCFCs than HFCs over the long-term unless additional policy steps are taken.

This analysis includes seven cases of future emissions of CFCs and their substitutes. Three of these cases are incorporated into the IS92 Scenarios. The first two cases, "Partial Compliance and High HCFC" and "Partial Compliance and Reduced HCFC" portray a future where only 70% of the developing world ratifies and complies with the London Amendments. In these scenarios, CFC production in the remaining 30% continue to grow until 2100. Also, the HCFC reductions in the US are not incorporated. The third scenario, "Partial Compliance and Technology Transfer", is incorporated into IPCC Scenarios IS92a, c, and f. It assumes partial compliance with the London Amendments but assumes that "technology transfer" results in a full phase-out of production of CFCs by 2075. It includes the phase-out of HCFCs in the US required by the Clean Air Act. The fourth case, "Global Compliance", is incorporated in IS92b and contains full global ratification and compliance with the London Amendments. The fifth case, "97 Phase-Out for Developed Countries", accelerates the phase-out schedule for CFCs.

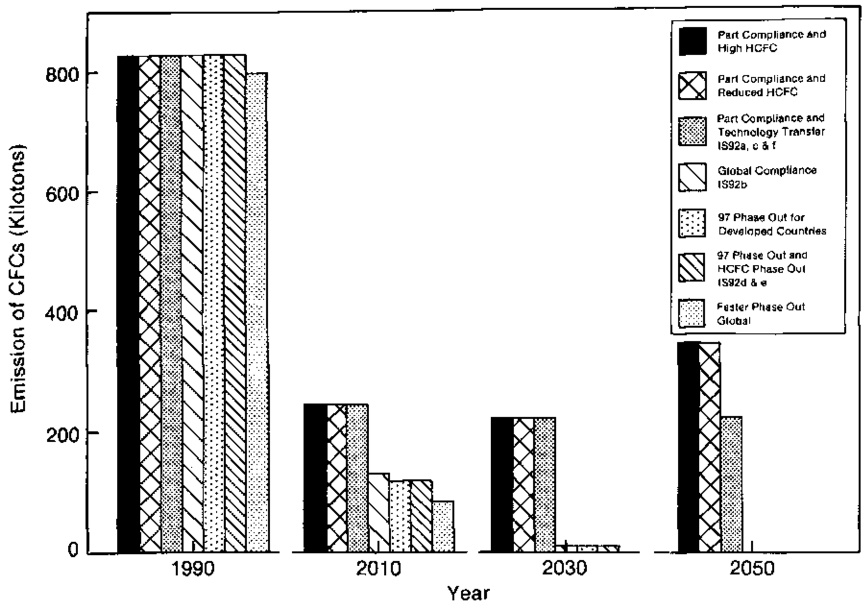

Figure A3.5: Emission of chlorofluorocarbons (CFCs) under a range of scenarios. Includes CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115.

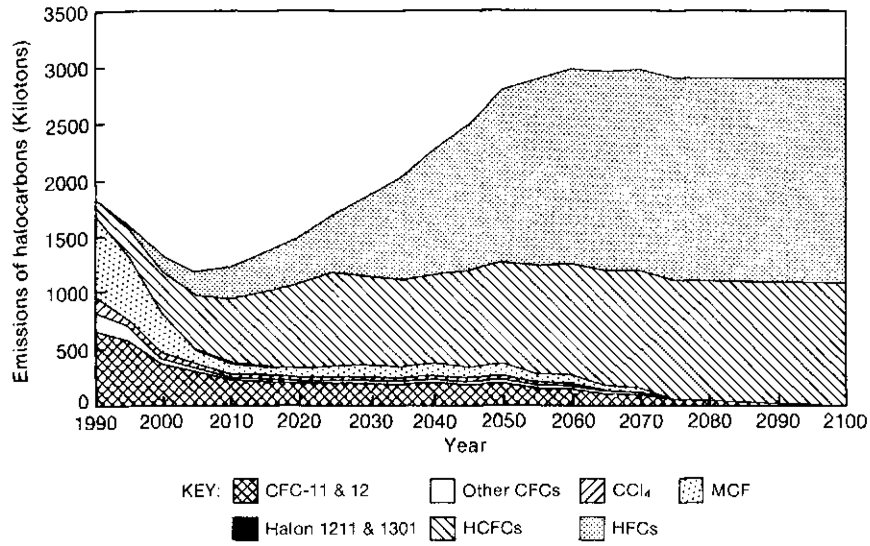

Figure A3.6: Emission of halocarbons under IS92a, c and f. These assume only partial compliance with the London Amendments to the Montreal Protocol but, through technical transfer to non-complying countries, a complete end to CFC production by AD 2075.

The sixth case, "97 Phase-Out and HCFC Phase-Out" is incorporated in IS92c and d and expands on the fifth case by incorporating a global phase-out of HCFCs. The seventh case, "Faster Phase-Out - Global", accelerates the phase-out of CFCs and HCFCs in developing countries.

For the calculations, US EPA's Integrated Assessment Model for CFCs was used. Detailed results can be found in the supporting document, Pepper *et al.* (1992). In the IS92a, emissions of CFCs, carbon tetrachloride, and methyl chloroform decline rapidly through 2010 (see Figures A3.5 and A3.6, "Partial Compliance and Technology Transfer Case"). After 2010, these emissions stabilize and ultimately decline to zero after 2075 as all the world adopts the prominent technologies. Emissions of HCFCs and HFCs grow rapidly throughout the whole time horizon in all cases, reflecting their roles as substitutes for the CFCs and the postulation of no controls on their emissions (except on HCFCs in the US). Its results indicate that the composition of substitutes could have an important impact on levels of radiative forcing.

If "technology transfer" to non-signatories of the agreement were not to lead to a phase-out of CFCs, the implications by 2100 could be substantial, leading to emissions almost back up to the level estimated for 2000.

The results for the emissions of CFCs are depicted, as an example, in the "Partial Compliance and High HCFC" case in Figure A3.5. In this case, after 2010, emissions of CFCs, carbon tetrachloride and methyl chloroform stabilize and then start to increase. This reflects growth from non-signatories of the London Amendments.

IS92b assumes full ratification of and compliance with the London Amendments. Emissions are nearly eliminated much earlier ("London Amendments-Global Compliance") than in IS92a. Moreover, recent data showing more severe ozone depletion (WMO, 1992) could lead to a more rapid phase-out of CFCs and halons, carbon tetrachloride, and methyl chloroform ("97 Phase-Out for Developed Countries"). Controls on the use of HCFCs are also possible.

A3.8 Agriculture, Forests and Land Conversion

A3.8.1 Agriculture

Details of the estimation of greenhouse gases from agricultural sources are available in Pepper *et al.* (1992). The distribution of the global emissions of non-CO_2 greenhouse gases among different sources in the base year has been taken from the assessment of the global budgets reported in Section A1 of this document. This distribution is still poorly understood for most gases. In particular, emissions of CH_4 from rice cultivation are highly uncertain but lower than believed in IPCC (1990). Average emission coefficients of 38 grams per square metre per year for land under rice cultivation have been selected for all scenarios based on the CH_4 emission budget of 60 teragrams (Tg). In IS92a and b, the emissions rise gradually from 60Tg in 1990 to 88Tg by 2050, then decline to 84Tg by 2100. The scenarios assume continuing advances in crop yields which average 0.5% annually over the period. Consequently, the growth in emissions is slower than growth in rice production, which more than doubles.

In IS92a and b, CH_4 emissions from enteric fermentation in domestic animals rise from 84Tg in 1990 to close to 200Tg by 2100. This increase reflects a rapid increase in consumption of meat and dairy products and assumes constant emissions per unit of production. Emissions of CH_4 from animal wastes have been added, changing with the levels of meat and dairy production. If meat production per animal were to increase, emissions would be lower. Emissions from animal wastes increase from 26Tg CH_4 in 1990 to 62Tg CH_4 by 2100. It is uncertain whether this growth in the production of meat and dairy products can actually be maintained, taking into account possible land and feed constraints which are not explicitly dealt with in these scenarios. Autonomous developments that affect the emissions from enteric fermentation or animal waste per unit of production, such as those resulting from changed feeding patterns, are not hypothesized either. Both types of factors could change the emission trends of these scenarios.

Emissions of N_2O from fertilized soils in 1990 of 2.2 TgN have been selected as the starting budget, falling within the range of uncertainty of 0.3 to 3.0 TgN reported in Section A1. They increase in proportion to fertilizer use, which more than doubles in IS92a and b. The impact of changing fertilization practices and the dependency of N_2O emissions on local soil types, moisture, agricultural practices, etc., has not been estimated.

A3.8.2 Forests and Land Conversion

Since SA90 was finalized, new data have become available regarding both tropical deforestation rates and the average content of carbon per hectare of above-ground vegetation. Both are higher than the assumptions used in SA90. The estimates of carbon in soils and fluxes of greenhouse gases with changes in land uses remain as in SA90. Neither of the possible effects on CO_2 fluxes due to increased fertilization or respiration, which may be associated with higher CO_2 atmospheric concentrations or temperature

Table A3.8: *Assumptions used in deforestation cases.*

Scenario Used In	Biomass Content	Rate of Deforestation
IS92a, b, & e	Moderate	Moderate (tied to moderate population growth)
IS92c	Moderate	Moderate (tied to low population growth)
IS92d	Moderate	Halt Tropical Deforestation
IS92f	Moderate	Moderate (tied to high population growth)
None	High	Moderate (tied to moderate population growth)
None	Moderate	High
None	High	High
None	Moderate	Halt Tropical Deforestation/Increase Establishment of Plantations

increases, have been incorporated in this analysis.

To incorporate the new data and the uncertainties still surrounding these parameters, eight cases of tropical forest clearing and emissions of greenhouse gases were developed. These eight cases include four cases which were incorporated within the new IPCC Scenarios which assume moderate assumptions of rates of tropical deforestation (except IS92d which has a halt to deforestation) and biomass content of vegetation in these forests. The eight cases also include four sensitivities around the case incorporated in IS92a. The sensitivity cases vary rates of deforestation, rates of establishment of plantations, and assumptions concerning the biomass content of the forests. Table A3.8 summarizes these cases and their assumptions.

As lands convert from one use to another, greenhouse gases can be released or taken up by vegetation and soils, for example by the burning or regrowth of forests or the tilling or amendment of soils. This analysis simulates and tracks the changes of land parcels from one use to another from 1975 to 2100, due to agricultural demand, burning, plantations, etc., and calculates the associated greenhouse gas emissions and uptake over time. As land is cleared, sometimes more than once in the period of analysis, only part of the carbon stored in vegetation and soils is released over an extended period of time. As regrowth occurs on cleared land, carbon is sequestered. We calculate the net balance of carbon from vegetation and soils of all lands estimated to be tropical forests at any time from 1975 through 2100. Assumptions about rates of carbon loss or absorption and other parameters used in this analysis, as well as the case results, are detailed in Pepper *et al.* (1992).

The IS92 Scenarios use the new FAO 1990 Tropical Forest Assessment (FAO, 1991) and the 1988 update of the 1980 Tropical Forest Assessment (FAO, 1988) for its deforestation rates. The new assessment estimates that, on average, 17 million hectares of tropical closed and open forest were cleared annually from 1981 to 1990. The 1988 FAO Tropical Forest Assessment provided estimates of clearing rates for the period 1976 to 1980. While questions have been raised concerning the reliability of these data, they are the best and most recent currently available for the world.

We estimated a constant rate of change in clearing rates over this period such that the average quantities of clearing for 1976 to 1980 and for 1981 to 1990 match those reported in the FAO 1988 and 1991 reports, respectively. Moreover, this estimate is constrained so that forest areas in 1980 equal the quantities given in the more complete and detailed 1980 assessment. This results in calculated clearing rates increasing from 13.2 million hectares in 1980 to 19.3 million hectares in 1990. After 1990, deforestation rates increase in proportion to population, but lagged twenty years and constrained by available forest area in each country. In the "high deforestation" sensitivity cases, these rates are increased by an additional 1% point per year. In the "halt deforestation" sensitivity case and in IS92d, we assume that rates of deforestation decline, starting in 1990. The IPCC Greenhouse Gas Task Force advised that it should be assumed that all forests not legally protected, including areas which have been classified as non-productive, can be subject to deforestation (IPCC, 1991c).

Forest clearing in IS92a, b, c, e, and f increases to 20 to 23.6 million hectares per year by 2025, depending on population growth, and then declines. In IS92d, clearing declines steadily after 1990 to 0.7 million hectares per year by 2025. In the high deforestation sensitivity cases, tropical forest clearing increases to 28.6 million hectares in 2025 before declining. In all sets of assumptions, available forest resources within each country provide upper bounds on future clearing. In the IS92a, 73% of all tropical forests (1.4 billion hectares), are cleared by 2100. In the high deforestation sensitivity case, this fraction increases to 91%. In IS92a, countries representing 43% of forest clearing in 1980 have (or have nearly) exhausted their forest resources by 2025. By 2050, this fraction increases to 52%.

Other factors which vary in the sensitivity cases include the fate of forest fallow, future rates of plantation establishment, and the carbon stored in the aboveground biomass. The high deforestation sensitivity cases include another possible net source of carbon: permanent clearing of forest fallow. These are areas of logged or abandoned agricultural lands which are regenerating to forest. The high deforestation sensitivity cases assume that up to 10 million hectares of forest fallow are currently being converted to permanent agriculture annually (Houghton, 1991) and that this clearing continues into the future until almost all forest fallow is converted. In IS92a, the establishment of plantations, which FAO (1988) estimates as 1.3 million hectares annually between 1980 and 1985, is assumed to continue with 118 million hectares added between 1990 and 2100. The high deforestation sensitivity cases assume that no new plantations are added after 1990.

Moderate estimates of carbon stored in the biomass are from OECD (1991) which have been adapted from Brown and Lugo (1984), Brown *et al.* (1989), and Brown (1991), and have been estimated using wood volumes. The moderate biomass estimates are used for the IS92 Scenarios. The high biomass estimates, used in the sensitivity analyses, increase the moderate estimates by the percentage corrections cited in Houghton (1991) to reflect uncertainties in measurement techniques and results from other studies utilizing alternative (i.e., destructive sampling) approaches. Table A3.9 summarizes current estimates of biomass contents and those used in all IS92 scenarios.

***Table A3.9:** Carbon stored in tropical forests (tons C/hectare).*

	IS92 a,b †††				Carbon Stocks from Houghton (1991) Earlier Estimate †		Recent Estimate ††		
	Closed B-leaf	Closed Conif.	Open B-leaf	Crops	Moist Forest (D/V)†	Seasonal Forest (D/V)†	Closed Forest (U/L)††	Open Forest (D/V)†	Crops
Vegetation									
Latin America	76	78	27	5	176/82	158/85	89/73	27/27	5
Asia	97	83	27	5	250/135	150/90	112/60	60/40	5
Africa	117	68	16	5	210/124	160/62	136/111	90/15	5
Soils	100	100	69	-	100	90	-	50	-

† For columns labelled (D/V), the first value is based on destructive sampling of biomass and the second value is calculated from estimates of wood volumes.

†† For columns labelled (U/L), the first value is for undisturbed forests and the second value is for logged forests.

††† Source: OECD (1991).

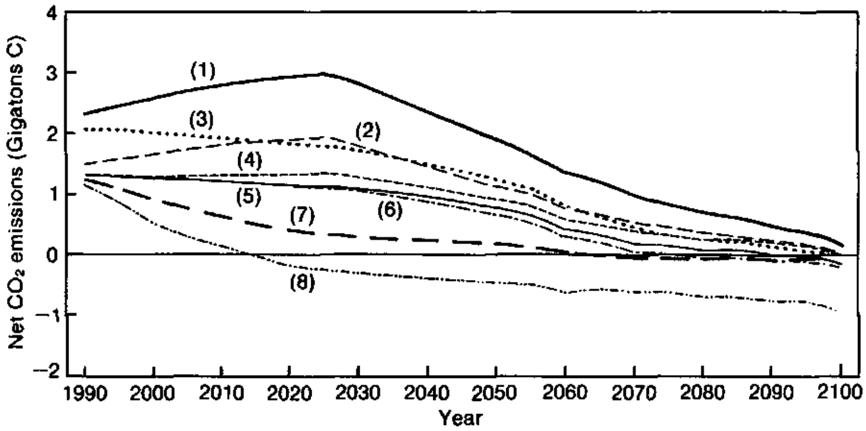

Figure A3.7: Comparison of net CO_2 emissions from tropical deforestation according to some longer-range scenarios: (1) High deforestation/high biomass; (2) High deforestation/moderate biomass; (3) moderate deforestation/high biomass; (4) IS92f; (5) IS92a, b and e - moderate deforestation/moderate biomass; (6) IS92c; (7) IS92d, and (8) No deforestation/high plantation. *(Note: does not include the effects of fertilization or increased respiration on net CO_2 emissions due to higher CO_2 atmospheric concentrations.)*

CO_2 emissions in the IS92 Scenarios and the sensitivity cases range from 1.1 GtC to 2.3 GtC in 1990. These include net soil carbon released as well. In the IS92a, emissions are relatively flat through to 1995 and then start to decline. Net emissions are slightly negative by 2100 due to carbon sequestration by plantations. In the high deforestation and high biomass sensitivity case, emissions increase to 3.0 GtC by 2025, decline to 1.9 GtC in 2050 and 0.2 GtC by 2100. Even though in all of the cases clearing of open forests in the period 1980 to 1990 represents over one third of total clearing, net emissions of CO_2 from open forests represent less than 10% of total deforestation emissions.

All these cases do not span the range of possibilities for both current and future emissions. There is a strong need for improvement of the base data. Moreover, current trends in deforested area, combined with changes in policies, could very well lead to emissions lower than in the moderate case.

In conclusion, the sensitivity analysis explores a wide range of possible futures and identifies the importance of several key assumptions. Figure A3.7 illustrates the CO_2 emissions from the IS92 Scenarios along with the sensitivities around IS92a. One sensitivity case, "High Deforestation/Moderate Biomass" illustrates the impact of the higher clearing rates and forest fallow clearing assumptions on CO_2 emissions. The sensitivity case, "Moderate Deforestation/High Biomass", illustrates the importance of assumptions concerning carbon stored within the biomass. The sensitivity case, "High Deforestation/High Biomass" shows the combined impact of these alternative assumptions. The "Halt Deforestation/ High Plantations" sensitivity case illustrates the potential for reducing emissions by quickly stopping forest clearing and actively establishing plantations. In this case, forest clearing is reduced starting in 1991 and eliminated by 2025. Up to 293 million hectares of plantations are established by 2100.

A3.8.3 Resolution of Land Assumptions

While these cases and sensitivities provide a plausible range of emissions they do not address all of the uncertainty. A key concern with these cases is consistency of the assumptions about land uses among the different sectors. Because the models and methodologies used for the different sectors are not fully integrated with respect to land use, this consistency is not automatically guaranteed. With population doubling by 2100, improved nutrition in the developing economies, and the agricultural land base possibly degraded, the demand for additional land conversion to produce crops especially in the developing countries would be significant, even if sustained productivity increases were achieved. Above, we already noted the anticipated demand for land for livestock and feed production, while the IS92a assumes over 190 EJ of energy from commercial biofuels by 2100, of which 70% would be in developing countries.

A review of current land uses, forest clearing, and plantation assumptions suggests that the assumptions in the new IPCC Scenarios are not inconsistent. FAO (1986) reported that in 1984, 1.5 billion hectares were used for arable land and permanent crops and 3.1 billion hectares were used for permanent pasture leaving 4.1 billion hectares of forest and woodlands. The moderate deforestation case assumes that on average 1.6 billion hectares of tropical forests will be cleared by 2100 while 0.1 billion hectares of forest plantations will be established, roughly allowing for a doubling of the arable land base. Table A3.10 summarizes these statistics for Latin America, Africa, and the Far East along with the IS92a assumptions for these regions. Clearing of forest land in these tropical regions matches well with the increase in population and demand for food. The largest concern would be in Asia where population densities are the highest and cleared forest lands might not have the same productivity as existing cropland, nor may the production be as sustainable. Any reduction in deforestation would reduce the potential land base and would have to be matched by increased productivity on existing agricultural land. Other anthropogenic influences on the terrestrial carbon cycle, such as pollution, erosion, desertification, logging in temperate and boreal zones and carbon sequestration in managed forests, have not been taken into account in this study because of the absence of quantitative information.

A3.9 Other Sectors and Gases

The 1992 Scenarios include emissions of additional gases and emissions from additional sectors. Specifically, emissions of N_2O, CH_4, CO, and NO_x from energy combustion and production were developed using assumptions about emission controls consistent with the US Clean Air Act and the Protocols under the Convention on Long-Range Transboundary Air Pollution. In the base year's emission budget, our estimate of emissions of CO from fossil fuels, by applying emission coefficients to fuel use, falls below the low end of the range given in Section A1 of this report. Our estimate of emissions reflects the latest data on energy consumption and emission coefficients, but the CO budget discrepancies need to be investigated further. Emissions of N_2O from the production of nitric and adipic acid have been included and reflect scenario assumptions on nitrogen fertilizer production and economic growth respectively. Emissions

Table A3.10: *Land-use assumptions (10^6 hectares).*

	Africa	Asia †	Latin America
FAO			
1984 Arable Land & Permanent Crops	154	272	177
1984 Permanent Pasture	630	35	551
Remaining Tropical Forest (1980)	704	431	938
Forest Cleared (1980-2100)	653	329	635
Plantation Area Established (1980-2100)	27	47	44
Maximum Energy Plantation Area††	88	101	118

† Far East as defined by FAO

†† Energy plantation area in addition to other plantation area

Table A3.11: *Global emissions of direct greenhouse gases under IS92a.*

	1990	2000	2025	2050	2100
CO_2 (GtC)					
Energy	6.0	7.0	10.7	13.2	19.8
Deforestation	1.3	1.3	1.1	0.8	-0.1
Cement	0.2	0.2	0.4	0.5	0.6
Total	7.4	8.4	12.2	14.5	20.3
CH_4 (Tg)					
Energy Production & Use	91	94	110	140	222
Enteric Fermentation	84	99	138	173	198
Rice	60	66	78	87	84
Animal Wastes	26	31	43	54	62
Landfills	38	42	63	93	109
Biomass Burning	28	29	32	34	33
Domestic Sewage	25	29	40	47	53
Natural	155	155	155	155	155
Total	506	545	659	785	917
N_2O (Tg N)					
Energy	0.4	0.5	0.7	0.8	0.8
Fertilized Soils	2.2	2.7	3.8	4.2	4.5
Land Clearing	0.8	0.8	1.0	1.1	1.0
Adipic Acid	0.5	0.6	0.9	1.1	1.2
Nitric Acid	0.2	0.3	0.4	0.5	0.5
Biomass Burning	0.5	0.6	0.7	0.7	0.7
Natural	8.3	8.3	8.3	8.3	8.3
Total	12.9	13.8	15.8	16.6	17.0
Halocarbons (kilotons)					
CFC-11	298	168	94	85	2
CFC-12	363	200	98	110	1
CFC-113	147	29	21	24	0
CFC-114	13	4	3	3	0
CFC-115	7	5	1	1	0
CCl_4	119	34	19	21	0
Methyl chloroform	738	353	97	110	0
HCFC-22	138	275	530	523	614
HCFC-123	0	44	159	214	267
HCFC-124	0	7	11	15	16
HCFC-141b	0	24	82	110	138
HCFC-142b	0	7	11	0	0
HCFC-225	5	17	30	38	40
HFC-134a	0	148	467	918	1055
HFC-125	0	0	14	175	199
HFC-152a	0	0	30	448	570

Table A3.12: *Global emissions of indirect greenhouse gases under IS92a.*

	1990	2000	2025	2050	2100
CO (TgC)					
Energy	130	140	160	219	385
Biomass Burning	297	309	341	363	353
Plants	43	43	43	43	43
Oceans	17	17	17	17	17
Wildfires	13	13	13	13	13
Total	499	522	574	655	811
NO_x (TgN)					
Energy	25	28	43	53	72
Biomass Burning	9	9	10	11	11
Natural Lands	12	12	12	12	12
Lightning	9	9	9	9	9
Total	55	58	74	85	104
VOC Emissions by Gas (Tg)					
Paraffins	56	59	84	106	152
Olefins	42	43	49	56	72
Aromatics (btx) †	15	16	21	25	36
Other	8	8	12	15	23
Total	121	126	166	202	283
VOC Emissions by Sector (Tg)					
Energy Production & Use	27	30	48	64	102
Biomass Burning	53	53	54	54	52
Industry	23	25	36	46	62
Other	18	19	27	38	67
Total	121	126	166	202	283
Sulphur (TgS)					
Energy Production & Use	65	67	101	132	123
Biomass Burning	2	2	3	3	3
Other Industrial	8	10	16	19	21
Natural	22	22	22	22	22
Total	98	101	141	175	169

† Benzene, toulene, and xylene

of CO_2 from cement production and CH_4 from landfills reflect regional population and economic growth assumptions as well as expectations of resource limitations and saturation. Emissions of N_2O, CH_4, CO, and NO_x from biomass burning are based on emission coefficients from Crutzen and Andreae (1990) and Andreae (1991), and future rates of deforestation, clearing of fallow lands for shifting agriculture, non-commercial biofuel use, and other burning activities. Emissions of volatile organic compounds (VOCs) are highly uncertain, especially for developing countries. They are based on a detailed, country level emissions inventory developed by EPA (1991). They are compared with other sources and extended into the future based on activities such as transportation energy use, deforestation and biomass burning, and industrial activity. Emissions of SO_x from energy use are based on a study performed by Spiro *et al.* (1991) where emissions reflect average sulphur content of the different fossil fuels and are adjusted for emission control programmes. Emissions of all trace gases by gas and sector are summarized in Tables A3.11 and A3.12.

All of the new IPCC Scenarios except for IS92d show significant increases in emissions of CO, NO_x and SO_x even the assumed of adoption of some emission controls on large stationary sources and mobile sources in the developing countries. Emissions of these gases could be significantly higher if we had not assumed significant penetration of local pollution controls. For example, in IS92a annual emissions of CO grow from 499 TgC in 1990 to 811 TgC by 2100 and annual emissions of NO_x grow from 55 TgN in 1990 to 104 TgN by 2100. Without the assumed pollution controls, annual emissions of CO and NO_x would increase to 1049 TgN and 108 TgN, respectively, by 2100.

A3.10 Conclusions

This chapter presents a new set of IPCC greenhouse gas emission scenarios. The purpose is not to predict which evolution of greenhouse gases is most probable among the array of plausible alternatives. Rather, comparison of alternatives may help policy-makers to consider the directions in which future emissions may evolve in the absence of new greenhouse gas reduction efforts, and the types of change in important parameters which could or would have to occur to significantly change future paths. Commitments by individual governments or companies to reduce emissions of greenhouse gases in response to the global warming or other environmental issues could significantly affect some of the individual emission sources. However, it is difficult to take these commitments into account in global emission estimates.

Two of the Scenarios "IS92a" and "IS92b" update the original Scenario A from IPCC (1990) by incorporating important information which has become available in 1990 and 1991. IS92a includes only those policies affecting greenhouse gas emissions which are agreed internationally or enacted into national laws (as of December 1991). IS92b includes proposed greenhouse gas policies as well. While some of the revisions to the assumptions used in SA90 are significant, the results of IS92a and b are on balance very similar to the original SA90. The other scenarios provided in this chapter explore a broader range of plausible assumptions than in SA90, and indicate that the array of possible future trends in greenhouse gas emissions spans an order of magnitude. That the different futures within this range are not all equally probable has not been systematically addressed in this analysis, but this topic should be pursued. A more thorough exploration of the uncertainties in assumptions and relationships among parameters could reveal more about the confidence policymakers should have in such emission scenarios and in the influence of their decisions on future emission paths.

Even with a wide range of possible greenhouse gas scenarios, a number of conclusions can be drawn from the analysis:

- CFC emissions are likely to be substantially lower than previously estimated by the IPCC, especially if technology transfer and world trade requirements lead all countries to comply with the London Amendments to the Montreal Protocol. However, the future production and composition of CFC substitutes could significantly affect the levels of radiative forcing from halocarbons.

- The commitments by many OECD Member countries to achieve and maintain stabilization or reduction of their CO_2 emissions by the year 2000, in absolute terms or per capita, could have an important impact on their own emissions but a small influence on global emissions by the year 2100. The CO_2 commitments may have the simultaneous effect of reducing other greenhouse gases as well. Most of the uncertainty over future growth in greenhouse gas emissions is likely to depend on how developing countries, Eastern European countries, and republics of the former Soviet Union choose to meet their economic and social needs.

- Population growth, robust economic growth, plentiful fossil fuels at relatively low costs, and net deforestation tend to push upward the trends in greenhouse gas emissions; decreases in energy required per unit of GNP, the economical availability of renewable energy supplies, plantations of biomass, the control of conventional air pollution, and improvements in agricultural productivity tend to diminish greenhouse gas emissions over the long-term. Public attitudes and governmental policies may have a strong influence on which of these variables will dominate over the coming century.

- CO_2 emissions from forest and land conversion are higher than previous estimates, ranging from 1.1 GtC to 2.3 GtC in 1990, because of higher recent estimates of both deforestation rates and biomass in forests in the tropics, as assessed by the FAO and several recent studies, respectively.

- There is no evidence to alter the main conclusions of IPCC (1990) regarding CO_2 emissions from fossil fuels. While several factors could lead to both higher or lower emissions, especially in the long-term, most expert analyses suggest that these emissions could rise substantially over the coming century. IS92a and b, which most resemble the SA90 in terms of assumptions for key parameters, show a range of emissions of 10.3 to 10.7 GtC in 2025, and 18.6 to 19.8 GtC in 2100. However, a broader range of alternative assumptions is plausible. The range of emissions estimated for the wider set of alternative scenarios is 7 to 14 GtC in 2025 and 5 to 35 GtC in 2100.

- Comparison with other studies of CO_2 scenarios indicates that the IS92a and b fall within the range of other short-term (to 2025) scenarios, including those of the World Energy Council, the International Energy Agency, and the Commission of the European Communities. By the year 2100, the IS92a and b are below but not distant from all the other long-term CO_2 scenarios reported except one. However, the range of alternative, new IS92 Scenarios encompasses virtually all the other scenarios, with a spread of almost an order of magnitude.

- There remains an important need to improve the estimates of greenhouse gas emissions in all sectors (especially in the forest and agriculture sectors) as well as of the underlying human-related variables (such as rates of land clearing).

References

Andreae, M.O., 1991: Biomass burning: its history, use and distribution and its impact on environmental quality and global climate. In: *Global Biomass Burning, Atmospheric, Climatic, and Biospheric Implications*. J.S. Levine (Ed.). MIT Press, Cambridge, MA.

Brown, S. and A.E. Lugo, 1984: Biomass of tropical forests: A new estimate based on forest volumes. *Science*, **223**, 1290-1293.

Brown, S., A.J.R. Gillespie and A.E. Lugo, 1989: Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science*, **35**, 881-902.

Brown, S., 1991: Personal Communication.

Bulatao, R.A., E. Bos and M.T. Vu, 1989: *Asia Region Population Projections: 1980-80 Edition; Latin America and the Caribbean (LAC) Region Population Projections: 1980-80 Edition; Africa Region Population Projections: 1980-80 Edition; Europe, Middle East, and Africa (EMN) Region Population Projections: 1980-80 Edition*. Population and Human Resources Department, World Bank, Washington, D.C.

Burniaux, J.-M., J.P. Martin, G. Nicoletti and J.O. Martins, 1991: *The Costs of Policies to Reduce Global Emission of CO_2: Alternate Scenarios with GREEN*. Paris, September 1991 (Revised version II, 1991).

CEC (Commission of the European Communities), 1989: *Energy in Europe: Major Themes in Energy*. Brussels.

Crutzen, P.J. and M.O. Andreae, 1990: Biomass burning in the tropics: impact on atmospheric chemistry and biogeo-chemical cycles. *Science*, **250**, 1669-1678.

Edmonds, J. and J. Reilly, 1985: *Global Energy: Assessing the Future*. Oxford University Press, New York.

Edmonds, J.A., J.M. Reilly, R.H. Gardner and A. Brenkert, 1986: *Uncertainty in Future Global Energy Use and Fossil Fuel CO_2 Emissions 1975 to 2075*. TR036, DOE3/Nbb-0081 Dist. Category UC-11, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

Edmonds, J.A, I. Mintzer, W. Pepper, K. Major, V. Schater, M. Wise and R. Baron, 1992: *A Comparison of Reference Case Global Fossil Fuel Carbon Emissions*. Washington, D.C.

EPA (Environmental Protection Agency), 1990: *Policy Options for Stabilizing Global Climate: Report to Congress - Technical Appendices*. United States Environmental Protection Agency, Washington, D.C.

EPA (Environmental Protection Agency), 1991: *Global Inventory of Volatile Organic Compound Emissions From Anthropogenic Sources*. EPA, Air and Energy Engineering Research Laboratory, Research Triangle Park, North Carolina.

FAO (Food and Agriculture Organization), 1986: *1985 FAO Production Yearbook*, **Vol. 39**. FAO, Rome.

FAO (Food and Agriculture Organization), 1988: *An Interim Report on the State of the Forest Resources in the Developing Countries*. FAO, Rome.

FAO (Food and Agriculture Organization), 1991: *Forest Resources Assessment 1990 Project*, Forestry N. 7. FAO, Rome.

Grossling, B.F. and D.T. Nielson, 1985: *In Search of Oil, Volume 1: The search for oil and its impediments*. Financial Times Business Information, London.

Houghton, R.A., 1991: Tropical deforestation and atmospheric carbon dioxide. *Clim. Change* (Submitted).

IEA (International Energy Agency), 1991: *International Energy Agency: Energy and Oil Outlook to 2005*. IEA, Paris.

IPCC (Intergovernmental Panel on Climate Change), 1990a: *Climate Change: The IPCC Scientific Assessment*. J.T. Houghton, G.J. Jenkins and J.J. Ephraums (Eds.). WMO/UNEP. Cambridge University Press, Cambridge, UK. 365pp.

IPCC (Intergovernmental Panel on Climate Change), 1990b: *Emissions Scenarios prepared by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change*. Report of the Expert Group on Emissions Scenarios.

IPCC (Intergovernmental Panel on Climate Change), 1991a: *Climate Change: The IPCC Response Strategies*. Island Press, Washington, D.C.

IPCC (Intergovernmental Panel on Climate Change), 1991b: *Energy and Industry Subgroup Report*. US Environmental Protection Agency, Washington, D.C.

IPCC (Intergovernmental Panel on Climate Change) Working Group I, 1991c: Summary of WGI task force meeting (Shepperton, UK, 8-11, July 1991).

Manne, A.S. and R.G. Richels, 1990: *Global CO_2 Emissions Reductions - the Impacts of Rising Energy Costs*. Electric Power Research Institute, Palo Alto, CA.

Masters, C.D., D.H. Root and E.D. Attanasi, 1991: Resource constraints in petroleum production potential. *Science*, **253**, 146-152.

Nordhaus, W.D. and G.W. Yohe, 1983: Future Carbon Dioxide Emissions from Fossil Fuels. In: *Changing Climate*. National Academy Press, Washington D.C., pp87-153.

OECD (Organization for Economic Cooperation and Development), 1991: *Estimation of Greenhouse Gas Emissions and Sinks*. Final Report from the OECD Experts Meeting, Paris, 18-21 February, 1991, revision of August 1991.

Pepper, W.J., J.A. Leggett, R.J. Swart, J. Wasson, J. Edmonds and I. Mintzer, 1992: *Emission Scenarios for the IPCC- an update:Background Documentation on Assumptions, Methodology, and Results*. US EPA, Washington, D.C.

Spiro, P.A., D.J. Jacob and J.A. Logan, 1991: Global inventory of sulphur emissions with 1°×1° resolution. *J. Geophys. Res.* (Submitted).

Swart, R.J., W.J. Pepper, C. Ebert and J. Wasson, 1991: *Emissions Scenarios for the Intergovernmental Panel on Climate Change - an Update: Background Paper and Workplan*. US EPA, Washington, D.C.

United Nations, 1990: *Population Prospects 1990*. United Nations, New York.

United Nations, 1992: *Long-Range World Population Projections*, United Nations Population Division, New York.

WEC (World Energy Conference), 1989: *Global Energy Perspectives 2000-2020*. WEC 14th Congress, Conservation and Studies Committee, Montreal.

Weyant, J., 1991: Stanford Energy Modeling Forum. Personal communication.

WMO, 1992: *Scientific Assessment of Ozone Depletion*. WMO/UNEP, WMO Global Ozone Research and Monitoring Project, Report No. 25, Geneva.

World Bank, 1991: *World Development Report 1991*. Oxford University Press, New York.

Zachariah, K.C. and M.T. Vu, 1988: *World Population Projections 1987-88 Edition*. Johns Hopkins University Press, Baltimore, Maryland.