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Baseline scenarios of global environmental change

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This paper presents three baseline scenarios of no policy action computed by the IMAGE 2 model. These scenarios cover a wide range of coupled global change indicators, including: energy demand and consumption; food demand, consumption, and production; changes in land cover including changes in extent of agricultural land and forest; emissions of greenhouse gases and ozone precursors; and climate change and its impacts on sea level rise, crop productivity and natural vegetation. Scenario information is available for the entire world with regional and grid scale detail, and covers from 1970 to 2100. The scenarios indicate that the coming decades could be a period of relatively rapid global environmental change as compared to the period before and after. The natural vegetation in industrialized regions could be threatened by climate change, but abandonment of agricultural lands could also make new lands available for reforestation and revegetation. The opposite is true for most of Asia and Africa. Here the impacts of climate change on vegetation may not be as significant as in temperate climates, but the demand for food will lead to a significant expansion of agricultural lands at the expense of remaining forests and other natural areas.

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It is impossible to evaluate policies to protect the global climate and environment without a benchmark of 'no action'. Such a benchmark is needed to evaluate the consequences of not acting, and to assess the added value of adopting policies to protect the global environment. The main objective of this paper is to present a set of baseline scenarios that illustrate these benchmark conditions of global environmental change. We call them 'integrated' scenarios because they give an integrated picture of global developments spanning a wide range of global change indicators, each of which are explicitly coupled. The scenarios include information about society related driving forces such as energy and food consumption, as well as emissions of major global air pollutants, and changes in the state of the global atmospheric, terrestrial and oceanic environments. Of course, the scenarios are far from being a comprehensive description of the global environment, but their wide scope and geographic description of the global environmental change is unique in the scientific literature. They have sufficient detail for use as reference scenarios in a wide range of policy and scientific evaluations, and are used for this purpose in other papers in this issue.[1]

Because of the great uncertainty of establishing future baseline conditions, we present three alternative scenarios. Each scenario examines the consequences on global environmental change of a different set of 'not implausible' developments of population, economy, and other driving forces:

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

Later, the assumptions of these scenarios are examined in detail.

A major challenge in developing scenarios of global environmental change is how to maintain their consistency. This is partly solved in this paper by using an integrated model of the global environment, IMAGE 2, for generating these scenarios. The model is a tool for accomplishing a measure of harmony between the many disparate components of the scenarios. The goal of IMAGE 2 is to provide a disciplinary and geographic overview of global environmental changes. The model is described in Alcamo,[2] and a brief overview is given below.

Method and assumptions for computing scenarios

The IMAGE 2 model

Assumptions about population, economy, and economic activity are the driving forces of scenarios in this paper. Based on these assumptions, IMAGE 2 computes future changes in the consumption of energy, food, and timber. This consumption leads to emissions to the atmosphere from fuel combustion and industrial production, shifts in land use and land cover, and changes in the fluxes of gases from the terrestrial environment. The emissions and fluxes of gases lead to changes in the atmospheric composition of various gases, as well as changes in the flux of heat and moisture between the terrestrial, oceanic and atmospheric environments. Eventually these fluxes affect regional climate, and these changes in regional climate then feedback to the terrestrial and oceanic environments in different ways, for example, by changing the productivity of crops and consequently the required amount of future agricultural land.

The IMAGE 2 model consists of 13 individual global submodels organized into three fully linked subsystems: Energy–Industry, Terrestrial Environment, and Atmosphere–Ocean (Figure 1). The *Energy–Industry* models compute the emissions of greenhouse and other gases from five sectors in 13 world regions (Figure 2) based on estimates of industrial production and energy consumption. The *Terrestrial Environment* models simulate changes in global land use and cover on a grid scale taking into account shifts in the demand and potential productivity of land. These models also compute the subsequent fluxes of gases between the terrestrial environment and atmosphere. The *Atmosphere–Ocean* models calculate the changes in atmospheric composition of greenhouse and other gases, changes in the heat and moisture balance of the earth, and subsequent shifts in temperature and precipitation patterns. Each submodel has been tested either with data from 1970 to 1990, or long-term averages, depending on suitability and availability of data. An over-

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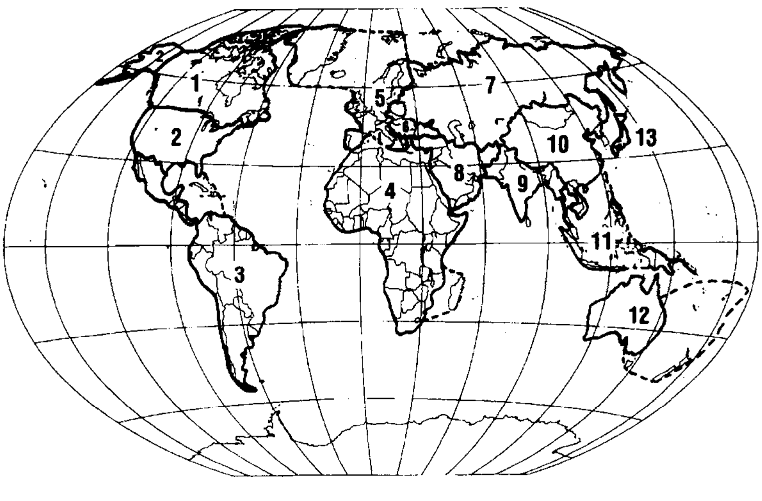
Environment, and the Dutch National Research Programme on Global Air Pollution and Climate Change. The Terrestrial Environment System of IMAGE contributes to IGBF–GCTE core research.

[1] J Alcamo and G J J Kreileman, 'Emission scenarios and global climate protection', in this issue; J C Bollen, A M C Toet and H J M de Vries, 'Evaluating cost-effective strategies for meeting regional CO_2 targets', in this issue; M Posch, J-P Hettelingh, J Alcamo and M Krol, 'Integrated scenarios of acidification and climate change in Asia and Europe', in this issue; R Leemans, A van Amstel, C C Battjes, G J J Kreileman and A M C Toet, 'The land cover and carbon cycle consequences of large-scale utilization of biomass as an energy source', in this issue

[2] J Alcamo (ed) *IMAGE 2.0: Integrated Modelling of Global Climate Change*, Kluwer Academic Publishers, Dordrecht, 1994

World regions in IMAGE 2



1 Canada
2 USA
3 Latin America
4 Africa
5 OECD Europe
6 Eastern Europe
7 CIS
8 Middle East
9 India + S.Asia
10 China + C.P. countries
11 East Asia
12 Oceania
13 Japan

Figure 1. World regions in IMAGE 2 model. A list of countries assigned to each region is presented in Appendix 1 of Alcamo *et al*, *op cit*, Ref 26.

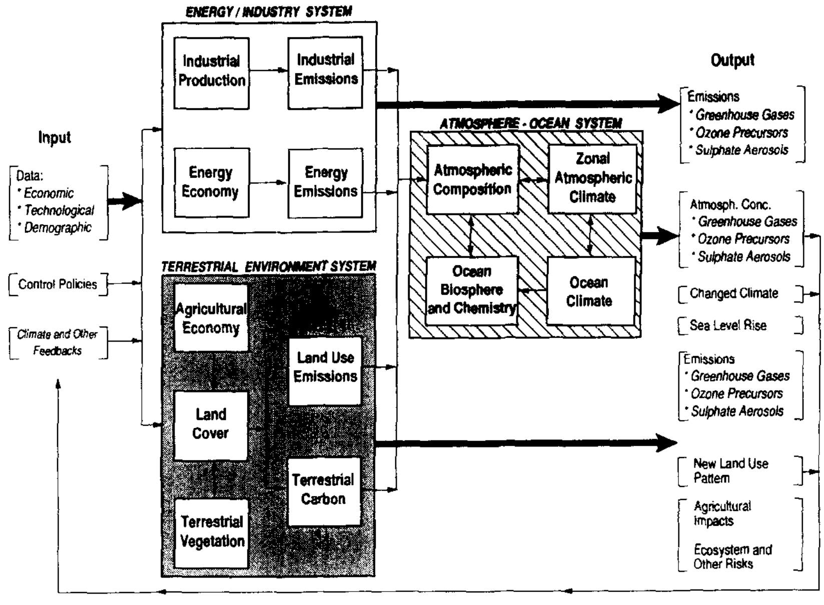


Figure 2. Schematic diagram of IMAGE 2 model.

view of model development and testing is given in Alcamo *et al.*[3] Details of development and testing of the Energy–Industry subsystem are given in de Vries *et al*;[4] for the Terrestrial Environment subsystem in Klein Goldewijk *et al*,[5] Kreileman and Bouwman,[6] Leemans and van den Born,[7] and Zuidema *et al*,[8] and for the Atmosphere–Ocean subsystem in de Haan *et al*[9] and Krol and van der Woerd.[10]

In the course of the paper we discuss critical points of the calculations used to generate the scenarios in this paper.

Primary driving forces and assumptions

As noted above, the main driving forces of global change in these scenarios are population and economic growth, and activity in economic sectors. Here we discuss demographic and economic assumptions, and in the section on energy consumption we discuss assumptions about economic activity.

Population growth. The intermediate and high baseline scenarios in this paper (Baseline A and C) use IPCC's medium population estimates (Table 1), and these estimates are close to medium population estimates of

[3]J Alcamo, G J J Kreileman, M Krol and G Zuidema, 'Modeling the global society-biosphere-climate system, Part 1: model description and testing', Water Air Soil Pollution, Vol 76, 1994, pp 1–35
[4]B de Vries, R van den Wijngaard, G J J Kreileman, J A Olivier and S Toet, 'A model for calculating regional energy use and emissions for evaluating global climate scenarios', Water Air Soil Pollution, Vol 76, 1994, pp 79–131
[5]K Klein Goldewijk, J G van Minnen, G J J Kreileman, M Vloedbeld and R Leemans, 'Simulating the carbon flux between the terrestrial environment and the atmosphere', Water Air Soil Pollution, Vol 76, 1994, pp 199–230
[6]G J J Kreileman and A F Bouwman, 'Computing land use emissions of greenhouse gases.' Water Air Soil Pollution, Vol 76, 1994, pp. 231–258
[7]R Leemans and G J van den Born, 'Determining the potential global distribution of natural vegetation, crops
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Table 1. Assumptions for population (millions)

			Baseline A and C			Baseline B		
Region	**1970**	**1990**	**2010**	**2050**	**2100**	**2010**	**2050**	**2100**
Canada	21.3	26.6	30.2	31.8	31.5	27.2	22.8	15.4
USA	205.1	249.9	283.0	298.2	295.2	263.6	234.9	166.0
Latin America	283.8	445.8	603.2	819.6	872.8	587.7	770.9	772.9
Africa	359.8	693.3	1117.8	2198.3	2862.1	1022.2	1621.1	1611.4
OECD Europe	351.1	377.1	398.2	394.4	387.5	385.0	323.0	218.4
Eastern Europe	108.4	123.4	135.5	149.3	147.8	132.5	128.9	97.2
CIS	242.8	289.4	317.7	350.0	346.6	310.8	302.2	277.6
Middle East	114.9	202.1	364.3	762.2	931.7	325.0	439.4	345.3
India + S Asia	739.4	1170.9	1635.1	2374.5	2643.5	1549.0	1896.9	1478.6
China + C P Asia	898.9	1242.1	1553.5	1886.3	1953.3	1460.6	1390.0	949.7
East Asia	239.5	368.0	513.9	746.2	830.8	486.8	596.1	464.7
Oceania	16.2	21.4	23.0	22.8	22.5	22.2	17.4	11.9
Japan	104.3	123.5	132.7	131.5	129.9	128.1	100.7	68.9
World	3685.7	5297.5	7108.0	10129.1	11455.2	6700.7	7844.3	6427.7

Source: Leggett et al. 1992.

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and agricultural productivity', Water Air Soil Pollution, Vol 76, 1994, pp 133–161
[8]G Zuidema, G J van den Born, J Alcamo and G J J Kreileman, 'Simulating changes in global land cover as affected by economic and climatic factors', Water Air Soil Pollution, Vol 76, 1994, 163–198
[9]B J de Haan, M Jonas, O Klepper, J Krabek, M S Krol and K Olendrzynki, 'A linked dynamics atmosphere-ocean model for assessing climate policies'. Water Air Soil Pollution, Vol 76, 1994, pp 283–318
[10]M S Krol and H van der Woerd, 'Simplified calculation of atmospheric concentration of greenhouse gases and other constituents for evaluation of climate scenarios', Water Air Soil Pollution, Vol 76, 1994, pp 259–281
[11]United Nations, *Long-range world population projections*, Population Division Report United Nations Population Division, New York, 1992
[12]W Lutz, C Prinz and J Langgassner, 'The IIASA World population scenarios', in W Lutz (ed), *Alternative Paths of Future World Population Growth*. International Institute for Applied Systems Analysis, IIASA, Laxenburg, 1994
[13]J Alcamo, A Bouwman, J Edmonds, A Grübler, T Morita and A Sugandhy, 'An evaluation of the IPCC IS92 emission scenarios', in J T Houghton, L G Meira Filho, J Bruce, H Lee, B A Callander, E Haites, N Harris and K Maskell (eds), *Climate Change 1994: Radiative forcing of climate change and an evaluation of the IPCC IS92 emission scenarios*, Cambridge University Press, Cambridge, 1995, pp 247–304
[14]World Bank, *World development report 1991*, Oxford University Press, New York, 1991
[15]Alcamo *et al*, *op. cit.*, Ref. 13
[16]Alcamo *et al*, op cit, Ref 13
[17]J Leggett, W J Pepper and R J Swart, 'Emissions Scenarios for the IPCC: an Update', in J T Houhgton, B A Callander
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the United Nations[11] and of the International Institute of Applied Systems Analysis (IIASA).[12] Hence there is some international agreement on these intermediate projections. The low baseline scenario (Baseline B) uses IPCC's low population estimate which is lower than that used for any CO_2 emission scenario found in the literature,[13] and somewhat below the low IIASA estimate. Summing up, there is more international support for the medium population estimates than for the low estimates.

Economic growth. The baseline scenarios in this paper use Gross Domestic Product (GDP) assumptions of IPCC (Table 2). These, in turn, are partly based on earlier IPCC work and partly on short-term estimates of the World Bank.[14]

Medium estimates from IPCC are used in this paper for Baseline A, and are lower than historical trends for most regions. Nevertheless these assumptions imply a substantial increase in GDP per capita. For example, GDP per capita in Latin America and East Asia will exceed current levels in OECD Europe in constant dollars.[15] Nevertheless, a large gap will remain in income between industrialized and developing regions. The low and high estimates used in Baselines B and C are also based on the IPCC and are representative of the low and high range of estimates used by other researchers to estimate global CO_2 emissions.[16]

Box 1. Main factors affecting energy consumption

Factors specified for scenario:

Activity in each economic sector
Structural change of economy
Technological change leading to improvements in energy efficiency

Factors computed internally by IMAGE 2

Fuel prices

Computing energy consumption

The following considerations steered the development of the baseline energy scenarios. First, the intermediate scenario (Baseline A) was intended to reflect the IPCC medium estimate of global CO_2 emission trends.[17] Its compatibility with the IPCC medium estimate enhances its usefulness internationally as a reference point for evaluating climate poli-

Table 2. Assumptions for Gross Domestic Product (US$ per capita per year)

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

Source: Leggett *et al* 1992.

cies. Second, the low and high scenario (Baseline B and C) were intended to give an independent view about the uncertainty around the medium estimate; therefore they use the driving forces of the low and high IPCC scenarios, but are not calibrated to obtain similar emission results. Third, since IMAGE 2 is fairly unique in its ability to perform regional energy and emission calculations, the baseline scenarios were intended to provide new information about regional energy use and emissions that are consistent with the 'best' global emission estimates.

(1) changes in the level of *activity* in each economic sector connected with changes in income and population;
(2) '*structural changes*' of the economy that lead to changes in energy intensity of sectors;
(3) '*technological changes*' that improved the performance of devices and appliances used to deliver energy services;
(4) *changes in fuel prices* that stimulate energy conservation and shifts in fuel mix.

To calculate a scenario of energy consumption for each of 13 world regions, IMAGE 2 takes into account four main factors (Box 1):

Economic activity. Historical data show that along with the growth of population and income comes an increase in the level of economic activity (eg the output of industry and the number of vehicles). The baseline scenarios assume that this trend will continue into the future. Behind this is the conventional economic thinking that as citizens become 'wealthier' (where wealth is poorly defined in units of GDP per capita) they purchase and possess more things. Based on these relationships and the scenarios of GDP per capita for each region noted above, we estimate activity in each sector and region for each baseline. This, of course, is only one view of the future, and not necessarily the most desirable one especially considering the impact of economic growth on the natural environment. Nevertheless, it is appropriate for a baseline scenario to reflect conventional economic thinking.

To estimate the future level of economic activity we first compute the relationship between GDP per capita and activity indicators in each of five sectors (Industry, Transport, Residential, Services, and 'Other')[18] and in each region for the period 1970 to 1990. This relationship is then used with the baseline scenarios of GDP (Table 2) to estimate future activity levels (Table 3).

Structural change. As economies grow, they go through major shifts in their overall structure, for instance, from heavy, energy intensive industries to lighter, more energy efficient industries. This trend will affect the overall energy intensity of the sectors in regional economies. For each scenario, we must specify how the energy intensity of each sector will change according to such structural shifts (here we refer to the unabated energy intensity, which is defined as the intensity independent of energy conservation). As a first step we assume that each region follows the typical trend shown in Figure 3, namely, as the activity level of a sector increases (eg as private consumption or industrial output per capita increases) then the average energy intensity of the sector first increases, and afterwards decreases and levels off to a minimum. The second step is to estimate where each sector of each region currently falls on this curve. This estimate is based on the trend of activity levels

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and S K Varney (eds), *Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment*, Cambridge University Press, Cambridge, 1992, pp 71–95

[18]'Other' stands for 'other energy use', and this includes all energy use not included by the other sectors. The activity indicator for this sector is GDP

Table 3. Assumptions for activity levels in various economic sectors

	Industry Sector: value added industrial output (US$/cap yr)								Services Sector: value added commercial services (US$/cap yr)							
			Baseline A		Baseline B		Baseline C				Baseline A		Baseline B		Baseline C	
Region	**1970**	**1990**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**	**1970**	**1990**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Canada	4493	6079	18740	33020	13185	18537	25632	57561	6382	12168	38002	67161	26660	37588	52075	117273
USA	4986	6560	19501	33918	14367	19794	26666	59143	10593	14869	44720	77976	32878	45397	61249	136161
Latin America	770	928	2420	7114	1604	3064	3871	16920	1034	1399	5134	15768	3073	6628	8460	37866
Africa	229	217	844	2397	526	1165	1265	5234	212	278	1073	4025	655	1582	1760	9312
OECD Europe	5176	6572	20259	35644	14254	20040	27690	62068	6241	11920	37260	65756	26138	36855	51023	114697
Eastern Europe	685	938	3973	6925	2588	3056	6459	16276	330	727	4571	8190	2792	3411	7620	19598
CIS	873	1358	4051	7016	2647	3110	6561	16526	228	553	1835	3401	1051	1314	3163	8364
Middle East	1211	995	2023	5536	1344	2247	3171	12902	1139	1249	3456	10198	1952	3918	5721	24111
India + S Asia	45	81	778	2562	485	1249	1189	5746	68	122	1091	4725	677	1926	1806	11015
China + C P Asia	30	120	1569	6147	1010	2731	2348	14156	26	103	1842	8774	1065	3690	3082	20489
East Asia	156	605	3004	11625	1968	5065	4778	26737	231	670	5001	20244	3013	8674	8167	46901
Oceania	4440	4973	17874	31338	13075	18060	24999	55874	7066	10835	39642	69693	28930	40059	55545	124458
Japan	4682	9970	37436	65675	27371	37828	52380	117136	6788	13174	50187	88242	36622	50714	70326	157592
World	1172	1392	3366	7352	2368	3670	4885	15255	1640	2314	5622	12856	3887	6250	8289	26858

	Residential Sector: private consumption (US$/cap yr)								Transport sector: number of passenger vehicles (vehicles per 1000 persons)							
			Baseline A		Baseline B		Baseline C				Baseline A		Baseline B		Baseline C	
Region	**1970**	**1990**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**	**1970**	**1990**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Canada	7211	12613	38659	68118	27200	38241	52877	118745	326.7	472.4	587.5	614.6	561.6	586.8	604.3	629.5
USA	10054	14540	43250	75357	31818	43905	59208	131531	449.8	566.1	599.6	610.9	591.9	599.9	606.4	619.4
Latin America	1133	1564	5139	15279	3171	6565	8312	36343	30.2	72.6	120.7	139.6	104.3	126.9	131.7	144.5
Africa	384	416	1252	4194	771	1794	1976	9500	11.6	15.1	44.0	60.8	30.8	51.6	53.3	63.2
OECD Europe	7142	11479	35233	62082	24790	34853	48192	108223	197.1	375.0	409.5	419.9	401.0	409.3	415.7	427.0
Eastern Europe	754	1064	5367	9390	3386	4076	8757	22068	34.4	145.0	225.7	236.6	211.0	217.7	235.5	244.4
CIS	1002	1783	5520	9657	3439	4139	9029	22751	18.3	59.0	206.5	236.6	150.8	176.0	234.5	247.4
Middle East	1620	1818	4492	12655	2666	5052	7236	29489	11.7	40.7	63.5	75.0	51.6	65.5	70.5	77.8
India + S Asia	169	220	1278	4982	794	2171	2048	11459	1.4	2.9	36.4	58.9	22.7	49.4	48.2	61.3
China + C P Asia	80	202	1915	8374	1164	3604	3048	19444	0.2	2.7	47.1	59.3	36.9	55.1	53.5	60.6
East Asia	363	832	4837	18861	3006	8218	7751	43379	4.6	15.6	59.0	63.1	55.4	61.4	61.2	63.7
Oceania	7226	10109	38148	67010	27860	38548	53422	119608	307.0	413.0	472.1	485.4	462.1	472.4	480.7	494.6
Japan	7041	13620	50964	89523	37220	51499	71370	159791	101.9	254.1	304.9	315.4	296.7	305.2	311.8	322.1
World	1853	2461	5806	12976	4027	6378	8512	27044	56.6	82.1	96.4	106.6	85.7	100.1	105.7	109.6

and energy data from 1970 to 1990. After estimating the current location of each sector on this curve, we then use the data for activity levels (Table 3) to extrapolate to the trend of energy intensity due to structural change. Trends in energy intensity for the important industry sector of Baseline A are depicted in Figure 4. Here the shapes of the curves are more important than the magnitude of the curves because measures of activity are not directly comparable between regions. Note that the different regions are expected to be in different phases of the theoretical curve (Figure 3) during the scenario period. Two regions depicted in Figure 4 are in the early part of the theoretical curve, China plus Centrally Planned Asia (moving from around point 'B' to 'C'), and

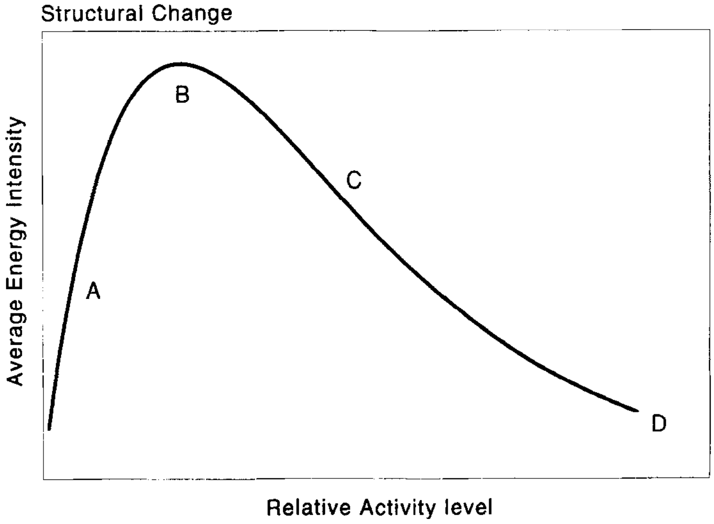


Figure 3. Idealized curve of structural change leading to change in energy intensity of a sector in a regional economy.

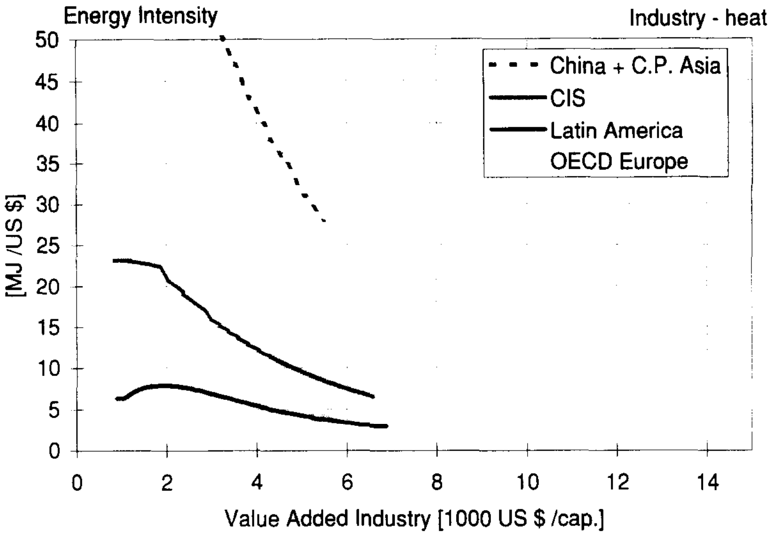


Figure 4. Structural change leading to change in energy intensity for the industry (heat) sector in Baseline A. Note that the horizontal axis is activity level rather than time, so the temporal trend of the assumed structural changes depends on how fast activity levels increase.

Latin America (moving from around point 'A' to 'C'). Meanwhile, the CIS moves through the middle towards the end of the curve (moving from around point 'B' to 'D'). OECD Europe is expected to be in the most advanced phase of the curve (around point 'D').

Technological change. While large-scale structural changes lead to shifts in the overall energy intensity of the economy, steady improvements in technology make new energy using appliances more energy efficient, often at no or even negative costs and irrespective of changes in fuel and electricity prices. These improvements are taken into account in the scenarios by specifying the rate at which new energy using devices become more energy efficient over time. This so-called 'marginal rate of autonomous energy efficiency improvement' must be specified for every sector and region. Selected results are given in Figure 5. For the industrial sector of OECD Europe, current improvements in energy efficiency are assumed to continue at about 0.25% per year, irrespective of fuel prices. In the CIS, where industry is more energy intensive than OECD Europe, a higher rate (0.65% per year) is assumed. A high rate of improvement is also assumed for China plus Centrally Planned Asia

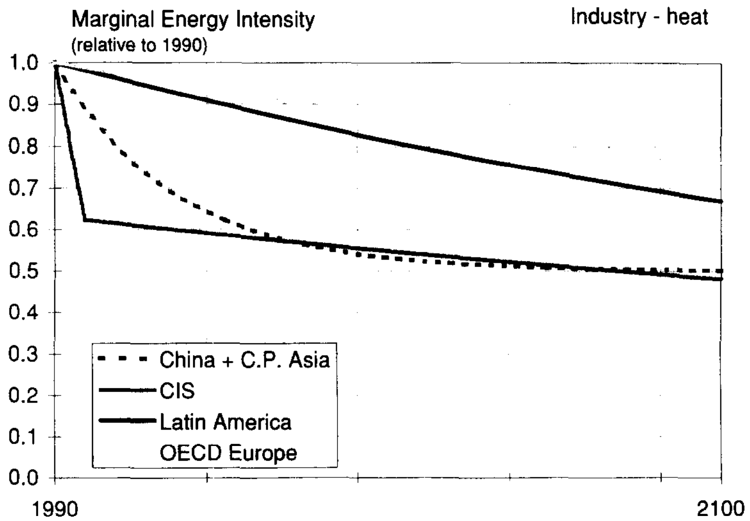


Figure 5. Technological change leading to change in marginal energy intensity for the industry (heat) sector in Baseline A.

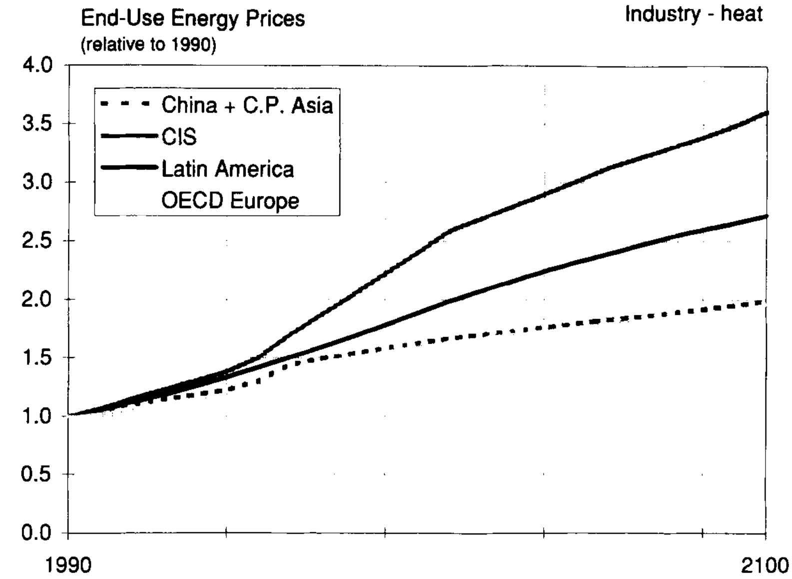


Figure 6. End use energy prices for the industry (heat) sector in Baseline A.

(0.60% per year) which reflects a common view that this region will strive to quickly modernize its industries. Latin America, however, is assumed to continue with its relatively low current rate of improvement (0.35% per year).

Energy prices. Consumers react to steeper energy prices by reducing energy use. This effect is simulated in the model explicitly. The fuel price changes that stimulate energy conservation are computed internally in the model as a function of fuel supply and are based on convergence towards global fuel prices. In the example for the industry (heat) sector shown in Figure 6, relative price changes are close for OECD Europe and China plus Centrally Planned Asia and substantially higher for Latin America and CIS. The differences in trends for different regions are mainly due to the convergence of fuel prices towards global prices.

To run the model, other energy related data must also be specified. The most important ones are fuelwood consumption, commercial biofuels consumption and the generation mix for electric power generation.

The IMAGE 2 model combines the preceding factors in estimating changes in the overall energy intensities of each region, and their future energy consumption. These are reported along with other scenario results later in the paper.

Box 2. Main factors affecting agricultural production

Factors specified for scenario:

Trade of agricultural products
Animal husbandry
Cropping intensity
Technological improvements in crop yield

Factors computed internally by IMAGE 2

Agricultural demand
Potential productivity of land due to climate

Computing change in agricultural production and land use

Land cover change is an essential aspect of global environmental change. For example, deforestation leads to releases of greenhouse and other gases, expansion of agricultural and urban land endangers natural ecosystem habitats, and forestation increases the uptake of CO_2 from the atmosphere. IMAGE 2 computes changes in land cover by taking into account the need for agricultural land (used here to mean pasture and cropland, and managed forests). The model computes these changes in land use by computing the changing demand in 13 world regions for livestock, crops, and forest products and the amount of crop, pasture, and forest land required to provide these products.

To calculate a scenario of agricultural production, IMAGE 2 takes into account the factors presented in Box 2. The need for agricultural land will depend, first and foremost, on regional agricultural demands which are computed as described below. However, for some regions, the amount of agricultural land will also depend on the amount of food traded with other regions, and this must also be specified for each scenario. In addition, there are a number of factors that are important to estimating requirements for agricultural land because they influence the amount of food that can be produced per hectare of land. One of these factors is the effect of climate on potential crop productivity, and this is computed internally by the model. The other three factors of this type must be specified for each scenario. They are: animal husbandry, cropping intensity, and technological improvements in crop yield.

Agricultural demand. Agricultural demand consists of the need for all agricultural commodities, specifically meat and crops consumed by humans, and feed required by livestock (demand for forest products are computed separately in the model, while the demand for commercial biofuels is generated by the Energy Economy model). To compute regional demands, the model multiplies per capita consumption of food times population estimates. The main task, therefore, is to compute per capita consumption of food. IMAGE 2 computes this consumption under the main premise that people eat more food as their income increases, up to a particular 'preferred' consumption level. Of course, in reality food prices also have a major influence on consumption levels – These are taken into account indirectly in the model by making food consumption dependent on the productivity and availability of new agricultural lands – The idea is that as good land is used up, prices increase and consumption is dampened.

Summing up to this point, IMAGE 2 computes per capita food consumption based on (1) income, (2) land productivity and availability, and (3) preferred level of food consumption. The first factor is taken from the GDP per capita assumptions for each region, specified in Table 2. The second factor is computed internally in the IMAGE 2 model. The third factor, preferred level of consumption, is very difficult to specify because it varies greatly from region to region, and depends on difficult to quantify cultural and geographical factors. Hence we take a pragmatic approach and run the IMAGE 2 model 'backwards' from 1970 to 2010 in order to obtain the trend of this factor. This is done by specifying for this period what the model is supposed to compute – per capita consumption of different foods from 1970 to 2010. Data for food consumption comes from AGROSTAT[19] for 1970 to 1990, and from trend estimates of IFPRI[20] from 1990 to 2010. The

[19]FAO, *Agrostat PC. Land Use*, Computerized Information Series 1/7, Food and Agriculture Organization of the United Nations, Rome, 1991

[20]M W Rosegrant, M Agcaoili-Saombilla and N D Perez, *Global Food Projections to 2020: Implications for Investment, Food Agriculture and the Environment*, Discussion Paper 5, International Food Policy Research Institute (IFPRI), Washington, DC, 1995

other important factors – income and land productivity/availability, are assigned or internally calculated as we noted above. Therefore, we can back calculate from the model a rough estimate of the preferred consumption level of the different foods in different regions for this period. We then extrapolate these trends from 2010 to 2100. (The same estimates of preferred consumption are used for all three baseline scenarios.) The preferred consumption level together with the computed consumption level for Baeline A in Latin America are shown later in Figure 11. The last step in computing agricultural demand is to multiply the computed regional per capita consumption by population data in Table 1 to obtain the tonnes of agricultural products of each type needed in each region and time step.

Food trade. The baseline scenarios of world food trade are based on three very simple rules based on 'self sufficiency ratios' (total production divided by total consumption): (1) Regions that currently export a particular agricultural commodity will continue to do so in the future, (2) the fraction of this export relative to the total production of this commodity remains the same ie the 'self sufficiency ratios' remain the same, and (3) currently importing countries maintain their current dependence on imports. The same assumptions are used for all three baseline scenarios. Hence, if agricultural production in a region increases, then the total amount of exports will also increase. Of course, this is just one of many possible ways of specifying a scenario of food trade, but considering the complexity of the subject it has the virtue of being simple.

Animal husbandry. Some factors concerned with the development of livestock can have an important effect on estimating future feed requirements and pasture and rangeland. One factor in particular is animal productivity, ie the amount of meat produced per animal. For this factor we assume that industrialized countries are close to their maximum value and that other regions will reach the current OECD Europe level when their GDP per capita reaches the current OECD level (Table 4). Hence, the trend of this factor varies from scenario to scenario along with economic assumptions of the scenarios.

Cropping intensity. An important variable affecting the overall land needed in a region for cropland is the number of crops grown per hectare of land over a calendar year. This must be specified for each scenario and

Table 4. Assumptions for improvement in productivity of beef cattle

	Productivity (kg/animal yr) Baseline A					Rate of increase in productivity (%/yr)		
	1970	1990	2010	2050	2100	Baseline A 1900–2100	Baseline B 1900–2100	Baseline C 1900–2100
Canada	86	99	135	163	163	0.45	0.36	0.53
USA	99	121	145	163	163	0.27	0.18	0.35
Latin America	35	36	41	75	162	1.38	0.80	1.36
Africa	18	24	24	30	57	0.79	0.31	1.19
OECD Europe	123	148	156	162	162	0.09	0.00	0.17
Eastern Europe	100	119	125	138	156	0.25	0.07	0.22
CIS	95	117	119	130	146	0.20	0.05	0.22
Middle East	23	46	49	73	162	1.16	0.47	0.67
India + S Asia	7	9	10	15	47	1.53	0.77	2.01
China + C P Asia	5	14	16	29	121	1.95	1.04	1.90
East Asia	18	27	34	76	162	1.63	1.31	1.66
Oceania	53	81	124	162	162	0.63	0.54	0.71
Japan	113	155	159	162	162	0.04	0.00	0.12

Table 5. Assumptions for cropping intensity[a]

	1970	1990	2010	2050	2100
Canada	0.444	0.568	0.625	0.631	0.631
USA	0.469	0.495	0.545	0.550	0.550
Latin America	0.845	0.812	0.889	0.969	1.000
Africa	0.683	0.726	0.841	0.959	1.000
OECD Europe	0.699	0.730	0.803	0.811	0.811
Eastern Europe	0.828	0.741	0.815	0.823	0.823
CIS	0.624	0.582	0.640	0.647	0.647
Middle East	0.577	0.695	0.780	0.868	0.900
India + S Asia	0.908	0.960	1.102	1.249	1.300
China + C P Asia	1.269	1.411	1.527	1.650	1.700
East Asia	1.044	1.088	1.261	1.438	1.500
Oceania	0.314	0.300	0.330	0.333	0.333
Japan	0.974	0.828	0.911	0.920	0.920

[a]Cropping intensity is defined as the number of crops grown each year per unit of cropland in a region. For example, if agricultural land is left fallow in 1 out of 5 years, then the cropping intensity is 4/5, or 0.8.

region over the scenario period. There is now an upward trend in this factor, and each of the baseline scenarios assume that this trend will continue up to a region specific maximum. Under Baseline A (Table 5), cropping intensities of temperate cereals sharply increase for most developing regions up to the second half of the next century, while they level off in the early part of the century in industrialized regions. The same assumptions are used for all baseline scenarios.

Technological improvement of crop yields. Improvement in management techniques, crop varieties, and machinery have contributed to a steady increase in crop yields throughout the world. This rate of technological improvement in crop yield must be specified for each scenario and region. The industrialized regions are assumed to have already passed the 'green revolution' although yields will continue to improve at somewhat lower rates due to biotechnology (Table 6). Scenarios for these regions are based on a slowing down of the 1970 to 1990 trends. For the developing regions, trends up to 2010 are taken from Alexandratos[21] which assumes that these regions will rapidly increase crop yields. This rapid rate of improvement levels off after 2030. Different rates of improvement are assigned to the different baseline scenarios, dependent on their rate of economic growth (Table 2).

Factors not taken into account. Before continuing, it is important to note two important factors not yet included in IMAGE 2 land cover calculations. First, the future degradation of land is not taken into account. It is crucial, of course, to factor in the loss of agricultural productivity

[21]N Alexandratos (ed) *Agriculture: Towards 2010*, An FAO study. Wiley, Chichester, 1995

Table 6. Assumptions for technological improvements in temperate cereals yield (1990 = 1.0)

				Baseline A		Baseline B	Baseline C
	1970	1990	2010	2050	2100	2100	2100
Canada	1.01	1.00	1.10	1.28	1.45	1.38	1.47
USA	0.77	1.00	1.27	1.60	1.82	1.68	1.97
Latin America	0.59	1,00	1.37	2.17	2.80	2.32	3.16
Africa	0.73	1.00	1.37	2.17	2.80	2.32	3.40
OECD Europe	0.64	1,.00	1.10	1.21	1.21	1.21	1.21
Eastern Europe	0.63	1.00	1.27	1.47	1.61	1.56	1.61
CIS	0.75	1.00	1.27	1.60	1.82	1.68	1.97
Middle East	0.71	1.00	1.27	1.60	1.82	1.68	1.97
India + S Asia	0.60	1.00	1.37	1.92	1.92	1.92	1.92
China + C P Asia	0.39	1.00	1.27	1.53	1.53	1.53	1.53
East Asia	0.85	1.00	1.10	1.28	1.45	1.35	1.53
Oceania	0.62	1.00	1.27	1.60	1.82	1.68	1.97
Japan	0.62	1.00	1.10	1.28	1.45	1.38	1.47

because of overuse and mismanagement. We note, however, that the model *does* take into account the current low productivity of some areas (such as the Sahel region of Africa) because of land degradation. The net effect of this omission is to *overestimate* the future availability of agricultural land. The other major omission is not including the potential for new irrigated agricultural land, although current irrigated land is included. This omission has the opposite effect of land degradation, in that it leads to an *underestimate* of the future availability of agricultural land. Future versions of IMAGE 2 will include these factors, and we can then investigate if these two factors compensate for each other.

Box 3. Main factors affecting emissions of air pollutants

Factors specified for scenario:
Emission factors

Factors computed internally by IMAGE 2:
For energy emissions: primary energy consumption
For industry emissions: level of industrial activity
For land use emissions: size of agricultural area, and other land use indicators

Computing changes in emissions and in the state of the atmosphere and climate

The IMAGE 2 model computes regional emissions of all radiatively important gases as well as sulphur dioxide which leads to the radiatively important sulphate aerosol. For the baseline scenarios, however, sulphate aerosol in the atmosphere is held constant at its 1990 level, so that the influence of changing sulphur dioxide emissions can be examined through sensitivity analysis. Emission calculations depend on a number of driving forces computed internally by the model (Box 3), as well as emission factors that must be specified for each scenario. For the scenarios in this paper we hold constant for the entire simulation period the estimated 1990 value of these emission factors in all emission categories. These emission factors are documented and explained in de Vries *et al.*[22]

Based on these emissions, IMAGE 2 computes the atmospheric buildup of many important pollutants, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), sulphur dioxide (SO_2), and various halocarbons. The method for these computations is reported in Krol and van der Woerd.[23] Increased levels of greenhouse gas emissions lead to changes in surface temperature and precipitation as described in de Haan *et al.*[24] The coupling between submodels in IMAGE 2 simulate some of the feedbacks that occur in nature between the atmosphere and terrestrial environment. These feedback processes can have an important impact on results as we will describe later.

Results of baseline scenarios

Here we present an overview of future global environmental change as computed in the baseline scenarios. Because of space limitations, we focus on global average results and details from 4 of the 13 world regions covered by the IMAGE 2 model (China plus Centrally Planned Asia,

[22]de Vries *et al*, *op cit*, Ref 4
[23]Krol and van der Woerd, *op cit*, Ref 10
[24]de Haan *et al*, *op cit*, Ref 9

OECD Europe, Latin America, and the former Soviet Union, now known as the Commonwealth of Independent States (CIS)). These regions were selected because they represent a wide range of economic and geographic situations. Results from other regions are also presented when particularly noteworthy.

Energy

We discussed previously how certain assumptions of the scenario and model lead to higher energy intensity of the economy, and some to lower. Figure 7 shows that their net effect is to decrease energy intensity in Baseline A. For the world as a whole, energy intensity decreases by a factor of 2.8 between 1990 and 2100. These estimates are in line with the range of long term energy scenarios found in the scientific literature.[25] Another important outcome is that the different regions converge towards a common energy intensity over the long-run (Figure 7).

We now examine calculations of secondary energy consumption because they indicate the amount of energy needed to provide future energy services and the sectors where it will be most needed. Results for Baseline A are depicted in Figure 8. In OECD Europe the use of energy stabilizes around 2035 because the rate of improvement of energy efficiency counteracts the relatively slow rate at which economic activity expands. The same trend is observed for other OECD regions in Baseline A. By comparison, secondary energy use in the CIS first sags in the 1990s because of economic recession, and then increases in accordance with the economic growth presecribed in Baseline A. The dominant sectors in these regions are transport, followed by industry. Meanwhile in China plus Centrally Planned Asia and Latin America, secondary energy use rapidly increases until the end of the next century (Figure 8). In both China and Latin America industry is the most important energy using sector. In 2100, transport is the second most important sector in Latin America, but in China the residential, services, and 'other' sectors are tied for second place.

[25] Alcamo *et al*, *op cit* Ref 13

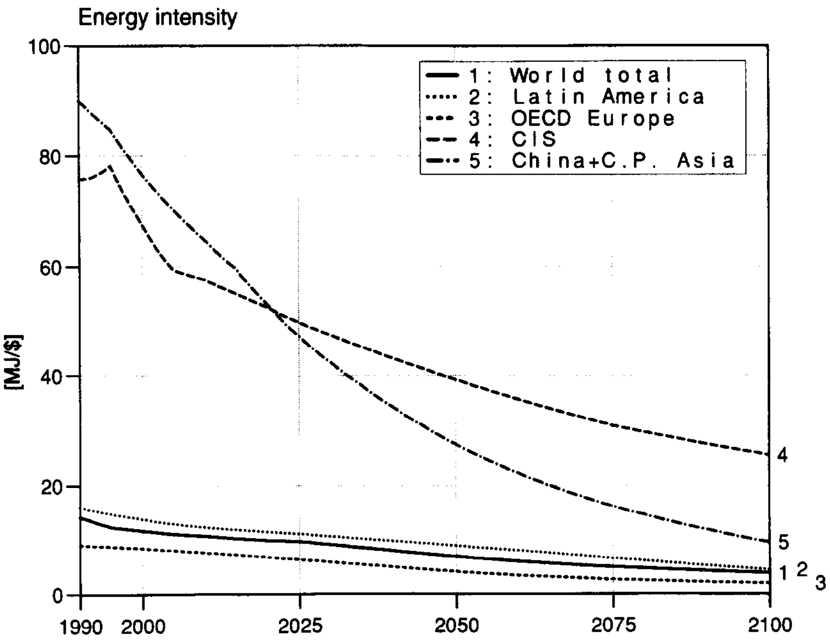


Figure 7. Regional energy intensity in Baseline A.

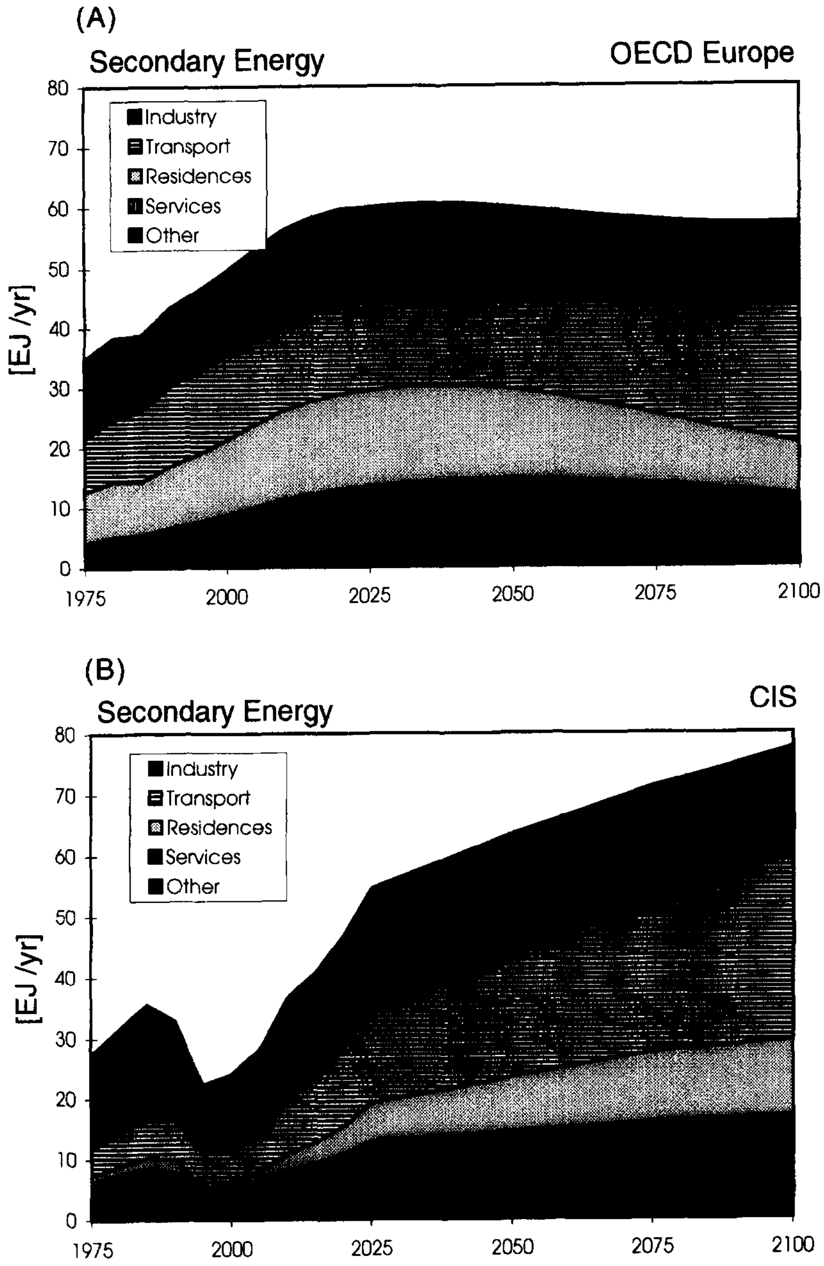
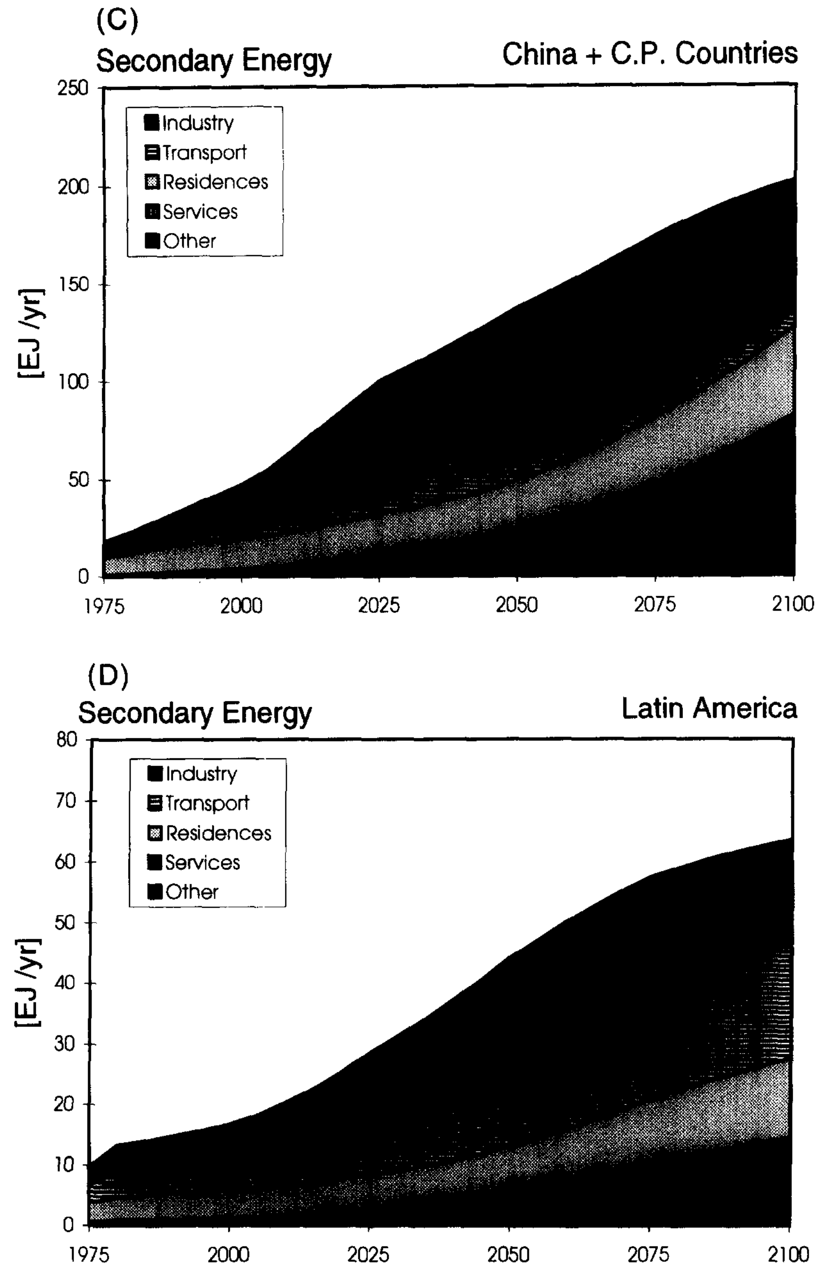


Figure 8. Secondary energy consumption by sector in Baseline A.

To sum up the findings of Baseline A, secondary energy use stabilizes in the coming decades in OECD regions. In other regions it continues to sharply increase until the end of the next century. Globally, the industry and transport sectors are about equally important.

While secondary energy consumption is a good indicator of the sectors of importance to future energy demand, primary energy consumption and its fuel profile are better indicators of the source of future emissions of greenhouse and other gases. Computed fuel profiles can be very different between countries because their domestic fuel resources are quite different, and because they have different economic capabilities to import fuels. As an example of these differences, in Baseline A OECD Europe maintains its reliance on oil while increasing use of nuclear and commercial biofuels. Meanwhile, China become even more reliant on its coal resources (Figure 9).



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A comparison of results for the three baselines indicates the influence of different driving force assumptions on primary energy consumption (Figure 10). Note that primary energy consumption of OECD Europe is about 78 EJ in 2100 (Figure 9) and secondary energy consumption about 57 EJ (Figure 8). This implies an overall conversion rate of 73%.

For OECD Europe, the three baseline scenarios show similar trends, namely an increase till 2025 and a decrease afterwards. Although Baseline C has a much higher rate of economic growth and economic activity than Baseline A, its primary energy consumption is not much larger than in Baseline A. This is because Baseline C also assumes a faster rate of improvement in energy efficiency which compensates somewhat for its higher level of activity. This is significant from the point of view of emissions because a small difference in primary energy consumption implies a small difference in emissions between these scenarios. Baseline B, with

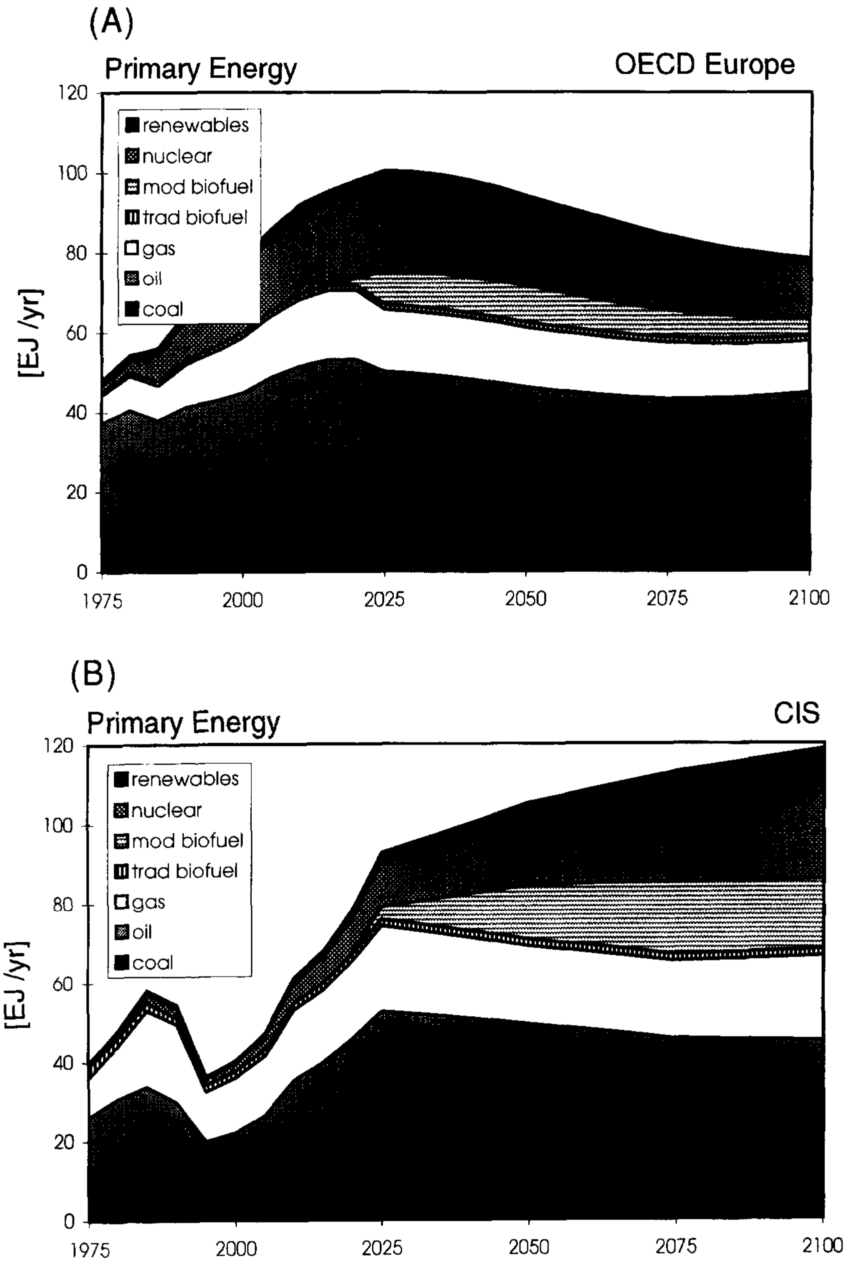

Figure 9. Primary energy consumption by fuel in Baseline A.

lower assumptions for population and economic growth leads to substantially lower primary energy consumption and emissions (Figure 10). In the CIS and Latin America, the economic growth rates of Baseline C lead to much higher primary energy consumption than Baseline A because the energy intensity of industry and transportation is assumed to remain higher than in OECD regions. In China Plus Centrally Planned Asia, as well as other developing regions in the model, primary energy use greatly increases in Baseline A and C, but stabilizes in the early part of the next century under Baseline B. Note the great range in estimates of the three baseline cases (Figure 10), indicating a similar uncertainty range for future emissions.

In summing up, energy use in OECD regions increases in the coming decades and goes down afterwards for all three baseline scenarios. In the other regions it steadily increases under the two highest scenarios,

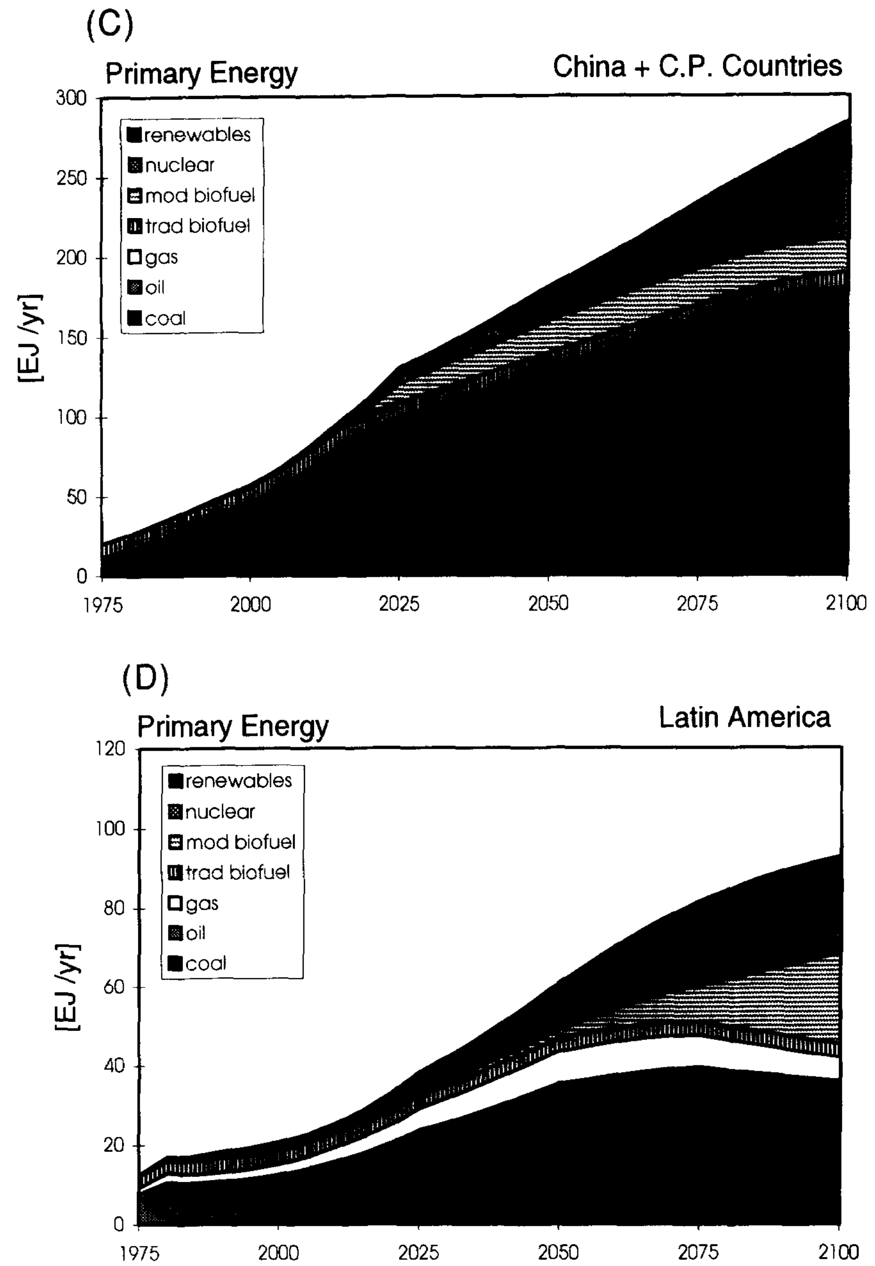

Figure 9. *Contd.*

but stabilizes in some regions under the lowest scenario. On the global level, primary energy consumption stabilizes by 2025 for the lowest scenario, whereas for the other two scenarios it increases by a factor of 4 to 5 between 1990 and 2100.

Agriculture

As we have seen, the baseline scenarios indicate that the world energy system will undergo important regional changes. We will now see that vigorous changes also occur in the world's terrestrial system. We first examine the effect of economic and population growth on food demand and then describe the influence of these demands and climate change on changing agricultural land, forest land and other land cover.

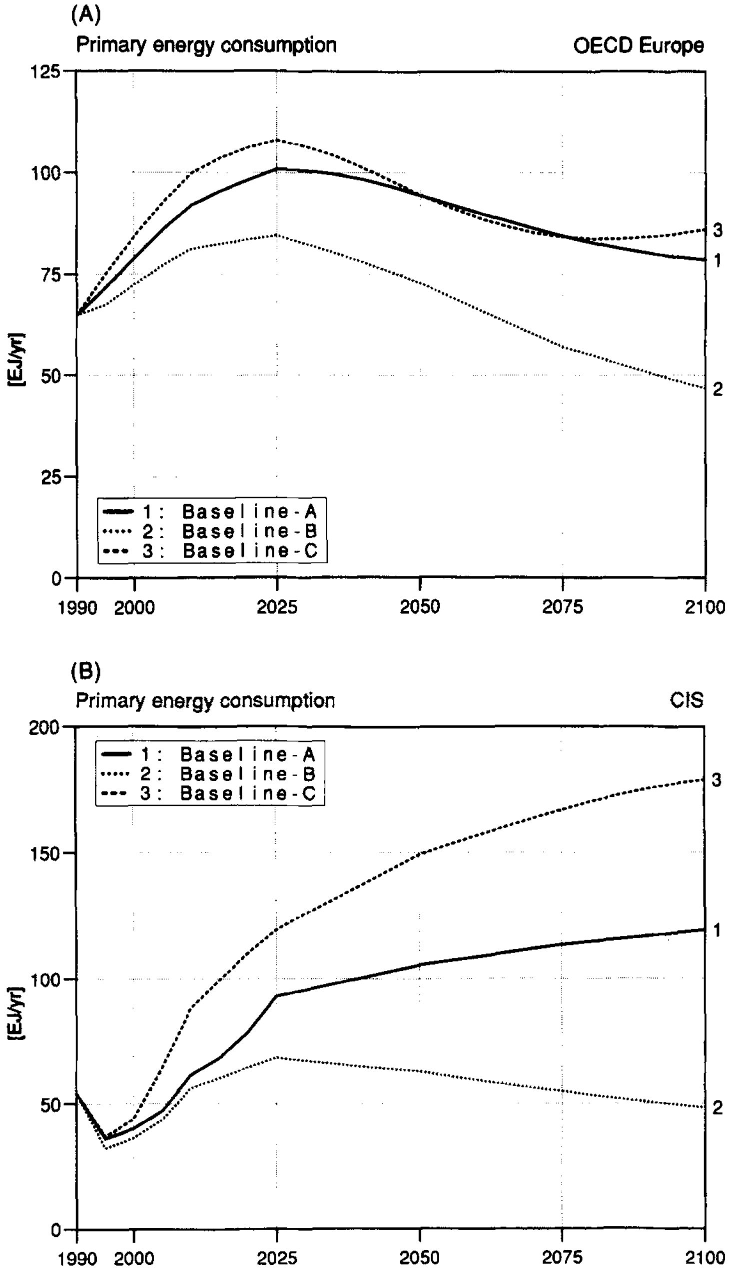

Figure 10. Primary energy consumption for three baseline scenarios.

Per capita food demand

We begin with Baseline A and the per capita consumption of agricultural commodities. We summarize results by aggregating the crops and animal products computed by IMAGE 2 into two large categories (a) 'Animal Products+', which have the larger land requirements per unit commodity and consist of all animal products plus oil crops, and (b) 'Cereals+', which have smaller land requirements per unit commodity and are made up of all cereals together with pulses, roots and tubers.

In OECD Europe, consumption grows slowly because it is already near its preferred level; cereals+ grow somewhat faster than animal products+ because of the assumed preference for non-meat foods (Table 7). These trends are typical of all industrialized regions under Baseline A. By contrast, there is a relatively rapid increase in the

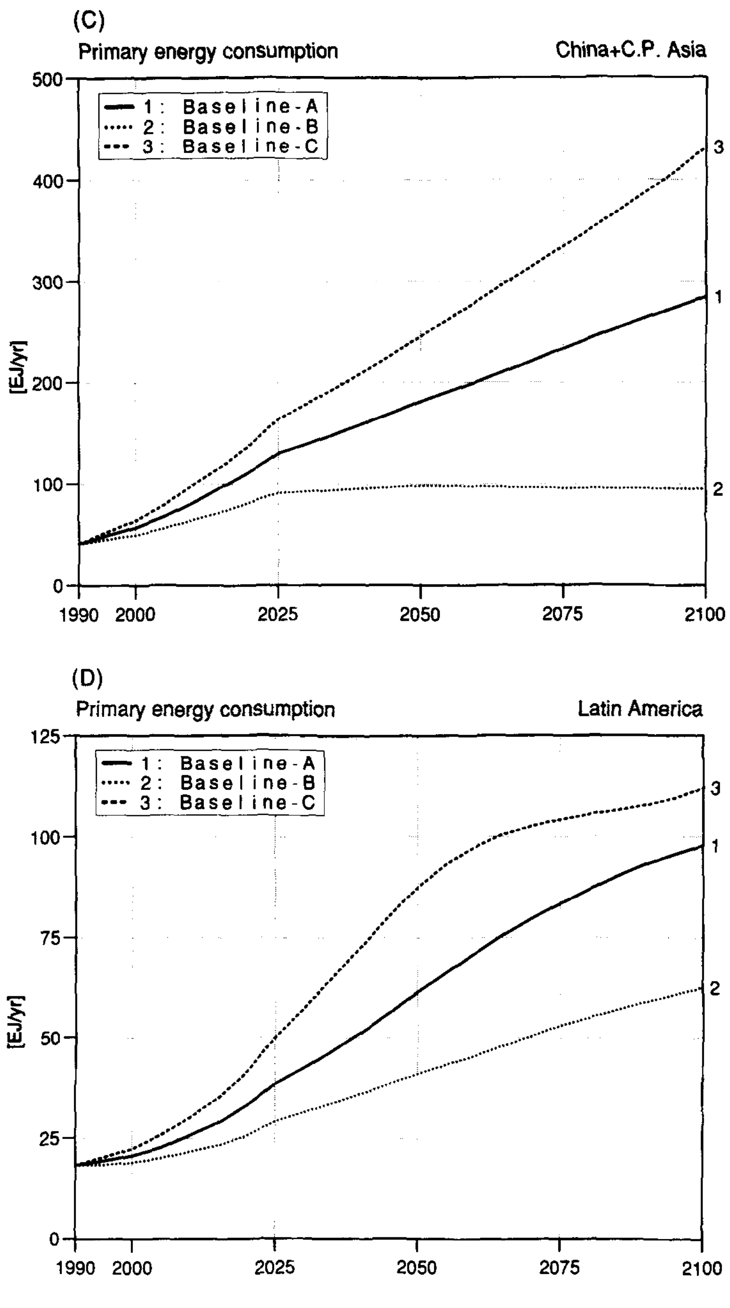

Figure 10. *Contd.*

consumption of all crops in the region of China plus Centrally Planned Asia, as income increases and pent-up demand is satisfied. This trend is typical of the other developing regions in the model.

Meanwhile Latin America, which maintains an economic level between the industrialized and developing regions, increases its consumption of food but at a lower rate than China. By 2100 total consumption of commodities is close to the assumed 'preferred' consumption level (Figure 11). This is because income increases, and there is no computed shortage of agricultural land. However, not all types of consumption converge to their preferred level at the same rate. The consumption of cereals+ converges much faster than animal products+ because land requirements of cereals (and roughly their price) is relatively lower.

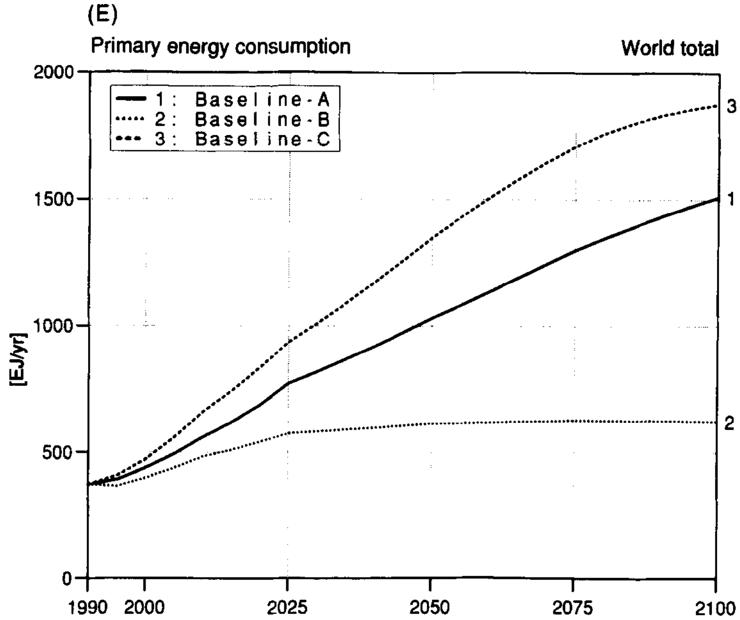

Figure 10. *Contd.*

Population of livestock

The number of livestock has an important influence on the total amount of agricultural land because of their need for pasture land or feed. To compute the number of livestock needed to satisfy the desired consumption of meat and dairy products, the model multiplies the per capita consumption of animal products times population, while taking into account that the productivity of animals is improving at the same time. Under Baseline A, the number of cattle goes down in OECD Europe and, after a few decades, in the CIS, despite the increasing per capita consumption of beef products noted above (Figure 12). This is because of the decrease in human population, and because the productivity of livestock is assumed to increase (Table 4). By contrast, increasing per capita demand together with an increase in population leads to a large initial growth in the number of cattle in Latin America and in China plus Centrally Planned Asia (Figure 12). Here the number of cattle decreases in the second half of the next century not only because of the same factors noted for OECD Europe, but in China also due to the limited amount of area where agricultural land can expand in the

Table 7. Caloric intake (cal/cap day) in Baseline A[a]

	1970	1990	2010	2050	2100
Cereals+					
Latin America	1274	1240	1303	1415	1440
OECD Europe	1076	1043	1098	1195	1267
CIS	1703	1445	1435	1441	1486
China + C P Asia	1694	1986	2171	2495	2715
Animal products+					
Latin America	427	608	710	943	1069
OECD Europe	901	1187	1274	1354	1395
CIS	752	943	989	1030	1012
China + C P Asia	140	328	422	610	900
Grand total					
Latin America	2478	2674	2914	3414	3635
OECD Europe	3215	3487	3710	3990	4165
CIS	3309	3383	3434	3504	3540
China + C P Asia	2005	2623	2941	3522	4100

[a]Note that the grand total figures are higher than the sum of the categories 'Cereals+' and 'Animal Products+'. The fraction of intake of the products that are not modelled (like fish, vegetables, and permanent crops) is kept constant and taken into account in the grand total.

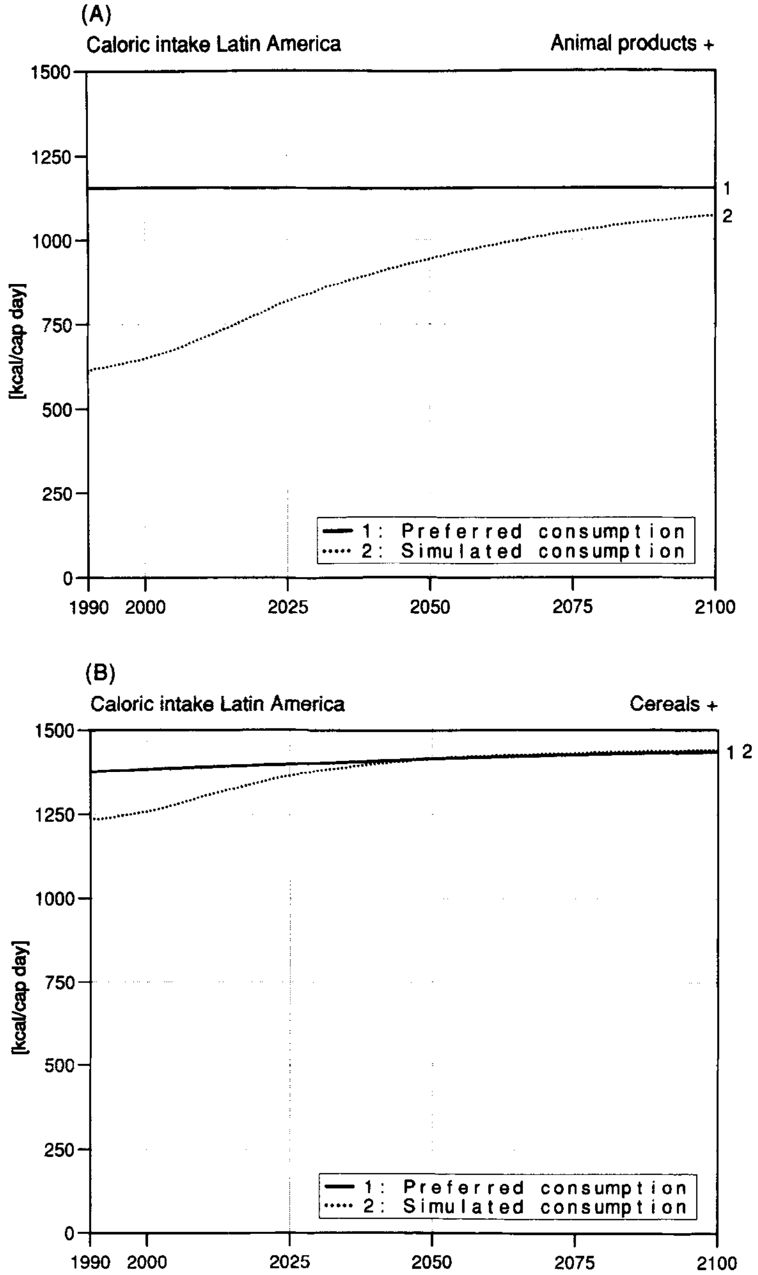

Figure 11. Computed per capita consumption of agricultural commodities for Latin America in Baseline A. Shown also is the assumed 'preferred consumption' level.

future. In China plus Centrally Planned Asia and other developing regions (for example Africa and India plus South Asia) the consumption of animal products+ does not reach the preferred level. This is because land requirements for these products are high compared to cereals+.

For the world as a whole, the Baseline A and Baseline C scenarios show similar trends for the number of animals. The number of cattle for example increases from around 1.4 billion in 1990 and levels off in 2040 at around 2.5 billion, then declines after 2050 down to around 1.6 to 1.7 billion in 2100 (Figure 13). This is because Baseline C assumes a faster growth of animal productivity which compensates for its faster growth in demand for beef and milk due to a higher economic growth. The level of cattle in a number of developing regions is limited by the availability of suitable land, as discussed in the previous section. This explains

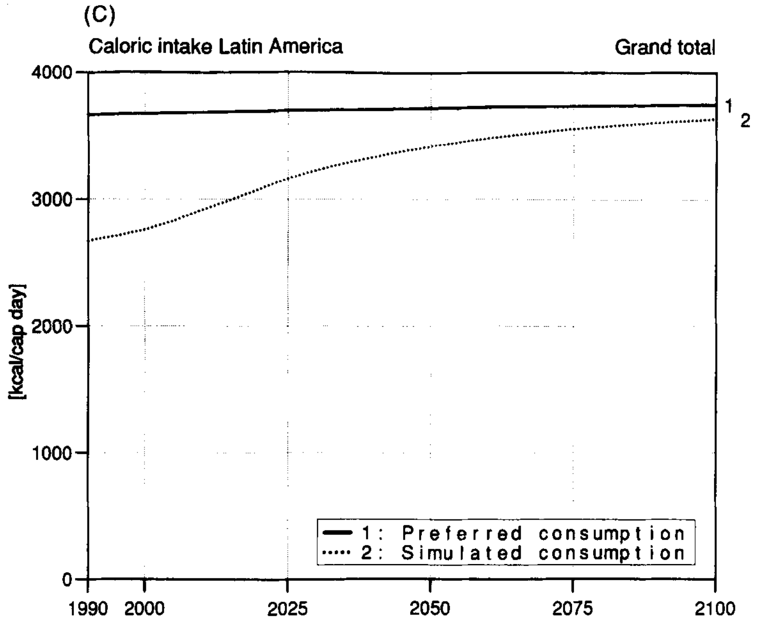

Figure 11. *Contd.*

why the maximum level of cattle in Baseline B can be close to the maximum level in the two highest scenarios. Due to the lower growth of population and economy this maximum level in Baseline B is reached about 30 years later than in the other two scenarios.

Total agricultural production

The sum of human consumption of crops together with consumption of feed by animals leads to total crop demands. Figure 14 shows that the total demand for temperate cereals in OECD Europe levels off because of opposing trends – per capita consumption slowly increases as we have seen above, but the human population goes down, and the number of feed consuming livestock levels off as we have also mentioned above. Consequently, the total demand for temperate cereals is almost constant. Meanwhile, in the CIS total demand for

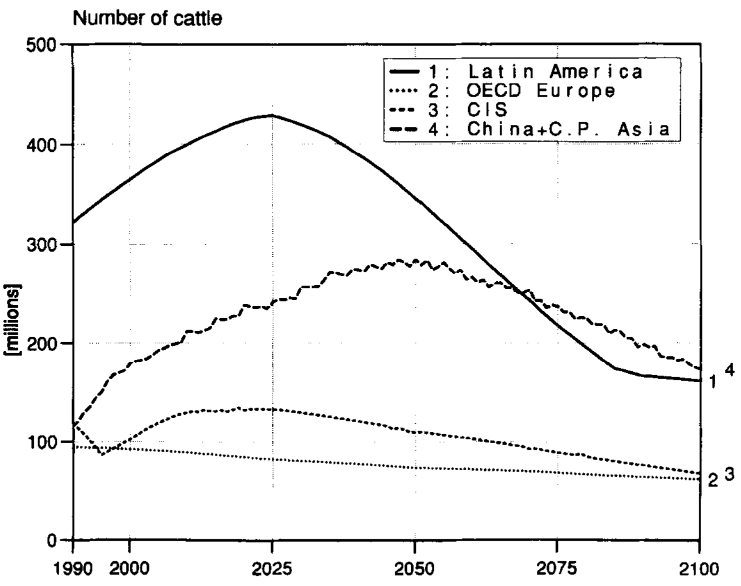

Figure 12. Number of cattle in Baseline A in four regions.

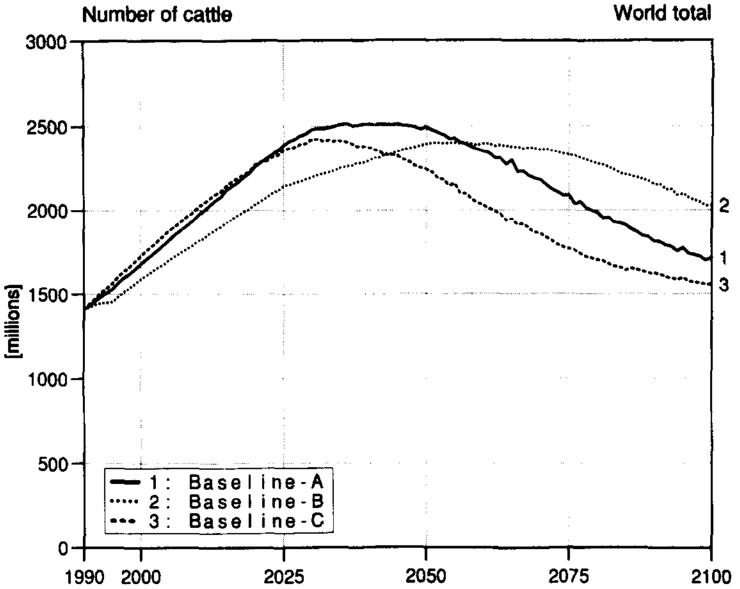

Figure 13. World total number of cattle in three baseline scenarios.

temperate cereals increases up to 2030 because population continues to go up, and then declines afterwards as population stabilizes and animal productivity goes up.

In China plus Centrally Planned Asia, total demand for temperate cereals rapidly increases in the next century reflecting the growth in human population and per capita consumption (Figure 14). This is representative for the developing regions where the availability of suitable lands become limiting, such as Africa and India plus South Asia. In Latin America, total demand for temperate cereals also increases in the next century, but at a lower rate than in China. The main factor in Latin America is the growth in human population.

For the global production of temperate cereals a rapid increase in the first part of the next century is followed by a slow increase in the second part of the century (Figure 15). Comparing the three baseline scenarios show that the trend in global production of temperate cereals is reflecting the trend of human population growth. This indicates that

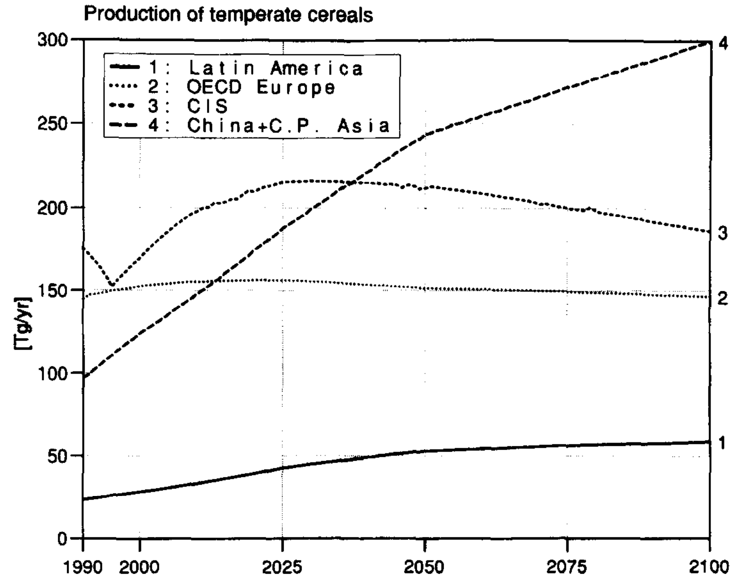

Figure 14. Total production of temperate cereals in Baseline A in four regions.

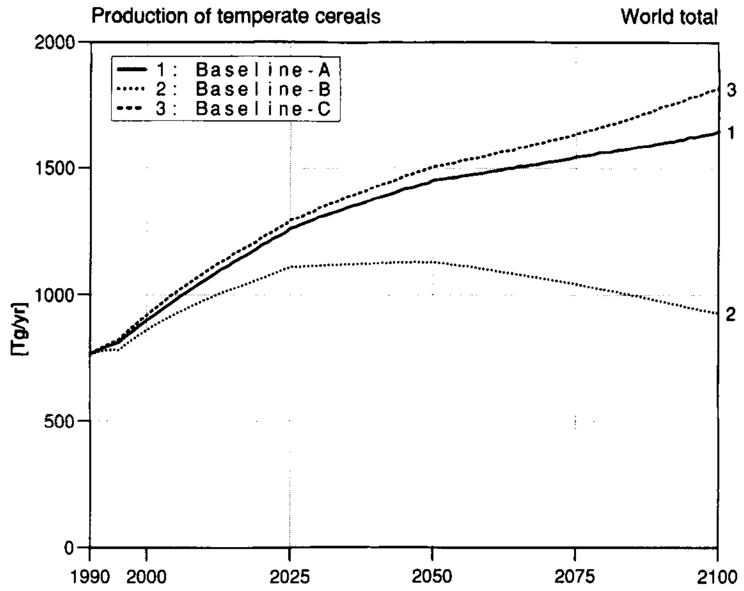

Figure 15. World total production of temperate cereals in three baseline scenarios.

the differences in the per capita consumption due to changes in economy and the availability of suitable agricultural land and the differences in the consumption of temperate cereals by animals are balancing each other on the global level. Baseline C leads to a somewhat higher production of temperate cereals than Baseline A. This is due to the assumption that the technological improvement of crop yield is higher in Baseline C than in Baseline A, which leads to a higher production in those regions that use up all their suitable land in the scenarios (China plus Centrally Planned Asia, Africa and India plus South Asia).

Summing up. The trends in crop demands are quite different in each region, although as a rule they are stabilizing or declining in industrialized regions, and increasing sharply in developing regions until the second half of the next century. These trends result mainly from changes in the per capita consumption of different types of commodities, the rate of growth of human population, and improvements in the productivity of animals.

The extent of agricultural land

Changing food demand is the major factor driving the demand for agricultural land. However, other factors also play an important role. Of particular significance are technological developments and climate which will lead to changes in crop and pasture yield per hectare. In the baseline scenarios, technology is assumed to have a net effect of improving yield in each region (see Table 6). The effect of climate change can be positive or negative, and is computed at each time step according to the climate computed by the model at that time step. Later we discuss climate's impact on crop productivity. The net result of these factors on the yield of temperate cereals is shown in Figure 16. In OECD Europe there is almost no net effect of climate change as can be seen from the trend in average yield after a few decades when technological improvements have reached their maximum level. By contrast, there is a continuous increase in the average yield of temperate cereals in the CIS. This

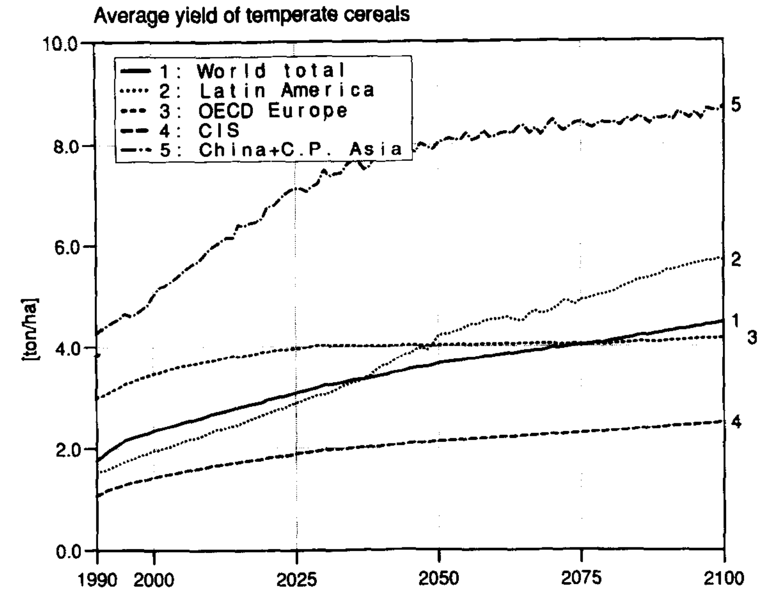

Figure 16. Average yield of temperate cereals Baseline A. The cropping intensity as given in Table 5 is included in this figure. If for example the average yield on the harvested area is 2 tonnes per hectare and the cropping intensity is 0.8, then the average yield presented in this figure is 1.6 tonnes per hectare.

yield increase is higher than the assumed technological improvements in yields, indicating that parts of the CIS become more suitable to grow temperate cereals. The increases in average yields by a factor of 2.0 to 3.5 in China plus Centrally Planned Asia and Latin America are mainly due to the assumed increase in cropping intensity and technological improvements.

Based on computed food demand and crop yields, and assumed food trade, the IMAGE 2 model computes future agricultural land. This includes both pasture and cropland. Under Baseline A the total amount of agricultural land decreases in Europe and the CIS (Figures 17 and 18). This stems from the stabilization of food demand, and because overall climate becomes more favourable for crop production (except in southern Europe and the southern CIS). Another favourable factor is the assumed improvement in crop and pasture yields arising from technology. This shrinking trend occurs in all industrialized regions, although the location of agricultural lands within these regions changes somewhat because of changed climate conditions.

In China, as well as in other parts of Asia and Africa, enormously increasing demands for food in the first half of the next century uses up virtually all suitable land for crops and livestock. Meanwhile in Latin America, agricultural land expands initially because of increasing numbers of livestock, and levels off after 2030 mainly because the improvements in crop and pasture yields outweight other factors (Figures 17 and 18).

On the global level the amount of agricultural land sharply increases up to 2030 due to the expansion of agricultural land in the developing regions (Figure 19). Afterwards, when a number of developing regions have used up all their suitable land for crops and livestock, the global trend is dominated by the trend in the developed regions where agricultural lands are abandoned. The impact of abandonment in the highest baseline scenario is even stronger than in Baseline A. In this scenario the faster improvements in animal productivity and crop yields in regions like Latin America and the CIS outweigh the increases in demand. The low scenario shows a much smaller amount of agricultural land, mainly due to the lower human population.

Agriculture effected by climate change

As already mentioned, changes in temperature and precipitation due to climate change can have both a negative and positive impact on crop yield. Figure 20 presents a global overview of the situation in year 2100 according to Baseline A. Shown is the change in their potential productivity due to climate change as computed by the FAO crop suitability

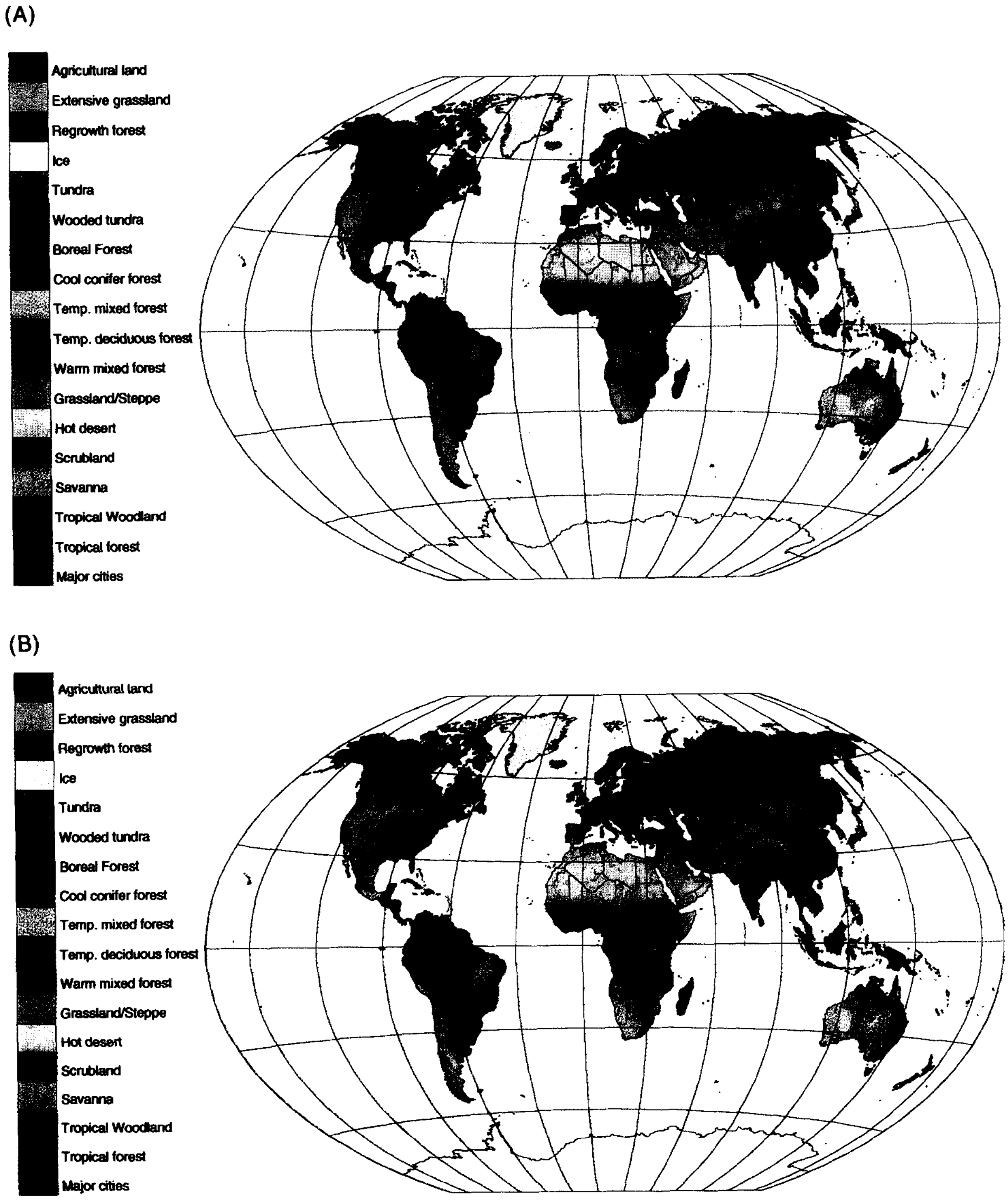

Figure 17. Global maps of land cover Baseline A (A) Land cover 1990, (B) Land cover 2100.

models. These models are embedded in the IMAGE 2 model as described by Leemans and van den Born.[26] The two types of crops that are shown, temperate cereals and maize, have different responses to changes in temperature, precipitation and atmospheric CO_2.

For the Baseline A scenario, yields of temperate cereals decrease in 21% of its current growing area because of climate change between 1990 and 2100, whereas 32% of the area of maize is affected (Figure

[26]Leemans and van den Born, *op cit*, Ref 7

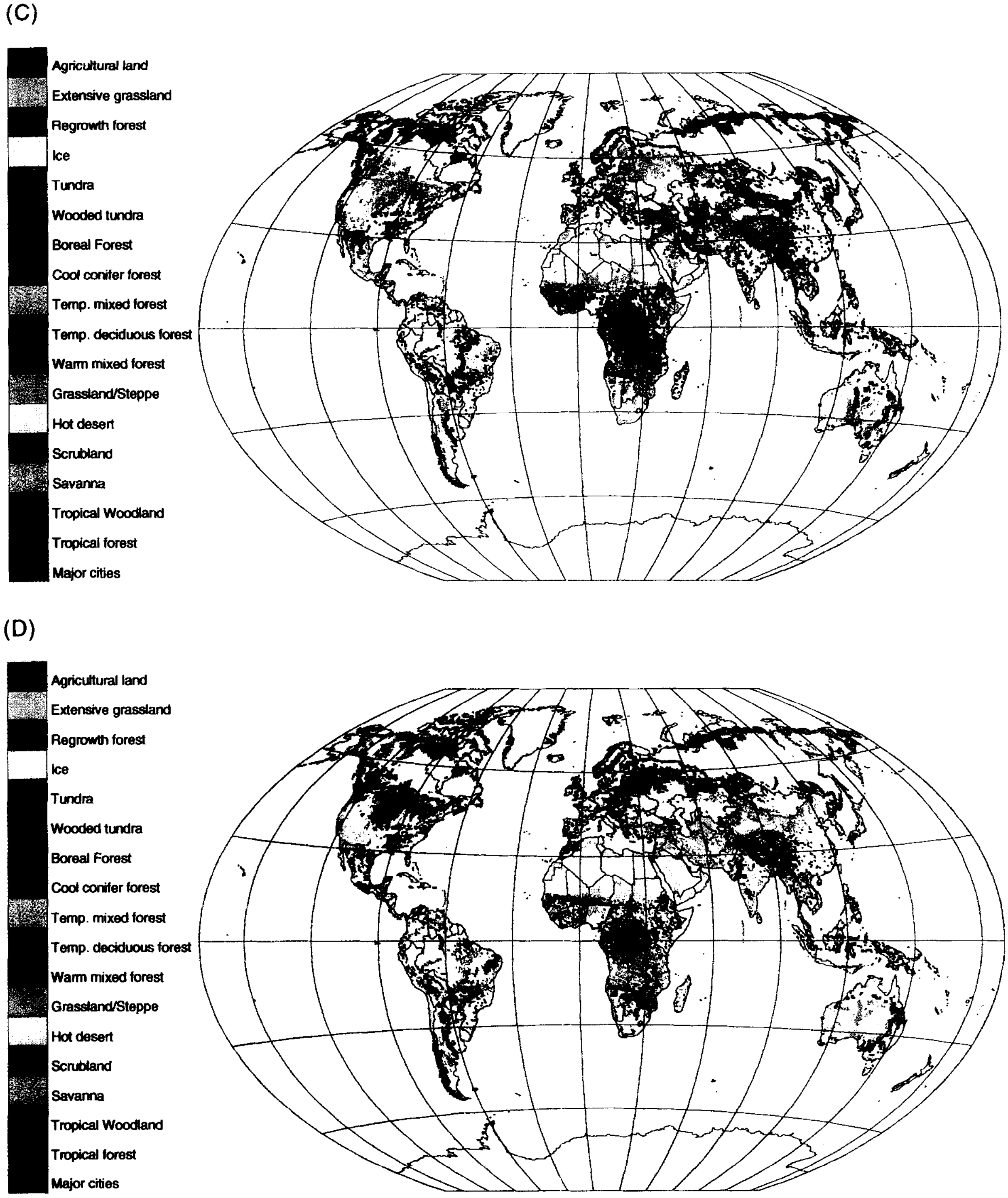

Figure 17. *cont.* (C) New Land Cover in 2100 relative to 1990, (D) Old Land Cover from 1990 replaced by 2100.

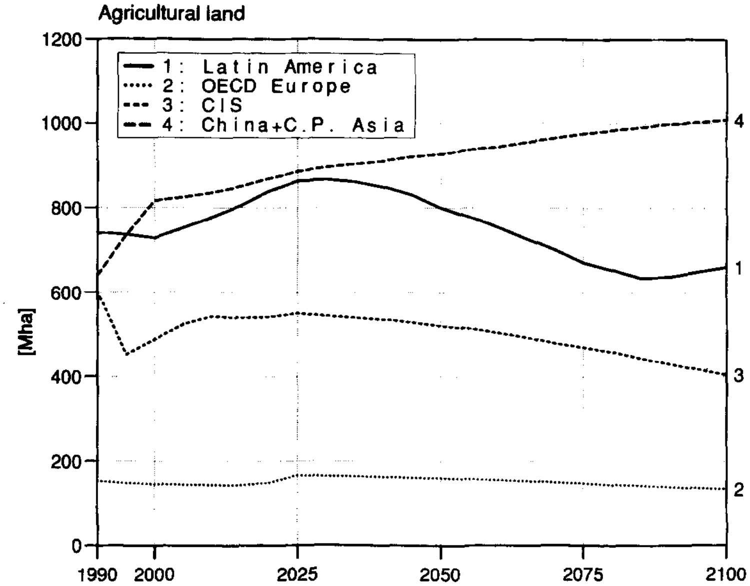

Figure 18. Total agricultural land in four regions Baseline A.

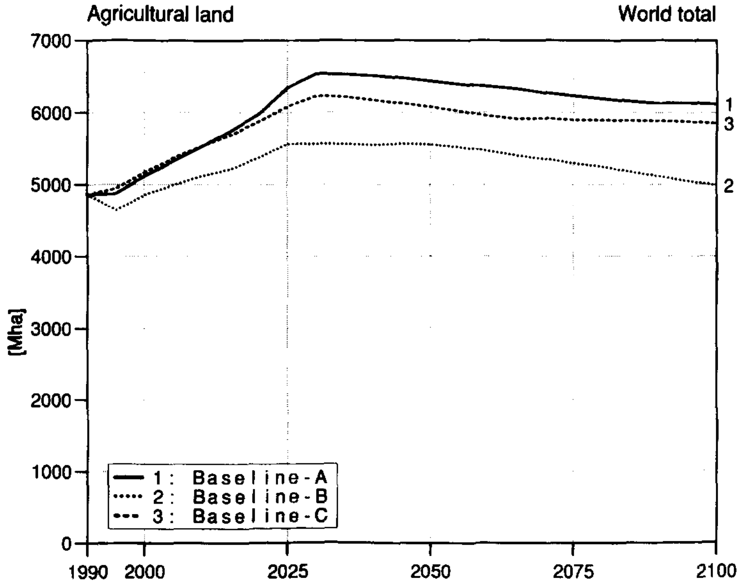

Figure 19. World total agricultural land in three baseline scenarios.

20). For the low and high scenarios, 18 to 23% of the area of temperate cereals has decreasing yields, and for maize 22 to 34% of the maize area.

Forests and other land cover

One of the most important consequences of expanding or shrinking agricultural land is the changing extent of forest land. This has great significance to biodiversity, to human cultures, and to the availability of timber. According to the baseline scenarios, agricultural land expands largely at the expense of forests, especially in the tropics (as it does in reality now). In the industrialized regions, where agricultural land shrinks according to the scenarios, then the IMAGE 2 model assumes that it will be replaced by naturally occurring vegetation. This means that much new forest land appears in these regions.

To examine scenario results, we first concentrate on the effect of socioeconomic factors simulated by IMAGE 2, namely the expansion of agri-

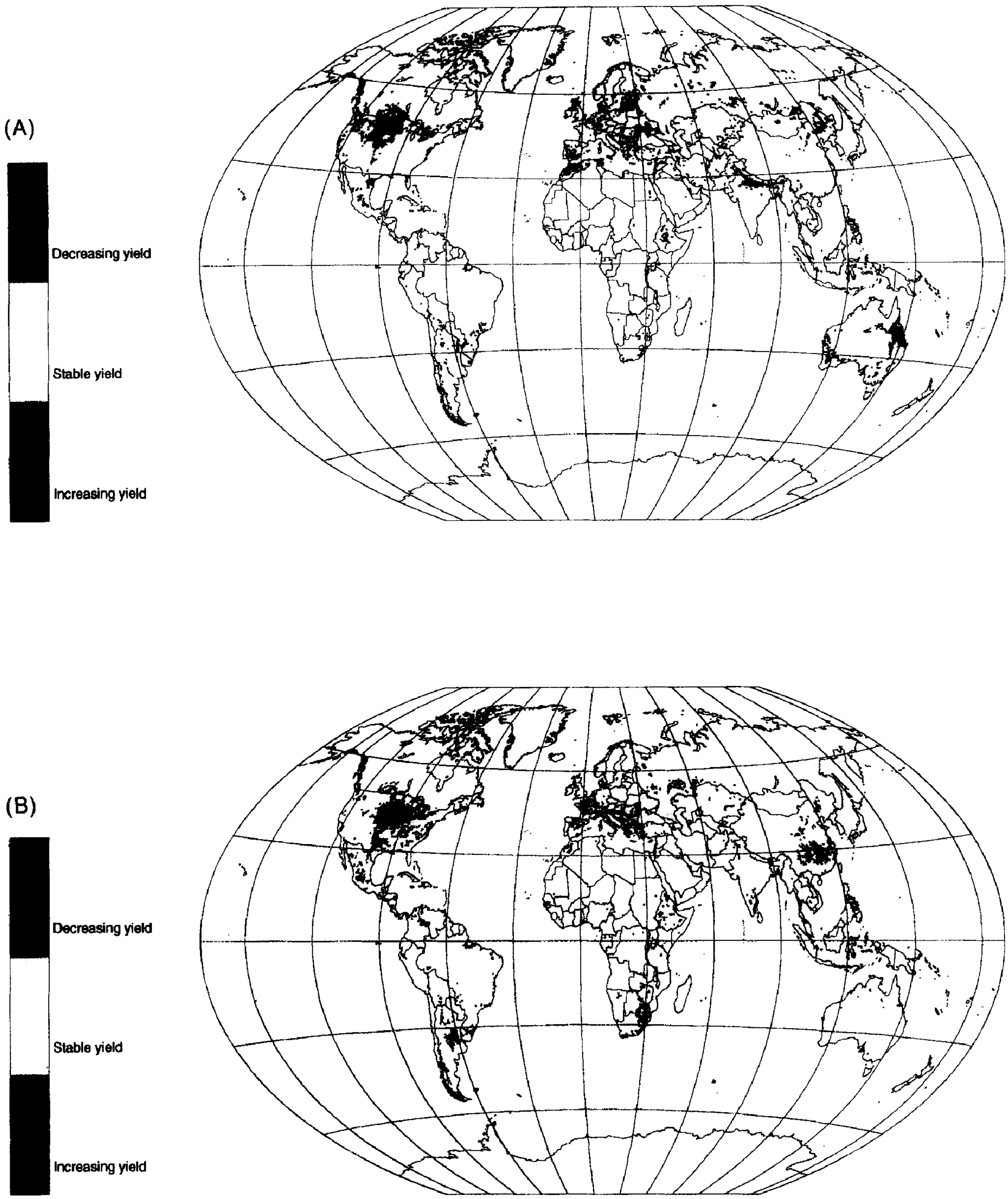

Figure 20. Change in yield of current cropland 1990–2100. Baseline A (A) Temperate cereals (B) Maize.

cultural land and clearing of forests for fuelwood (areas managed for lumber are assumed to be reforested). Under Baseline A, these factors alone lead to a shrinking of global forests from around 4296 to 3170 million ha between 1990 and 2100 (Figure 21). The corresponding rates of deforestation are 17.0 million ha/yr in the first half of the next century, and 0.2 million ha/yr in the second half (Table 8). This can be compared to the estimated rate of 15.4 to 16.9 million ha/yr in tropical countries

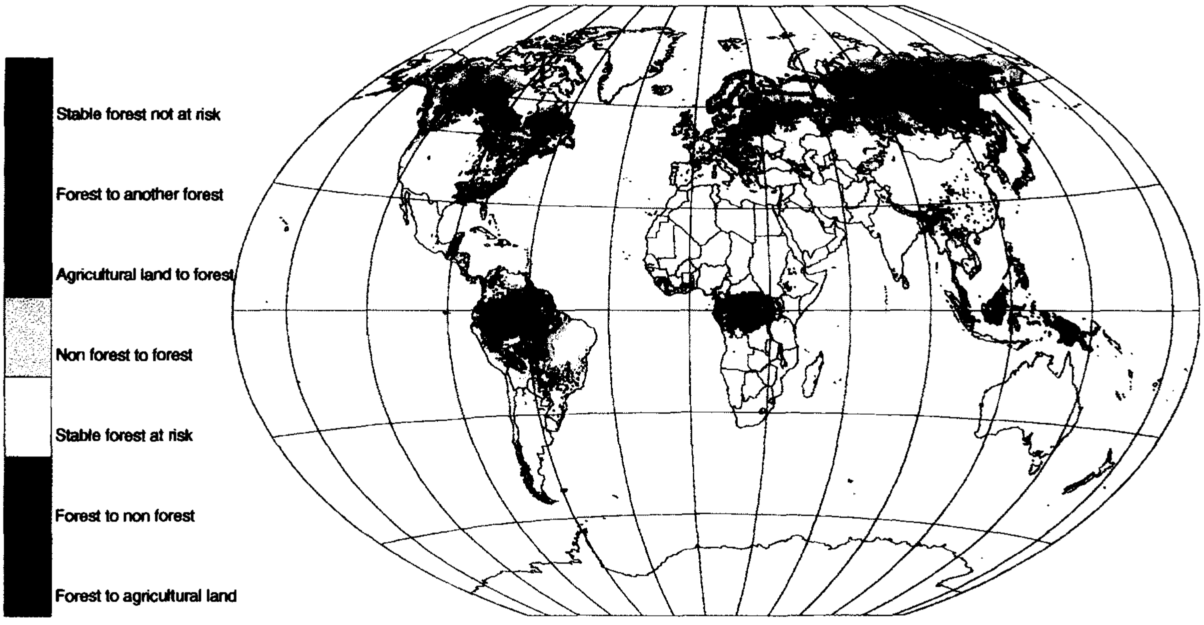

Figure 21. Status of forests 1990–2100.

Table 8. Overview of scenarios for global forests

Scenario	Net forest area (million ha)			Net deforestation rate (Million ha/yr)		Gross deforestation rate (Million ha/yr)	
	1990	2050	2100	1990–2050	2050–2100	1990–2050	2050–2100
Baseline A with climate change	4296	3435	3719	14.4	−5.7	19.3	0.7
Baseline A without climate change	4201	3179	3170	17.0	0.2	18.3	1.0

in the 1980s.[27] Most of this decline is due to expansion of agricultural land in developing regions and a small amount to fuelwood demand. We note that this is the *net* decrease in forest land, because some new forest land (427 million ha) is added from abandoned agricultural lands in Europe and other industrialized regions.

Adding the effect of climate change to Baseline A changes the picture considerably (Table 8): rather than a continuous decline, global forest area stops shrinking around 2040, and then slowly rises to about 3719 million ha in 2100. Hence, climate change makes a net addition to forest area because of its net global influence is to lessen the area needed for agriculture (See Figure 19). Climate change also adds some new forest areas where climate becomes suitable and there is enough time for forests to migrate. However, we already noted that climate change will have a negative net effect on agriculture in some regions.

An indication of the uncertainty of this intermediate estimate is given by the lower (Baseline B) and higher (Baseline C) scenarios. For these scenarios, the net deforestation rates range from 6.7 to 10.6 million ha/yr in the first half of the next century, and increase of forests by 5.3 to 8.1 million ha/yr in the second half.

The first columns in Table 8 are net forest area, and they are useful for assessing total world timber resources. However, a better indicator of threat to biodiversity and forest ecosystems is the gross rate of deforesta-

[27]WRI, *World Resources, 1992–1993*, World Resources Institute, Washington, DC, 1992; FAO, *Forest Resources Assessment 1990: Tropical Countries*, FAO Forestry Paper No 112, Food and Agricultural Organization of the United Nations, Rome, 1993

tion, ie the amount of forest land converted to another land cover type (Figure 21). Under climate change, more forest land is converted than without climate change. Moreover, this still underestimates the impacts of climate change on forests because it does not indicate the area that would remain forest but in a degraded state. Hence, a better indicator of the risk of climate change to forests is the extent of current forest area where future climate will no longer be suitable for the same type of forest (that is where potential vegetation changes). The area of forests affected by climate change in 2100 is one third of the current forest area (Figure 21).

Impacts on other land cover

Climate change and the expansion of agriculture affects not only the condition of forests, but also the condition and existence of other natural areas. For example, savanna areas of East Africa disappear because of the expansion of agriculture, and much of the tundra area in Northern Siberia is replaced by boreal forest as a result of climate change (Figure 17 – land cover maps shown earlier). Under Baseline A, 34% of the earth's terrestrial area is converted from one major land cover type to another between 1990 and 2100.

Figure 22 presents a global overview of the threat to natural vegetation. In the period 1990 to 2100 (Baseline A) a total of 16% of the earth's land area, including a large part of Africa and Asia, is threatened by socio-economic factors, mainly from the demand for agricultural land and fuel-wood. During the same period, 41% of the area will be threatened by climate change, meaning that the potential vegetation in this area will

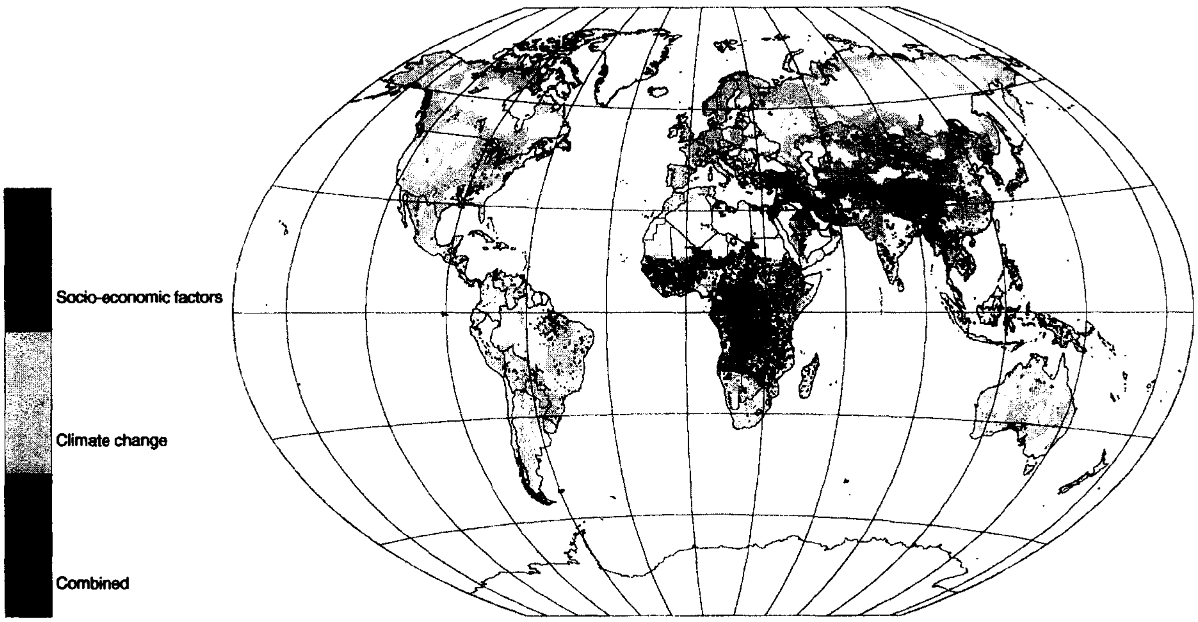

Figure 22. Threat to natural vegetation according to Baseline A scenario (1990–2100). Socio-economic here refers to current areas of natural vegetation that may be used for new agricultural land or forest products to satisfy future food and fuel demands of Baseline A. Climate change refers to areas where the potential vegetation is estimated to change because of climate change.

change as a result of climate change. Note that much of the northern temperate zone, and large parts of the rest of the world will be affected.

Emissions of air pollutants

Regional emissions of greenhouse and other important pollutant gases are the sum of emissions arising from all economic sectors and sources in the region (Appendix 1). Figure 23 shows that emissions of CO_2, the main greenhouse gas, stabilizes by 2030 in OECD Europe, CIS, and Latin America. This has to do with either the stabilizing of energy consumption or the increased use of lower carbon fuels in these regions. By comparison, emissions in the region of China plus Centrally Planned Asia steadily increase along with the growth of its economy.

In Figure 24 we examine the global emissions of key gases divided into four large categories: energy, industry, land use and natural. Land use (deforestation and decomposition of organic matter) is an important category of CO_2 emissions up to the middle of the twenty-first century but then the declining rate of deforestation leads to a decline in its importance. The deforestation rate declines for different reasons in different regions – in industrialized regions because the expansion of agricultural land slows, and in developing regions because the remaining forest area is depleted. The rapid but temporary decrease in land use emissions of CO_2 after 2025 comes from the rapid decline of deforestation in Africa as most of the region's forest areas are depleted for agriculture. Land use remains a significant source of CO_2 in OECD Europe and CIS after 2040 because of the decomposition of wood products produced earlier in the scenario period.

Land related sources make up the main part of two important greenhouse gases, methane (CH_4) and nitrous oxide (N_2O) emissions. This is because an important source of these gases is agricultural activity, which grows in importance throughout the scenario period. By contrast, land related sources make up a smaller and smaller part of the total emissions of carbon monoxide (CO) and volatile organic compounds (VOC), two gases which play an important role in the formation of ozone in the troposphere. The reason for this is that an important source of these

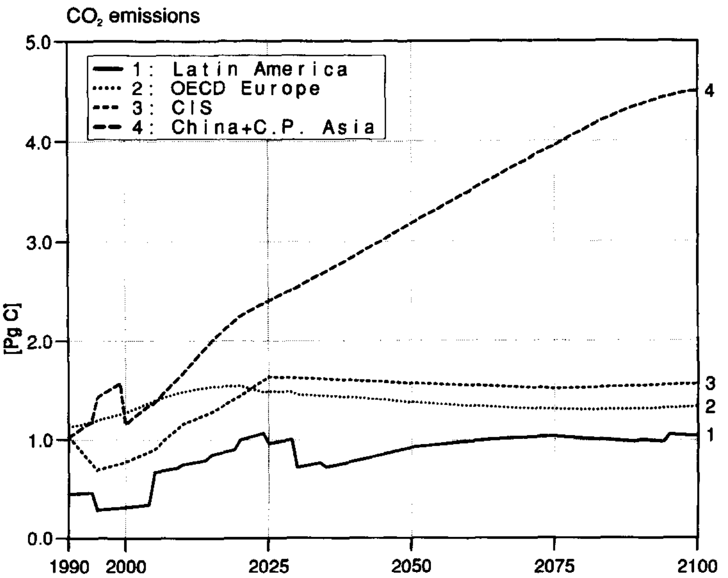

Figure 23. Time trends of CO_2 emissions for four regions in Baseline A.

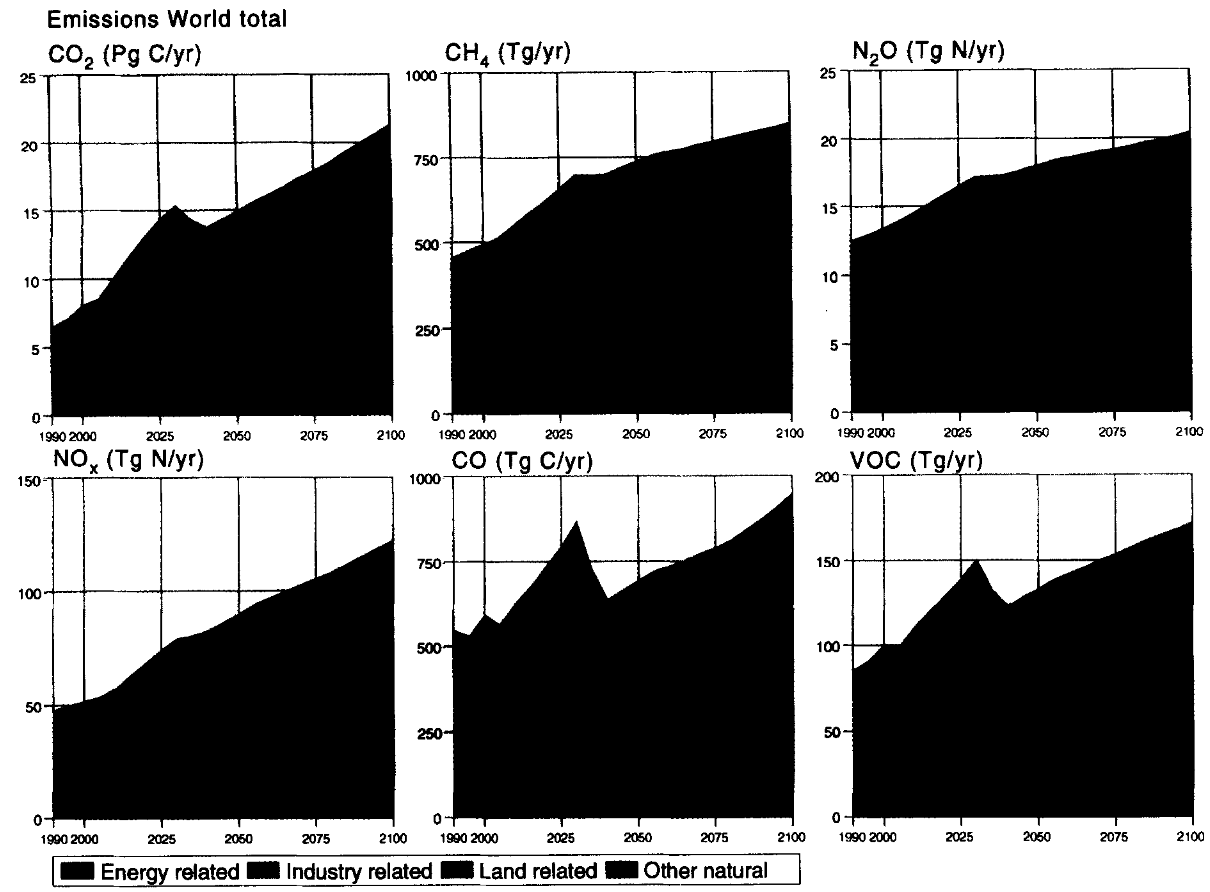

Figure 24. Global emissions of greenhouse gases and ozone precursors Baseline A.

gases is deforestation, which as mentioned above, diminishes over the scenario period.

Energy related sources make up by far the largest part of global CO_2, NO_x, CO and VOC emissions. The use of fossil fuels in the transport sector explains much of the increase in NO_x, CO and VOC, while industry is of primary importance to CO_2. Natural sources (such as emissions by ocean biota and lightning) are an important component of global N_2O, NO_x, and CO emissions.

Figure 25 compares different baseline estimates of global CO_2 emissions, the most important important greenhouse gas (Appendix 1). Emissions in Baseline A, the intermediate scenario, reach 22.0 Gt C/yr in 2100, while Baselines B and C span from 8.5 to 27.8 Gt/yr. Results for Baseline A in 2100 are close to the intermediate IPCC emission scenario (IS92a), but Baselines B and C are much less extreme than the minimum and maximum IPCC scenarios (IS92c and e). This is interesting because Baselines B and C have the same economic and population assumptions as the extreme IPCC scenarios. The difference is caused by the different models and input assumptions used to make these estimates. Although economic growth is substantially higher in Baseline C than B, opposing trends reduce the differences between the scenarios. On one hand, the higher economic level leads to more economic activity which will obviously tend to increase emissions. On the other hand, higher economic growth will lead to a variety of economic effects that will tend to lower emissions. For example, a higher rate of structural change is

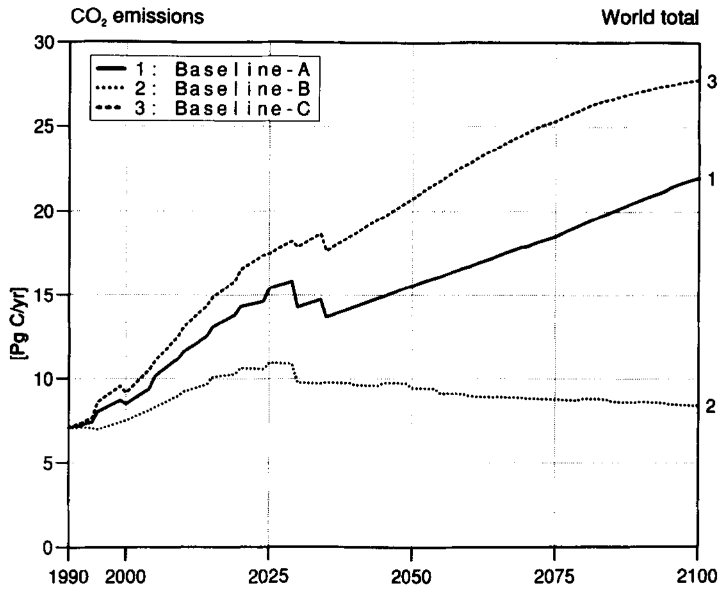

Figure 25. Global emissions of CO_2 for three baseline scenarios.

assumed, and therefore a faster shift will occur from energy intensive heavy industry to lighter industry. In addition, appliances and power plants with a higher rate of energy efficiency will be introduced at a faster rate into the economy. The net effect of these opposing tendencies is that the differences between Baseline A to C in energy use and emissions (Figure 25) is smaller than the differences between corresponding IPCC scenarios with the same economic and population assumptions. In the same way, the Baseline B scenario (the lowest of the three IMAGE baseline scenarios) does not give as low an estimate of CO_2 emissions as the lowest IPCC scenario (IS92c).

Atmosphere, ocean and climate

Change in atmosphere and climate

Changes in emissions and fluxes of gases lead to changes in atmospheric concentrations of various gases. Under Baseline A, CO_2 reaches an atmospheric concentration of 737 ppm, more than twice current levels. Baselines B and C range from 528 to 886 ppm (Figure 26). In Baseline B, although emissions stabilize (Figure 25) concentrations continue to increase because of the long response time of the climate system.

The increase in global average surface temperature between 1990 and 2100 resulting from the buildup of CO_2 and other greenhouse gases is 2.8°C (Figure 27), ranging from approximately 4.0°C in the higher latitudes to 2.5°C in the Tropics. The global average increase for the low and high scenarios are 1.6 and 3.4°C, respectively. The lower economic growth of the low scenario results in a slowing of the growth in global temperature by the second half of the next century. For the two higher baseline scenarios (A and C) the rate of temperature increase is more rapid in the coming decades than between 1970 and 1990 or in the second half of the next century. This is because of the rapid buildup in emissions before that time, and because the driving forces of climate change slow down in the second half of the next century.

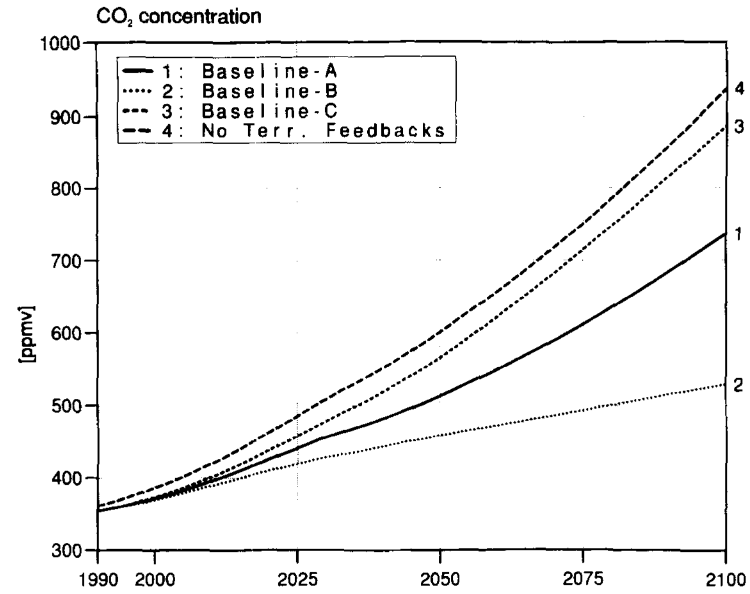

Figure 26. Average atmospheric level of CO_2 for Baselines B and C, and Baseline A with and without climate change included.

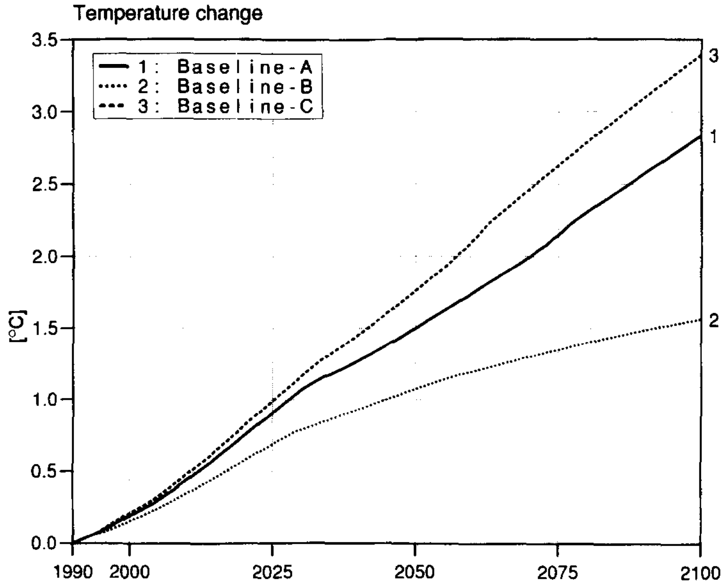

Figure 27. Increase in global average surface temperature relative to 1990 for three baseline scenarios.

Sea level rise

Increased ocean temperatures, together with the melting of glaciers and ice caps lead to an increase in the mean sea level during the scenario period. According to Baseline A, sea level will rise by 43 cm between 1990 and 2100 (Figure 28). The lower and higher scenarios have a range of 32 to 49 cm increase for the same period (Figure 28).

The temporal pattern of sea level rise is different from many other indicators in this paper. For example, it has already been mentioned that the rate of deforestation and global temperature change slows down in the second half of the next century. This is because the driving forces of climate change grow more slowly in this period. In contrast to this trend, sea level rise accelerates in the second half of the twenty-first century because of the slow response time of the ocean to large-scale changes in global climate.

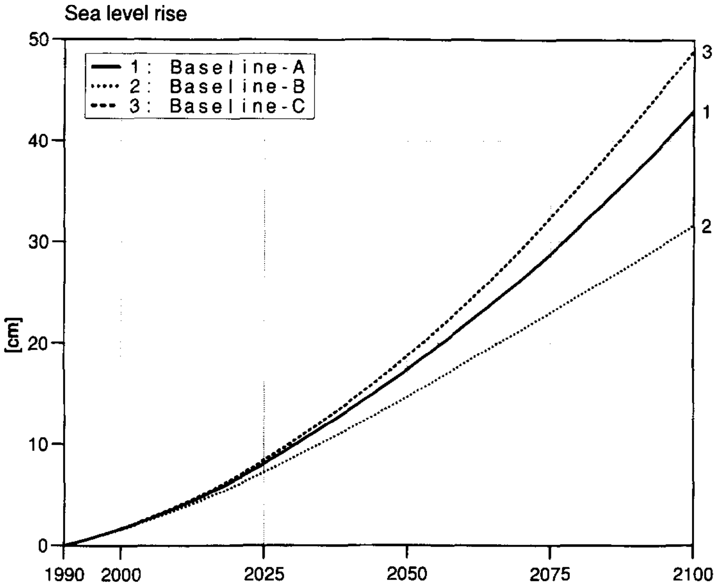

Figure 28. Mean sea level rise relative to 1990 for three baseline scenarios.

Feedbacks between atmosphere, climate and the terrestrial environment

Because IMAGE 2 is an integrated model, it can simulate many of the couplings that occur between the atmosphere, climate and terrestrial environment. These couplings lead to important feedback processes, especially between the atmosphere and terrestrial environment. In the following paragraphs we explain the important impact of these feedback processes on scenario calculations.

Impact on emissions. Emissions of nitrous oxide (N_2O) arise partly from volatilization of organic fertilizers applied to agricultural fields and other soil processes. Since these soil-related emissions change with temperature and precipitation,[28] their long-term trend depends on the rate of climate change. Under Baseline A, land use related emissions of N_2O reach 11.4 Tg/yr in 2100 without climate feedback, and 15.0 Tg/yr with feedbacks included. Hence climate feedbacks have a considerable effect on emissions.

Impact on concentration. Increased surface temperatures tend to dampen the buildup of CO_2 in the atmosphere because of the following feedbacks:

- CO_2 fertilization – increased atmospheric CO_2 increases plant productivity which in turn increases plant uptake of atmospheric CO_2 and dampens the buildup of atmospheric CO_2.
- Soil respiration – changes in average temperature and soil moisture tend to change the decomposition rate of organic matter in soil, and thus the amount of CO_2 released by soil to the atmosphere. This can enhance or dampen the release of CO_2 from the biosphere to the atmosphere.
- Plant productivity – temperature change affects plant productivity, and hence the rate at which plants take up CO_2 from the atmosphere.

The net effect of these feedbacks on the atmospheric concentration of CO_2 is presented in Figure 26. Under Baseline A, atmospheric concentra-

[28]Kreileman and Bouwman, *op cit*, Ref 6

tions reach 937 ppm without feedbacks and 737 ppm if they are included. Hence the feedbacks have a substantial impact on the computed atmospheric concentration of CO_2.

Impact on agricultural land. Changes in temperature and precipitation may either enhance or reduce potential crop productivity and therefore affect the amount of agricultural land required to satisfy food demand. The net effect of this climate feedback is quite different from region to region. For Latin America, climate change tends to lower the demand for agricultural land because climate change has a net positive effect on potential crop productivity in the region's temperate zone (Figure 20). Climate change has the opposite effect on China and Centrally Planned Asia, where more agricultural land is required because of climate change. For the world as a whole, these regional trends tend to compensate, and as a result somewhat less agricultural land is needed with climate change than without.

Discussion and main findings

Scenario estimates have many sources of uncertainty. The uncertainty of scenario calculations stems from many sources, especially the uncertainty of driving forces, and the uncertainty of the structure and parameters of the IMAGE 2 model used for scenario calculations. The testing and uncertainty of the various submodels of IMAGE 2 is discussed in detail elsewhere.[29] Here we concentrate on the effect of uncertain driving forces, ie the assumptions about population, income, activity in economic sectors, and all other factors that must be specified for each scenario. Since each of the baseline scenarios uses a different set of driving forces, the range of baseline results is a rough indicator of the effect of uncertain driving forces on model calculations. Figure 29 shows that baseline calculations of different global change indicators vary by about ±10–60%, depending on the variable. The variation below the median value is much larger than above it, indicating that the medium baseline (Baseline A) may be biased towards the high side of the mean. It should be emphasized that these variations are only caused by the selected range of scenario driving forces, and not because of internal model uncertainty. Moreover, these estimates do not reflect the errors that accumulate in the scenarios as energy calculations are used to estimate emissions, and emissions used to estimate climate change, and so on. These cumulative errors have not yet been investigated.

Many results of the three baseline scenarios tend to converge. Although the three scenarios use quite different assumptions for main driving forces of global change, their results tend to converge. Note, for example, the small variation in baseline estimates of total forest area shown in Figure 29. Indeed, in some cases their temporal trends actually overlap, as in the number of livestock. They tend to converge because of compensating factors. For example, the higher economic growth in Baseline C as compared to A tends to both increase energy consumption because economic activity grows faster, and decrease energy consumption because the efficiency of energy use improves at a faster pace.

The main difference between the baselines is that in Baseline B (the scenario with the lowest economic growth and population) many global

[29]Alcamo, *op cit*, Ref 2

Variation of baseline estimates (Year 2100)

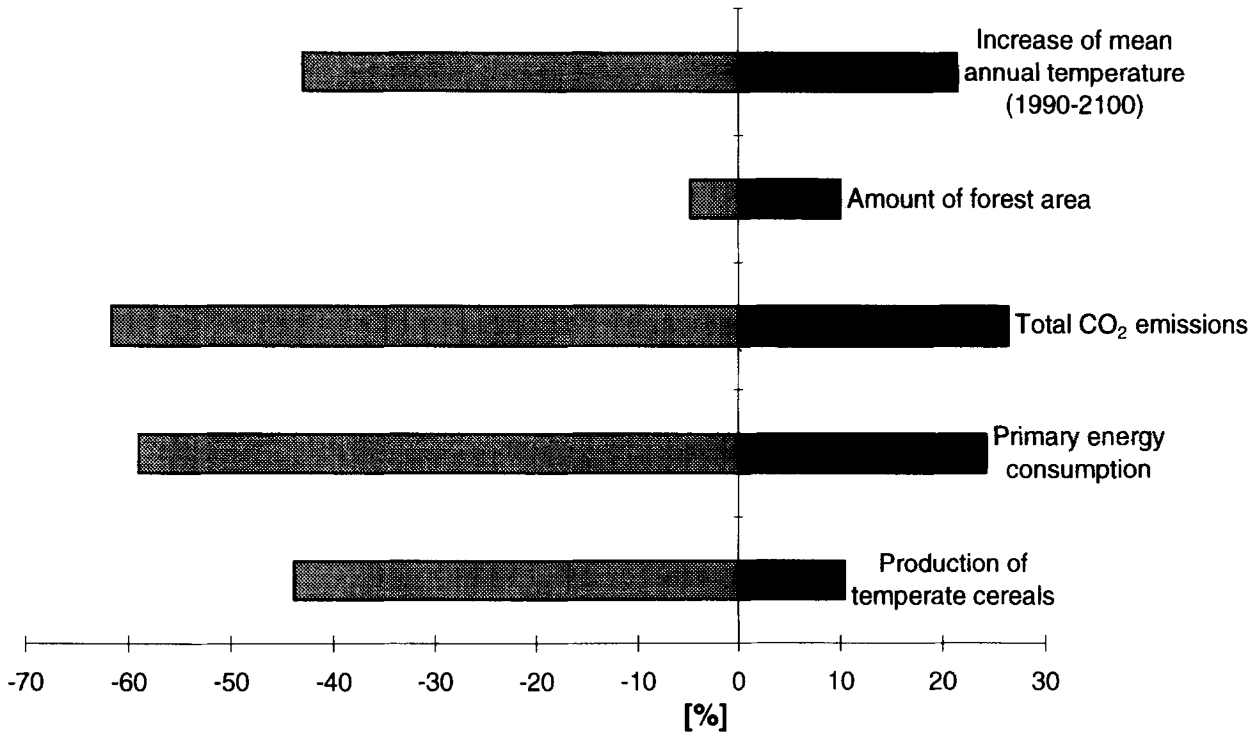

Figure 29. Range of baseline estimates in the year 2100 for various indicators (global averages). The median of these estimates are all Baseline A except for forest area which has a median value from Baseline B.

change indicators tend to stabilize by the middle of next century, but in the other two scenarios they continue to grow. This applies to secondary and primary energy consumption, emissions of many gases, growth in agricultural land, and increase in global temperature.

There are contrasting regional trends in energy consumption. In the baseline scenarios, the combination of many different factors (eg structural changes in regional economies, technological improvements in energy conversion, fuel price increases) has the net effect of substantially decreasing energy intensity of regional economies. In industrialized regions the trend in energy intensity together with the leveling off of population leads to a stabilization of overall energy use in the coming decades. By comparison, the growth of population in developing regions outweighs steady improvements in energy efficiency, with the result that energy consumption steadily grows in the next century, and only slows down in the second half of the century. In the baseline scenarios, this increase in energy consumption is accompanied by a large increase in the emissions of greenhouse gases and other pollutants (Appendix 1).

Agricultural land goes through important expansion or contraction in different parts of the world. Under the baseline scenarios, agriculture continues to intensify in developing regions (eg cereal yields increase by a factor of 2 to 4 by the middle of next century), but this intensification cannot keep up with increasing demand for food and fuelwood.

Hence the amount of agricultural land grows rapidly in developing regions, and only begins to stabilize at the end of next century. In some developing regions land may be inadequate to satisfy the demands for livestock. In industrial regions, the growth in crop yield and stabilization of food demand lead to continued abandonment of agricultural land.

Climate change will affect crop productivity both positively and negatively depending on location, and its net effect will be to increase the demand for land in some regions and decrease it in others.

Large changes occur in the extent of forests and other natural areas. The expansion of agriculture together with climate change will lead to significant changes in forest and other non-agricultural land cover. For the intermediate scenario, we estimate that 34% of the earth's land cover will convert from one major type to another between 1990 and 2100. This will have profound implications on the viability of natural ecosystems and the prospects of maintaining current biological diversity.

Under the baseline scenarios, climate change enlarges the size of forests (less agricultural land needed and replaced partly by forests). At the same time it also increases forest area under risk because local climate becomes unfavourable for the current forest types.

Feedbacks are important in the global system. Important feedback processes occur in the global system because of interactions between the atmsophere, climate and terrestrial environment. These feedback processes can have an important impact on scenario calculations of emissions, atmospheric levels of gases, extent of agricultural land, and other indicators of global environmental change. For that reason they should be taken into account in baseline studies.

The pace of global environmental change may be higher in the coming decades than before or after. Under the baseline scenarios many important indicators of the global environment will change more rapidly in the coming decades than in the period before or after (Figure 30). For example, under Baseline A, global surface temperature increases by 0.30 per decade up to 2030 and 0.25 per decade afterwards. Also, between 1990 and 2030, the number of livestock in the world increases by a factor of 2, the amount of agricultural land by a 33%, and the deforestation rate is comparable with current rates. The pace of change will be much faster in developing countries than in industrialized countries, but the loss of forests and natural areas are of global concern. The pace of change is even faster in the high baseline scenario, although it is somewhat slower for most indicators in the low scenario. This rapid change arises mainly from scenario assumptions about population and economic growth. But it should be noted that these assumptions are consistent with conventional projections of population and income.

Closing remarks

The baseline scenarios in this paper are an effort to fill in some of the gaps in the complex picture of future global environmental changes. They show some of the couplings between components of the global

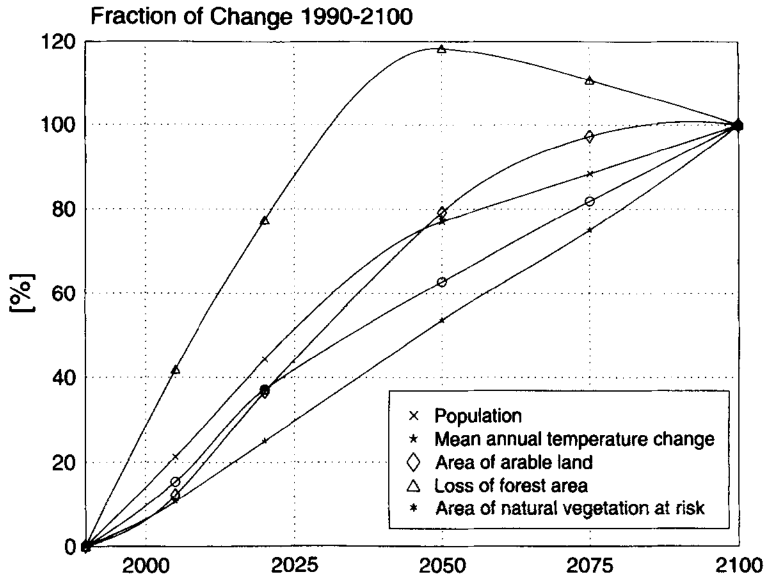

Figure 30. Temporal trends of various global change indicators in Baseline A. Note units have been normalized.

system, and the implications these couplings could have on the global society and environment. They also give insight into trends that may continue or newly emerge in the absence of international policy intervention. In so doing, these baseline scenarios also point out where policy intervention may be especially important:

- To avoid high energy use and emissions in particular from the future industry and transport sectors in both industrialized and developing regions.
- To protect natural vegetation in the northern and southern temperate zones from climate changes.
- To protect natural vegetation in the tropics and developing countries from expanding agriculture.
- To slow down the especially rapid pace of global environmental change that may occur in the coming decades.

Appendix

Overview of the global emissions for several air-pollutants and greenhouse gases for the different baseline scenarios

Table A1. Baseline A

Regions	CH_4 (Tg CH_4/yr) 1990	2010	2025	2050	2100	CO (Tg C/yr) 1990	2010	2025	2050	2100
Canada	22.2	22.7	22.7	22.3	21.9	2.9	3.0	3.0	3.0	3.6
USA	38.3	44.5	49.8	44.1	40.1	26.2	27.4	56.9	26.2	33.7
Latin America	50.9	62.8	69.7	67.9	60.4	80.8	99.4	102.5	79.8	95.3
Africa	46.3	72.8	109.0	116.7	173.3	98.9	177.2	246.3	68.1	128.2
OECD Europe	28.4	30.9	32.1	30.2	27.6	37.2	23.1	24.4	22.1	27.4
EEU	10.6	14.8	18.9	17.8	16.3	10.4	11.4	13.6	13.5	16.7
CIS	83.9	86.4	95.9	91.7	86.9	30.4	37.1	55.8	59.5	77.6
Middle East	16.3	30.2	39.2	55.6	77.4	18.7	36.6	53.0	95.0	176.9
India + S Asia	50.8	66.7	82.4	103.5	128.4	45.5	57.2	71.8	80.5	104.4
China + C P Asia	50.6	68.3	83.7	102.9	124.8	73.3	78.9	108.9	132.4	152.5
East Asia	24.3	33.9	40.5	48.9	53.5	25.2	43.7	52.6	55.4	79.8
Oceania	10.3	10.9	10.2	9.6	9.1	5.9	4.6	5.3	5.6	6.8
Japan	3.4	3.6	4.3	4.2	3.8	3.4	4.0	4.0	4.7	6.1
World	436.2	547.4	658.4	715.1	823.2	458.7	603.6	797.9	646.0	908.9
	CO_2 (Pg C/yr)					**N_2O (Tg N/yr)**				
Canada	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.3
USA	1.5	2.2	2.4	2.0	2.0	0.8	1.0	1.0	1.0	1.2
Latin America	0.5	0.7	1.0	0.9	1.1	2.8	3.1	3.4	3.6	3.9
Africa	0.3	1.3	2.6	1.2	2.9	2.3	2.8	3.5	3.3	4.0
OECD Europe	1.1	1.5	1.5	1.4	1.3	0.5	0.7	0.7	0.7	0.7
EEU	0.3	0.5	0.7	0.6	0.6	0.2	0.2	0.2	0.2	0.2
CIS	1.0	1.2	1.6	1.6	1.6	0.7	0.8	0.9	1.0	1.2
Middle East	0.2	0.5	0.7	1.1	2.0	0.2	0.3	0.4	0.7	1.0
India + S Asia	0.2	0.6	1.0	1.8	3.5	0.8	1.2	1.5	1.8	1.9
China + C P Asia	1.0	1.7	2.4	3.2	4.5	1.1	1.4	1.7	2.1	2.3
East Asia	0.3	0.6	0.7	0.9	1.5	0.7	0.9	1.0	1.2	1.3
Oceania	0.1	0.2	0.1	0.1	0.1	0.3	0.4	0.4	0.4	0.6
Japan	0.3	0.5	0.5	0.5	0.6	0.1	0.1	0.1	0.1	0.1
World	7.1	11.6	15.4	15.6	22.0	10.7	13.0	15.0	16.2	18.5
	NO_x (Tg N/yr)									
Canada	0.5	0.5	0.5	0.4	0.5					
USA	5.6	6.3	6.5	5.9	5.4					
Latin America	2.1	2.9	4.0	5.2	6.1					
Africa	1.9	3.4	6.3	7.6	17.1					
OECD Europe	2.3	1.9	2.0	1.8	1.6					
EEU	1.9	2.6	3.6	3.4	2.8					
CIS	4.3	5.2	7.9	7.8	7.8					
Middle East	1.6	3.1	4.7	8.5	16.0					
India + S Asia	1.6	3.3	5.5	11.1	20.4					
China + C P Asia	3.9	8.3	11.9	14.6	17.5					
East Asia	1.1	2.9	3.4	4.9	7.4					
Oceania	0.5	0.5	0.5	0.5	0.6					
Japan	1.4	1.1	1.1	1.2	1.6					
World	28.8	41.9	57.9	73.0	104.7					
	VOC (Tg VOC/yr)									
Canada	1.4	1.6	1.6	1.5	1.4					
USA	14.7	16.1	19.5	15.2	15.4					
Latin America	12.0	14.8	16.0	14.1	15.8					
Africa	13.9	24.3	34.3	13.5	24.7					
OECD Europe	8.1	9.3	9.6	8.4	8.3					
EEU	1.6	1.8	2.0	2.1	2.4					
CIS	8.4	9.3	12.4	12.3	11.6					
Middle East	3.4	6.2	8.5	13.2	17.9					
India + S Asia	6.9	9.3	12.9	17.1	22.7					
China + C P Asia	11.6	13.0	16.4	21.4	31.8					
East Asia	4.2	7.4	9.0	9.9	11.3					
Oceania	1.3	1.4	1.5	1.5	1.5					
Japan	3.8	6.0	7.0	8.3	10.0					
World	91.1	120.6	150.7	138.5	174.8					

Table A2. Baseline B

Regions	CH_4 ($Tg\ CH_4/yr$) 1990	2010	2025	2050	2100	CO (Tg C/yr) 1990	2010	2025	2050	2100
Canada	22.2	22.3	22.1	21.4	20.3	2.9	2.7	2.6	2.3	1.9
USA	38.3	41.2	43.8	36.6	27.4	26.2	25.0	44.2	20.0	18.7
Latin America	50.9	58.0	66.5	62.4	57.6	80.8	86.8	110.4	69.8	90.2
Africa	46.3	60.3	80.4	92.7	107.2	98.9	123.5	164.2	111.4	87.0
OECD Europe	28.4	29.9	30.2	26.0	18.5	37.2	22.0	20.9	16.7	13.4
EEU	10.6	14.1	15.6	12.6	7.4	10.4	10.5	11.0	8.4	4.6
CIS	83.9	82.9	84.8	75.0	61.6	30.4	32.6	41.5	38.0	35.5
Middle East	16.3	24.7	29.2	33.2	31.9	18.7	28.7	35.5	50.6	64.9
India + S Asia	50.8	61.2	70.2	76.3	65.6	45.5	51.7	56.6	65.3	75.2
China + C P Asia	50.6	61.6	71.5	75.9	67.8	73.3	68.4	86.0	89.4	73.2
East Asia	24.3	31.9	37.3	39.4	32.1	25.2	38.4	46.1	42.0	43.4
Oceania	10.3	10.5	9.8	8.2	7.3	5.9	4.3	5.0	5.3	10.6
Japan	3.4	3.5	4.0	3.3	2.6	3.4	3.7	4.0	3.0	2.5
World	436.2	501.9	565.3	562.9	507.3	458.7	498.3	627.9	522.1	521.0
	CO_2 (Pg C/yr)					N_2O (Tg N/yr)				
Canada	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
USA	1.5	1.9	1.8	1.3	1.0	0.8	0.9	0.9	0.8	0.7
Latin America	0.5	0.6	0.9	0.6	0.8	2.8	3.0	3.3	3.3	3.4
Africa	0.3	0.7	1.3	1.0	1.0	2.3	2.5	2.9	3.1	3.4
OECD Europe	1.1	1.3	1.2	1.0	0.6	0.5	0.6	0.6	0.5	0.4
EEU	0.3	0.5	0.5	0.4	0.2	0.2	0.2	0.2	0.2	0.1
CIS	1.0	1.0	1.2	0.9	0.6	0.7	0.7	0.8	0.9	1.8
Middle East	0.2	0.3	0.4	0.6	0.7	0.2	0.2	0.3	0.5	0.5
India + S Asia	0.2	0.4	0.6	0.9	1.1	0.8	1.1	1.3	1.4	1.2
China + C P Asia	1.0	1.3	1.7	1.8	1.5	1.1	1.4	1.6	1.8	1.7
East Asia	0.3	0.5	0.5	0.5	0.6	0.7	0.9	1.0	1.0	0.9
Oceania	0.1	0.1	0.1	0.1	0.1	0.3	0.4	0.4	0.4	0.3
Japan	0.3	0.4	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1
World	7.1	9.3	10.9	9.5	8.5	10.7	12.2	13.7	14.2	13.6
	NO_x (Tg N/yr)									
Canada	0.5	0.4	0.4	0.3	0.2					
USA	5.6	5.4	5.2	4.1	2.9					
Latin America	2.1	2.5	3.4	3.6	5.1					
Africa	1.9	2.4	3.7	4.0	6.3					
OECD Europe	2.3	1.7	1.7	1.4	0.9					
EEU	1.9	2.4	2.7	1.9	0.8					
CIS	4.3	4.6	5.6	4.6	3.3					
Middle East	1.6	2.4	3.0	4.3	5.6					
India + S Asia	1.6	2.6	3.7	5.6	6.7					
China + C P Asia	3.9	6.5	8.4	8.4	6.4					
East Asia	1.1	2.5	2.9	3.2	3.4					
Oceania	0.5	0.5	0.5	0.4	0.3					
Japan	1.4	1.0	0.9	0.8	0.6					
World	28.8	35.0	42.2	42.7	42.7					
	VOC (Tg VOC/yr)									
Canada	1.4	1.4	1.4	1.1	0.8					
USA	14.7	14.7	16.1	11.1	8.3					
Latin America	12.0	12.9	16.3	11.5	13.9					
Africa	13.9	17.1	22.7	16.6	13.8					
OECD Europe	8.1	8.6	8.3	6.6	4.0					
EEU	1.6	1.7	1.8	1.5	1.0					
CIS	8.4	8.5	9.7	8.5	6.0					
Middle East	3.4	4.9	5.8	7.0	6.4					
India + S Asia	6.9	8.2	9.7	11.8	13.2					
China + C P Asia	11.6	11.2	12.8	13.6	13.6					
East Asia	4.2	6.5	7.8	7.2	6.5					
Oceania	1.3	1.3	1.4	1.2	1.7					
Japan	3.8	5.2	5.6	4.9	3.5					
World	91.1	102.3	119.4	102.7	92.5					

Table A3. Baseline C

Regions	CH_4 (Tg CH_4/yr) 1990	2010	2025	2050	2100	CO (Tg C/yr) 1990	2010	2025	2050	2100
Canada	22.2	22.7	22.5	22.1	22.0	2.9	3.0	3.0	3.0	3.7
USA	38.3	45.3	49.1	44.1	40.4	26.2	27.4	46.2	26.0	33.4
Latin America	50.9	60.1	67.0	66.2	63.8	80.8	69.0	76.4	91.4	94.4
Africa	46.3	76.8	115.3	147.2	198.1	98.9	180.9	203.5	82.5	151.1
OECD Europe	28.4	31.1	32.0	30.4	28.3	37.2	23.4	24.6	20.6	26.0
EEU	10.6	18.0	21.9	21.6	25.2	10.4	12.7	15.3	16.8	31.2
CIS	83.9	99.4	105.3	102.6	95.7	30.4	49.4	63.8	65.5	77.6
Middle East	16.3	32.5	43.5	60.6	85.7	18.7	39.8	57.2	103.9	177.1
India + S Asia	50.8	68.1	85.9	113.1	131.6	45.5	63.2	75.4	94.4	116.7
China + C P Asia	50.6	74.1	95.3	121.6	161.1	73.3	88.8	132.1	162.4	202.8
East Asia	24.3	34.0	39.9	49.6	53.0	25.2	43.4	49.8	59.3	84.5
Oceania	10.3	10.9	10.1	9.5	9.3	5.9	5.1	5.6	6.1	8.0
Japan	3.4	3.7	4.6	4.6	4.3	3.4	4.3	4.9	5.2	7.5
World	436.2	576.5	692.3	793.2	918.5	458.7	610.4	757.9	737.2	1013.9

Regions	CO_2 (Pg C/yr) 1990	2010	2025	2050	2100	N_2O (Tg N/yr) 1990	2010	2025	2050	2100
Canada	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.3
USA	1.5	2.4	2.5	2.1	2.1	0.8	1.0	1.0	1.1	1.2
Latin America	0.5	0.5	0.8	1.1	1.3	2.8	3.0	3.2	3.5	4.0
Africa	0.3	1.5	2.4	2.2	3.6	2.3	2.9	3.5	3.6	4.4
OECD Europe	1.1	1.6	1.6	1.3	1.4	0.5	0.7	0.7	0.7	0.8
EEU	0.3	0.7	0.9	0.9	1.0	0.2	0.2	0.2	0.2	0.2
CIS	1.0	1.6	2.0	2.1	2.2	0.7	0.8	0.9	1.0	1.3
Middle East	0.2	0.5	0.7	1.2	2.2	0.2	0.3	0.4	0.7	1.1
India + S Asia	0.2	0.8	1.5	3.1	4.6	0.8	1.3	1.5	1.9	1.8
China + C P Asia	1.0	2.1	3.2	4.5	6.1	1.1	1.5	1.8	2.3	2.5
East Asia	0.3	0.6	0.9	1.3	1.9	0.7	0.9	1.0	1.1	1.3
Oceania	0.1	0.2	0.2	0.1	0.1	0.3	0.4	0.4	0.4	0.5
Japan	0.3	0.6	0.6	0.6	0.9	0.1	0.1	0.1	0.1	0.2
World	7.1	13.1	17.5	20.7	27.8	10.7	13.1	15.0	16.8	19.7

Regions	NO_x (Tg N/yr) 1990	2010	2025	2050	2100
Canada	0.5	0.5	0.5	0.4	0.5
USA	5.6	6.7	7.0	6.0	5.2
Latin America	2.1	2.8	4.3	6.2	6.5
Africa	1.9	3.9	7.4	11.9	20.1
OECD Europe	2.3	2.0	2.2	1.9	1.8
EEU	1.9	3.5	4.4	4.3	4.0
CIS	4.3	7.4	9.8	10.2	10.2
Middle East	1.6	3.4	5.2	9.4	16.3
India + S Asia	1.6	4.3	8.2	17.8	25.4
China + C P Asia	3.9	10.1	15.3	19.4	24.5
East Asia	1.1	3.1	4.2	5.9	8.1
Oceania	0.5	0.5	0.5	0.5	0.6
Japan	1.4	1.2	1.2	1.4	2.1
World	28.8	49.4	70.1	95.3	125.2

Regions	VOC (Tg VOC/yr) 1990	2010	2025	2050	2100
Canada	1.4	1.6	1.6	1.5	1.6
USA	14.7	16.5	18.8	16.0	17.6
Latin America	12.0	11.3	13.5	17.0	16.1
Africa	13.9	25.0	29.6	17.6	29.7
OECD Europe	8.1	9.7	9.8	8.7	11.7
EEU	1.6	2.0	2.3	2.7	4.4
CIS	8.4	11.8	14.1	14.0	13.0
Middle East	3.4	6.7	9.3	14.7	19.6
India + S Asia	6.9	10.7	14.7	21.7	23.3
China + C P Asia	11.6	14.9	20.0	28.1	42.7
East Asia	4.2	7.5	8.9	10.6	13.7
Oceania	1.3	1.5	1.6	1.6	1.8
Japan	3.8	6.6	8.2	10.5	14.3
World	91.1	125.8	152.4	164.8	209.4