MIT Joint Program on the Science and Policy of Global Change

Emissions Inventories and Time Trends for Greenhouse Gases and other Pollutants

Monika Mayer, Rob Hyman, Jochen Harnisch and John M. Reilly

Technical Note No. 1

July 2000

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To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

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Postal Address: Joint Program on the Science and Policy of Global Change
MIT E40-271
77 Massachusetts Avenue
Cambridge MA 02139-4307 (USA)

Location: One Amherst Street, Cambridge
Building E40, Room 271
Massachusetts Institute of Technology

Access: Phone: (617) 253-7492
Fax: (617) 253-9845
E-mail: globalchange@mit.edu
Web site: http://mit.edu/globalchange/

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Abstract

We provide details on the development of greenhouse gas and other pollutant inventories for 1995 that are used in the MIT Emissions Prediction and Policy Analysis (EPPA) model. The 1995 inventories developed here are the basis for developing emissions coefficients (emissions per unit of economic activity by sector). For a variety of reasons that vary depending on the particular pollutant, we expect these coefficients to change over time. We provide details on the methods we used to estimate how these coefficients change over time. The greenhouse gases and pollutants discussed include: methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), other nitrogen oxides (NO_x) sulfur dioxide (SO_2), carbon monoxide (CO), non-methane volatile organic carbon (NMVOC), black carbon (BC), organic carbon (OC), and ammonia (NH_3). This technical note is aimed a documenting in detail the approaches used in developing emissions inventory to facilitate the process of updating and improving the accuracy of the inventory as data and measurement improve. There remain substantial uncertainties in even the current estimates of anthropogenic sources of many of these emissions.

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[1] Corresponding author: jreilly@mit.edu. The authors were all with the MIT Joint Program on the Science and Policy of Global Change at the time of publication. Mayer is now with AVL List GmbH, Graz, Austria; Hyman is at the U.S. Environmental Protection Agency; Harnisch is with ECOFYS energy & environment, Energy Technologies Centre (ETZ), Nuremberg, Germany.

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1. Estimation of Agricultural Emissions of Methane and Nitrous Oxide

CH_4 and N_2O emissions tied to the EPPA sector AGRIC include emissions from the following anthropogenic sources:

1) Emissions from harvested land (rice paddies, synthetic nitrogen fertilizer, manure, leaching, etc.)
2) Emissions from animal management (enteric fermentation, manure)
3) Large scale biomass burning

Hereinafter emissions from 1) and 2) are referred to as agricultural emissions.

For 1995 estimates of CH_4 and N_2O agricultural emissions we used inventories by ICF Consulting Group, *U.S. EPA* [1999], and the Australian Bureau of Agricultural and Resource Economics (ABARE) (Brown et al. [1999]). Large scale biomass burning emissions were derived from the EDGAR (*Olivier et al.*, [1995]) inventory. The EDGAR estimates are for 1990. We use these biomass burning emissions unaltered for 1995 as well as for future projections.

For each of the 12 regions *r* we assume the sum of agricultural and biomass burning emissions to be proportional to the output of the production of the EPPA sector AGRIC.

$$E_{N2O,r} = C_{n,r} \text{ x } AGRIC_r \qquad (1)$$

$$E_{CH4,r} = C_{m,r} \text{ x } AGRIC_r \qquad (2)$$

$E_{N2O,r}$ and $E_{CH4,r}$ are the regional emissions of nitrous oxide and methane, respectively. The regional coefficients $C_{m,r}$ (for methane) and $C_{n,r}$ (for nitrous oxide) were derived for 1995 by employing ICF's, ABARE's and EPA's emission estimates and EPPA's agricultural output data. The coefficients $C_{m,r}$ and $C_{n,r}$ are likely to change over time. Given that the process related emission coefficients do not change (e.g. per dairy cow we have always the same CH_4 emissions per year) we expect the relative contribution of the single sources to vary in future (e.g. livestock might grow faster than harvested area) and therefore the total emissions of each source will change differently over time. Altering contributions of different subsectors of the AGRIC production sector will be reflected in a change of our coefficients $C_{m,r}$ and $C_{n,r}$. In order to estimate the time behavior of $C_{m,r}$ and $C_{n,r}$, we projected agricultural emissions based on possible future development of the activity level of the factors determining methane and nitrous oxide emissions. The following emission sources were taken into account:

- Harvested rice area (flooded rice fields) -> for CH_4 emissions
- Harvested area -> for N_2O emissions
- Synthetic nitrogen fertilizer use -> for N_2O emissions
- Ruminant and non-ruminant livestock -> for CH_4 and N_2O emissions

The emissions are always calculated as follows:

$$\text{Emissions} = \text{activity level x emission factor} \qquad (3)$$

For each source and gas the emissions are derived on an annual basis. We assume that only the activity levels (harvested area, harvested rice area, N-fertilizer, livestock) change over time but not the emission factors itself. *FAO*'s statistical database was used to derive for each of the 12 regions harvested area, harvested paddy rice area, rice yields, N-fertilizer use, ruminants, non-ruminants for 1995. (FAO data are on a country basis; at the time of the study available from 1961 to 1999). Growth rates were determined as well (for the time period from 1990 – 1999) in order to have an indicator for recent trends. Future projections of all activity levels are based on published estimates as far as possible (for detailed references see following sections). Projections found in the literature do not go beyond 2030. For this study it was assumed that after 2030 growth rates will remain at the 2030 level.

1.1. Harvested Area

For the period from 1995 to 2030 the expert judgment of *Brown* [1995], *Oram and Hojjati* [1995] and the paper of *Nevision et al*. [1996] provided guidelines for the estimates of harvested area. For the EPPA regions EEX and ROW we had to extrapolate from existing estimates for Africa, Middle East, and Latin America. The available expert estimates are based on modeling of potential arable land (e.g. *FAO*), past experience in developed countries (incl. soil erosion, salination, water management) and sustainability. Experts believe that except for the OOE developed countries will not expand their harvested area. For China the latest data by IIASA (based on remote sensing) were used, and the harvested area is therefore larger than older estimates. This confirms earlier opinions that China's harvested area was underestimated *Heilig* [1999].

Table 1: Harvested cereal area in 10^6 ha

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	59.0	2.4	47.4	36.1	26.2	94.0	137.4	132.5	100.1	18.2	19.7	62.4	735.3
2000	59.0	2.4	47.6	36.1	26.2	94.2	142.9	132.7	100.3	18.2	19.8	64.9	744.3
2010	59.0	2.4	48.1	36.1	26.2	94.7	154.5	133.1	100.6	18.3	19.9	70.4	763.3
2020	59.0	2.4	48.6	36.1	26.2	95.2	167.0	133.5	101.0	18.4	20.0	76.4	783.7
2030	59.0	2.4	49.1	36.1	26.2	95.6	180.6	133.9	101.4	18.5	20.1	82.8	805.6
2040	59.0	2.4	49.6	36.1	26.2	96.1	195.2	134.3	101.7	18.6	20.2	89.8	829.2
2050	59.0	2.4	50.1	36.1	26.2	96.6	211.1	134.7	102.1	18.7	20.3	97.4	854.5
2060	59.0	2.4	50.6	36.1	26.2	97.1	228.2	135.1	102.5	18.8	20.4	105.6	881.8
2070	59.0	2.4	51.1	36.1	26.2	97.6	246.7	135.5	102.8	18.9	20.5	114.5	911.2
2080	59.0	2.4	51.6	36.1	26.2	98.1	266.7	135.9	103.2	19.0	20.6	124.1	942.9
2090	59.0	2.4	52.1	36.1	26.2	98.5	288.3	136.3	103.6	19.1	20.7	134.6	977.0
2100	59.0	2.4	52.6	36.1	26.2	99.0	311.7	136.7	104.0	19.2	20.8	146.0	1013.7

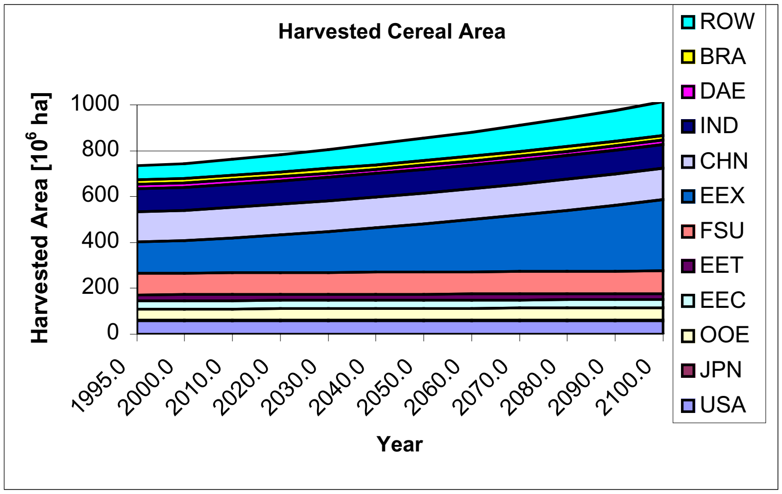

Figure 1: Harvested cereal area in 10^6 ha

1.2. Harvested Paddy Rice Area

The projections of harvested paddy rice area are very similar to the ones for total harvested cereal area. Unless there were was additional information available the growth rates are the same as for total harvested cereal area. One of the important differences is China where harvested rice area declined over the last decade (*FAO* data). Also *Oram and Hojjati* [1995] data indicate a decrease in rice paddies in China for that time period. In this study harvested area was kept constant for China.

Table 2: Harvested Rice Area in 10^6 ha

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	1.25	2.12	0.12	0.37	0.01	0.50	25.73	31.11	42.91	13.93	4.38	27.18	149.60
2000	1.25	2.12	0.12	0.37	0.01	0.50	26.75	31.11	43.02	13.98	4.38	28.29	151.89
2010	1.25	2.12	0.12	0.37	0.01	0.50	28.92	31.11	43.23	14.10	4.38	30.64	156.76
2020	1.25	2.12	0.12	0.37	0.01	0.51	31.27	31.11	43.45	14.21	4.39	33.19	161.99
2030	1.25	2.12	0.12	0.37	0.01	0.51	33.81	31.11	43.67	14.32	4.39	35.96	167.63
2040	1.25	2.12	0.12	0.37	0.01	0.51	36.55	31.11	43.89	14.44	4.39	38.95	173.71
2050	1.25	2.12	0.13	0.37	0.01	0.51	39.51	31.11	44.11	14.55	4.40	42.20	180.27
2060	1.25	2.12	0.13	0.37	0.01	0.52	42.72	31.11	44.33	14.67	4.40	45.71	187.33
2070	1.25	2.12	0.13	0.37	0.01	0.52	46.19	31.11	44.55	14.79	4.41	49.52	194.95
2080	1.25	2.12	0.13	0.37	0.01	0.52	49.93	31.11	44.77	14.91	4.41	53.64	203.18
2090	1.25	2.12	0.13	0.37	0.01	0.53	53.98	31.11	45.00	15.03	4.42	58.11	212.05
2100	1.25	2.12	0.13	0.37	0.01	0.53	58.36	31.11	45.22	15.15	4.42	62.95	221.62

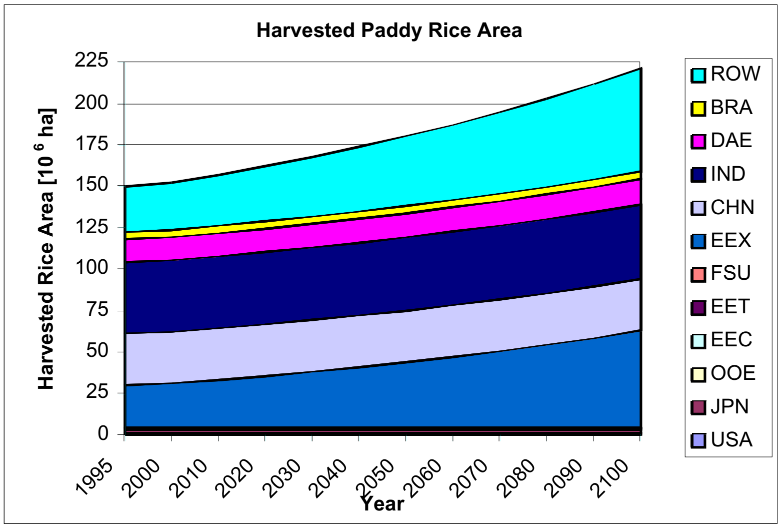

Figure 2: Harvested Rice Area in 10^6 ha

1.3. Paddy Rice Yields

Projections for the paddy rice yields are based on *FAO* [1993] data (projections through 2010) and past growth rates from *FAO*. For future projections *FAO*, [1993] distinguishes only between developed and developing countries. The current record yield is about 8 tons/ha (Australia).

Table 3: Paddy rice yields in tons/ha

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
1995	6.6	6.3	7.2	5.8	3.8	2.3	3.0	6.0	2.7	2.8	2.6	3.1
2000	7.0	6.4	7.6	6.0	4.1	2.5	3.3	6.3	3.1	3.0	2.8	3.4
2010	7.3	6.5	8.0	6.4	4.4	2.7	3.7	6.7	3.6	3.3	3.1	3.8
2020	7.7	6.5	8.4	6.7	4.8	3.0	4.2	7.0	4.1	3.5	3.5	4.3
2030	8.1	6.6	8.8	7.0	5.2	3.2	4.7	7.4	4.7	3.8	3.8	4.8
2040	8.5	6.7	9.2	7.4	5.6	3.5	5.2	7.7	5.4	4.1	4.2	5.3
2050	8.9	6.7	9.7	7.8	6.1	3.8	5.8	8.1	6.2	4.5	4.7	5.9
2060	9.4	6.8	10.2	8.2	6.6	4.1	6.5	8.5	7.1	4.8	5.2	6.6
2070	9.9	6.9	10.7	8.6	7.1	4.4	7.2	9.0	8.2	5.2	5.7	7.4
2080	10.4	6.9	11.3	9.0	7.7	4.8	8.1	9.4	9.4	5.6	6.3	8.2
2090	10.9	7.0	11.9	9.5	8.3	5.2	9.0	9.9	10.8	6.1	7.0	9.2
2100	11.5	7.1	12.5	10.0	9.0	5.6	10.1	10.4	12.4	6.6	7.7	10.3

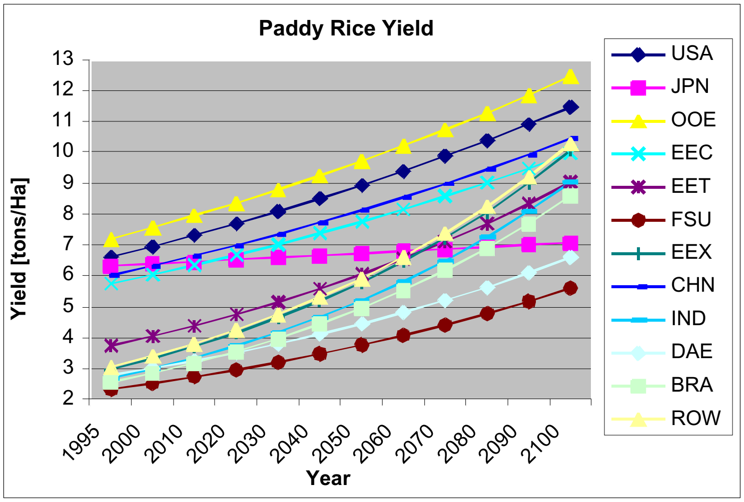

Figure 3: Paddy rice yields in tons/ha

1.4. Nitrogen Fertilizer Use

The projections are based on *Daberkow et al.* [1999] and *FAO* total N-fertilizer consumption data; 1995 values are from *FAO*.

Table 4: Nitrogen Fertilizer use (all crops) in million tons per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	11.2	0.5	3.6	9.5	2.0	2.7	7.1	23.4	9.8	1.7	1.2	5.3	77.9
2000	11.5	0.5	3.8	9.6	2.2	2.8	7.6	23.8	10.4	1.8	1.2	5.5	80.6
2010	12.2	0.5	4.0	9.7	2.5	3.0	8.7	24.6	11.8	2.0	1.4	5.9	86.4
2020	13.0	0.5	4.3	9.9	2.8	3.3	9.9	25.5	13.3	2.2	1.5	6.4	92.7
2030	13.8	0.6	4.7	10.0	3.2	3.6	11.2	26.4	14.9	2.5	1.7	7.0	99.6
2040	14.6	0.6	5.0	10.2	3.6	4.0	12.8	27.4	16.9	2.8	1.9	7.6	107.3
2050	15.5	0.6	5.4	10.4	4.1	4.4	14.6	28.3	19.0	3.2	2.1	8.2	115.7
2060	16.5	0.6	5.7	10.5	4.7	4.8	16.6	29.4	21.4	3.6	2.4	8.9	125.0
2070	17.5	0.6	6.2	10.7	5.4	5.2	18.9	30.4	24.2	4.1	2.6	9.6	135.3
2080	18.6	0.6	6.6	10.8	6.1	5.7	21.5	31.5	27.2	4.6	2.9	10.4	146.6
2090	19.7	0.6	7.1	11.0	7.0	6.2	24.5	32.6	30.7	5.2	3.3	11.3	159.2
2100	21.0	0.6	7.6	11.2	7.9	6.8	27.9	33.8	34.6	5.8	3.7	12.2	173.1

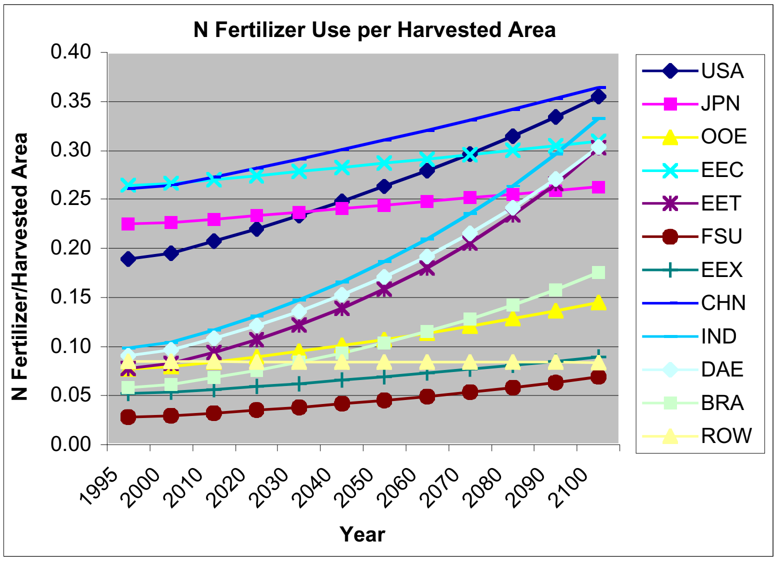

Figure 4a: Nitrogen Fertilizer use per Harvested Acre

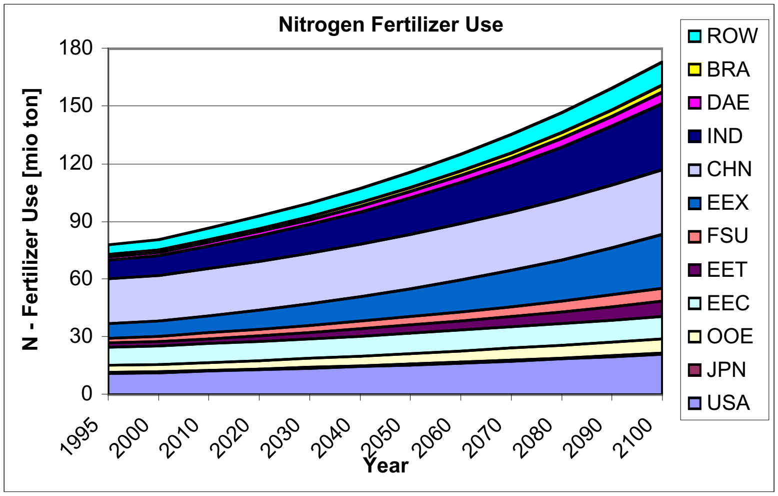

Figure 4b: Nitrogen Fertilizer use

1.5. Livestock

Projections for ruminants and non ruminants are derived from *Agcaoili and Rosegrant* [1995]; 1995 data are from *FAO*.

Table 5: Ruminant projections in million of head per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	113.6	5.0	282.4	209.1	48.3	189.5	974.8	364.7	469.4	26.0	181.3	390.3	3254.3
2000	115.9	5.1	288.1	213.4	49.3	193.3	1019.6	377.7	486.2	26.9	186.8	404.2	3366.4
2010	120.7	5.3	299.8	222.1	51.3	201.2	1115.6	405.1	521.4	28.9	198.4	433.5	3603.1
2020	125.6	5.5	312.1	231.1	53.4	209.4	1220.7	434.4	559.2	31.0	210.6	464.9	3857.9
2030	130.7	5.7	324.8	240.6	55.5	217.9	1335.7	465.9	599.8	33.2	223.6	498.6	4132.1
2040	136.0	5.9	338.1	250.4	57.8	226.8	1461.5	499.7	643.3	35.6	237.5	534.8	4427.4
2050	141.6	6.2	351.9	260.6	60.2	236.1	1599.1	535.9	689.9	38.2	252.2	573.6	4745.4
2060	147.4	6.4	366.2	271.2	62.6	245.7	1749.7	574.8	739.9	41.0	267.8	615.2	5087.9
2070	153.4	6.7	381.2	282.3	65.2	255.8	1914.5	616.5	793.6	43.9	284.3	659.8	5457.0
2080	159.6	7.0	396.7	293.8	67.8	266.2	2094.8	661.2	851.1	47.1	301.9	707.6	5854.8
2090	166.2	7.3	412.9	305.8	70.6	277.1	2292.0	709.1	912.8	50.5	320.6	758.9	6283.8
2100	172.9	7.6	429.8	318.3	73.5	288.4	2507.9	760.5	979.0	54.2	340.4	813.9	6746.3

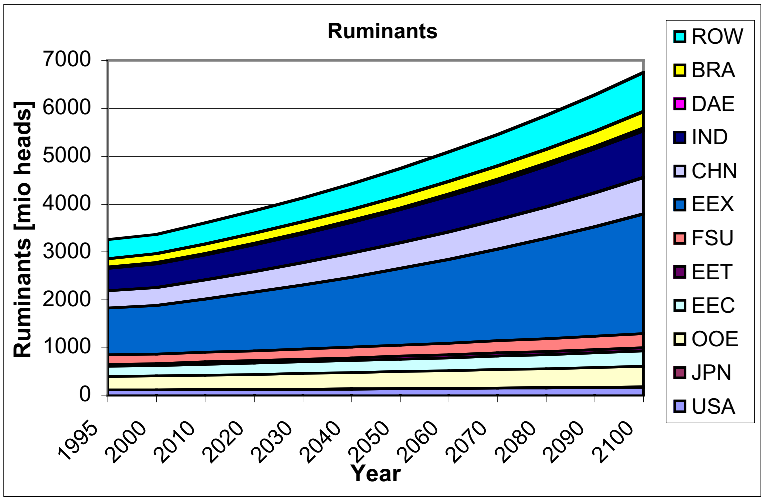

Figure 5: Ruminant projections in million of head per year

Table 6: Non ruminant projections in millions of head per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	65.8	10.3	18.3	120.5	48.8	55.0	110.7	440.3	15.5	21.2	36.3	47.8	990.4
2000	66.9	10.5	18.6	122.6	49.8	56.1	116.4	458.2	16.1	22.1	37.6	50.0	1024.9
2010	69.3	10.8	19.3	127.0	51.8	58.4	128.7	496.4	17.5	23.9	40.4	54.7	1098.0
2020	71.8	11.2	19.9	131.5	53.9	60.7	142.2	537.7	18.9	25.9	43.3	59.8	1177.0
2030	74.3	11.6	20.7	136.2	56.1	63.2	157.2	582.5	20.5	28.1	46.4	65.4	1262.3
2040	77.0	12.0	21.4	141.1	58.4	65.8	173.7	631.1	22.2	30.4	49.8	71.6	1354.4
2050	79.7	12.5	22.2	146.1	60.8	68.5	191.9	683.6	24.1	32.9	53.4	78.3	1454.0
2060	82.6	12.9	22.9	151.3	63.3	71.3	212.1	740.5	26.1	35.7	57.3	85.7	1561.7
2070	85.5	13.4	23.8	156.7	65.9	74.2	234.4	802.2	28.2	38.6	61.4	93.8	1678.1
2080	88.6	13.8	24.6	162.3	68.5	77.2	259.1	869.0	30.6	41.9	65.9	102.6	1804.1
2090	91.7	14.3	25.5	168.1	71.3	80.4	286.4	941.4	33.1	45.3	70.7	112.3	1940.5
2100	95.0	14.8	26.4	174.0	74.3	83.6	316.5	1019.8	35.9	49.1	75.8	122.9	2088.1

2. CH_4 Emissions from Agriculture

2.1. Paddy Rice

Paddy rice emissions are calculated as follows:

$$CH_{4rice} = \text{harvested paddy rice area x emission coefficient} \qquad (4)$$

The emission coefficients for several regions are from *Neue and Sass* [1998], these coefficients do not change over time. See also Sass, et al. [1999].

Table 7: CH_4 emission coefficients for several EPPA regions in Tg CH_4 / 10^6 ha

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
1995	0.25	0.312	0.312	0.312	0.312	0.312	0.31	0.34	0.20	0.38	0.312	0.312

Table 8: CH_4 emissions from paddy rice fields in Tg CH_4 per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	0.313	0.661	0.037	0.115	0.004	0.156	7.976	10.576	8.582	5.292	1.365	8.479	43.557
2000	0.313	0.661	0.037	0.115	0.004	0.157	8.294	10.576	8.603	5.313	1.366	8.825	44.264
2010	0.313	0.661	0.038	0.115	0.004	0.157	8.966	10.576	8.647	5.356	1.367	9.560	45.760
2020	0.313	0.661	0.038	0.115	0.004	0.158	9.694	10.576	8.690	5.399	1.368	10.356	47.373
2030	0.313	0.661	0.038	0.115	0.004	0.159	10.480	10.576	8.734	5.443	1.370	11.219	49.111
2040	0.313	0.661	0.039	0.115	0.004	0.160	11.330	10.576	8.777	5.486	1.371	12.153	50.986
2050	0.313	0.661	0.039	0.115	0.004	0.161	12.249	10.576	8.821	5.530	1.373	13.165	53.007
2060	0.313	0.661	0.040	0.115	0.004	0.161	13.243	10.576	8.865	5.575	1.374	14.262	55.189
2070	0.313	0.661	0.040	0.115	0.004	0.162	14.317	10.576	8.910	5.620	1.375	15.450	57.543
2080	0.313	0.661	0.040	0.115	0.004	0.163	15.479	10.576	8.955	5.665	1.377	16.736	60.083
2090	0.313	0.661	0.041	0.115	0.004	0.164	16.735	10.576	8.999	5.710	1.378	18.130	62.826
2100	0.313	0.661	0.041	0.115	0.004	0.165	18.092	10.576	9.045	5.756	1.379	19.640	65.787

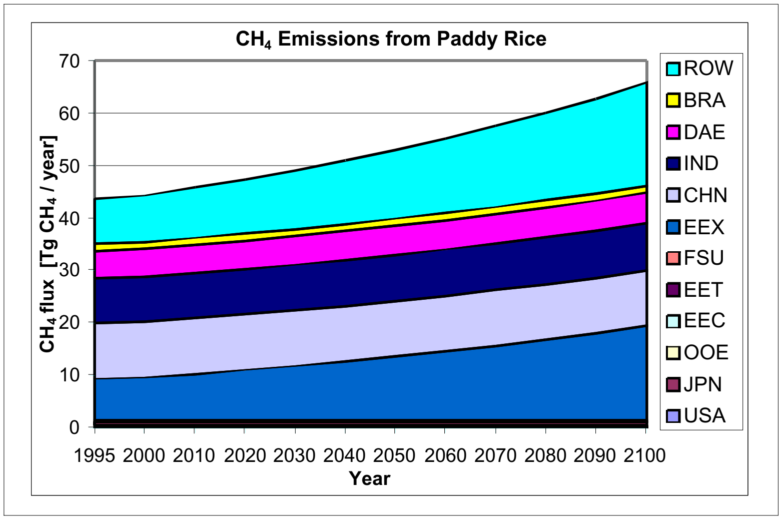

Figure 6: CH_4 emissions from paddy rice fields in Tg CH_4 per year

Important agricultural factors known to influence CH_4 emissions from paddy rice (arrows indicate trend):

- Planting density: Experiments showed that increasing plant density by a factor of 4 increased CH_4 emissions by a factor of two *Khalil et al.* [1998]
- Water management
- Fertilizer: N-fertilizer ↓, organic fertilizer ↑ (*van der Gon* [1999])
- Yield, rice cultivars: No clear trend from studies
- Sulphate deposition ↓ (*Bouwman* [1991])

All those factor depend very much on the specific situation and no general trend can be estimated. With increasing replacement of organic fertilizer (e.g. green manure) by synthetic N-fertilizer, methane emissions are likely to decrease for a given area, whereas yield increases are likely to result in higher CH_4 emissions.

2.2. Enteric Fermentation and Ruminant Manure

CH_4 emissions from ruminants are derived for each region:

$$CH_{4rum} = \text{ruminants x emission coefficient} \tag{5}$$

The emission coefficient is an average for all ruminants and a combined coefficient for enteric fermentation and manure. The coefficients are from the IPCC 1996 Guidelines for National Greenhouse Gas Inventories; *IPCC* [1996][. Coefficients do not change over time.

Table 9: CH_4 emissions coefficient for ruminants in Tg CH_4 / mio heads

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
1995	0.07	0.035	0.02	0.042	0.03	0.03	0.017	0.035	0.04	0.017	0.05	0.04

The difference in the emission coefficients is caused by:

- Different ratio of cattle to other ruminants like sheep or goats
- Different ratio of beef to dairy cattle; beef cattle have the highest emission coefficient of all ruminants
- Different animal management systems – food, waste management, …
- Different cow sizes

Table 10: CH_4 emissions from ruminants in Tg CH_4 per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	7.95	0.174	5.648	8.78	1.448	5.684	16.57	12.76	18.77	0.442	9.06	15.61	102.92
2000	8.11	0.177	5.762	8.96	1.478	5.799	17.33	13.21	19.44	0.457	9.34	16.16	106.25
2010	8.44	0.185	5.997	9.32	1.538	6.036	18.96	14.17	20.85	0.491	9.91	17.34	113.27
2020	8.79	0.192	6.242	9.70	1.601	6.282	20.75	15.20	22.36	0.526	10.53	18.59	120.79
2030	9.14	0.200	6.496	10.10	1.666	6.538	22.70	16.30	23.99	0.564	11.18	19.94	128.85
2040	9.52	0.208	6.761	10.51	1.734	6.805	24.84	17.49	25.73	0.605	11.87	21.39	137.48
2050	9.91	0.217	7.037	10.94	1.805	7.083	27.18	18.75	27.59	0.649	12.60	22.94	146.73
2060	10.31	0.225	7.325	11.39	1.878	7.372	29.74	20.11	29.59	0.696	13.38	24.60	156.65
2070	10.73	0.235	7.623	11.85	1.955	7.673	32.54	21.57	31.74	0.747	14.21	26.39	167.29
2080	11.17	0.244	7.935	12.34	2.035	7.986	35.61	23.14	34.04	0.801	15.09	28.30	178.71
2090	11.63	0.254	8.258	12.84	2.118	8.312	38.96	24.81	36.51	0.859	16.02	30.35	190.95
2100	12.10	0.265	8.595	13.36	2.204	8.651	42.63	26.61	39.16	0.921	17.01	32.55	204.10

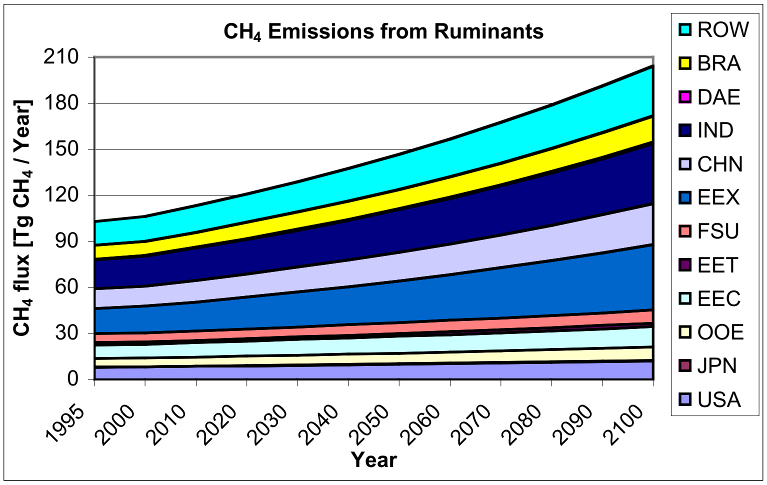

Figure 7: CH_4 emissions from ruminants in Tg CH_4 per year

2.3. Non Ruminant Manure

CH_4 emissions from non ruminant manure are calculated for each region by the equation:

$$CH_{4\ \text{non-rum}} = \text{non ruminants x emissions coefficient} \qquad (6)$$

The emission coefficients are derived from IPCC, 1996 and they are not changed over time.

Table 11: CH_4 emission coefficient for non-ruminants in Tg CH_4 / mio heads

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
1995	0.014	0.004	0.02	0.008	0.01	0.008	0.001	0.006	0.006	0.002	0.008	0.002

The emission coefficients depend on the manure management system and on temperature (increase of emissions with temperature). The more intensive the animal management the more emissions can be expected.

Table 12: CH_4 emissions from non ruminants in Tg CH_4 per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	0.921	0.041	0.365	0.964	0.488	0.440	0.111	2.642	0.093	0.042	0.291	0.096	6.49
2000	0.937	0.042	0.372	0.981	0.498	0.449	0.116	2.749	0.097	0.044	0.301	0.100	6.68
2010	0.970	0.043	0.385	1.016	0.518	0.467	0.129	2.978	0.105	0.048	0.323	0.109	7.09
2020	1.005	0.045	0.399	1.052	0.539	0.486	0.142	3.226	0.114	0.052	0.346	0.120	7.52
2030	1.041	0.046	0.413	1.090	0.561	0.506	0.157	3.495	0.123	0.056	0.372	0.131	7.99
2040	1.078	0.048	0.428	1.129	0.584	0.526	0.174	3.786	0.133	0.061	0.398	0.143	8.48
2050	1.116	0.050	0.443	1.169	0.608	0.548	0.192	4.102	0.144	0.066	0.427	0.157	9.02
2060	1.156	0.052	0.459	1.210	0.633	0.570	0.212	4.443	0.156	0.071	0.458	0.171	9.59
2070	1.197	0.053	0.475	1.254	0.659	0.593	0.234	4.813	0.169	0.077	0.492	0.188	10.20
2080	1.240	0.055	0.492	1.298	0.685	0.618	0.259	5.214	0.184	0.084	0.527	0.205	10.86
2090	1.284	0.057	0.510	1.344	0.713	0.643	0.286	5.649	0.199	0.091	0.565	0.225	11.56
2100	1.330	0.059	0.528	1.392	0.743	0.669	0.316	6.119	0.215	0.098	0.606	0.246	12.32

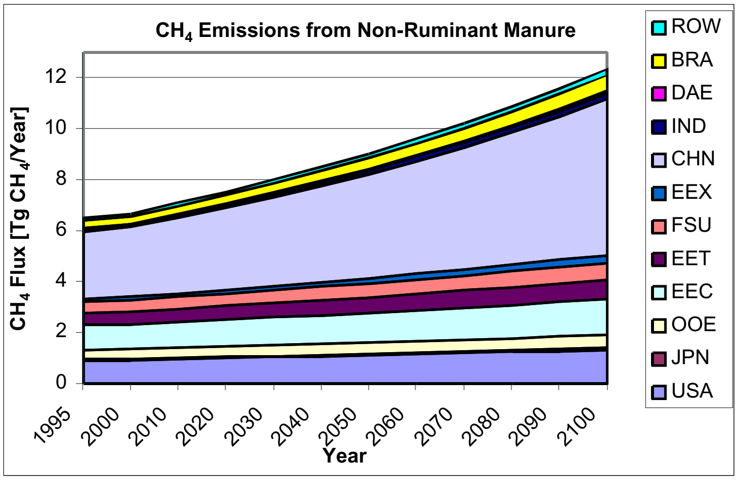

Figure 8: CH_4 emissions from non-ruminants in Tg CH_4 per year

2.4. Total Agricultural CH_4 Emissions (incl. Biomass Burning)

Total methane emissions are the sum of methane from paddy rice fields, ruminants, non ruminants and biomass burning (*Olivier et al*. [1995]). Biomass burning data are for 1990, they are kept constant through 2100.

Table 13: CH_4 emissions from biomass burning, EDGAR 1990 in Tg CH_4 per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1990	0.00	0.00	0.00	0.00	0.00	0.00	7.21	0.08	0.20	0.24	1.88	0.97	10.57

Table 14: Total agricultural CH_4 emissions in Tg CH_4 per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	9.19	0.88	6.05	9.86	1.94	6.28	31.87	30.24	27.66	6.02	12.60	25.15	167.72
2000	9.36	0.88	6.17	10.06	1.98	6.40	32.95	30.80	28.35	6.05	12.88	26.06	171.96
2010	9.73	0.89	6.42	10.46	2.06	6.66	35.27	31.99	29.81	6.13	13.48	27.97	180.88
2020	10.11	0.90	6.68	10.87	2.14	6.93	37.80	33.27	31.38	6.22	14.12	30.04	190.45
2030	10.50	0.91	6.95	11.31	2.23	7.20	40.55	34.64	33.05	6.30	14.80	32.26	200.70
2040	10.91	0.92	7.23	11.76	2.32	7.49	43.56	36.11	34.85	6.39	15.52	34.65	211.71
2050	11.34	0.93	7.52	12.23	2.42	7.79	46.83	37.70	36.77	6.48	16.28	37.23	223.52
2060	11.78	0.94	7.82	12.72	2.52	8.10	50.41	39.40	38.82	6.58	17.10	40.01	236.19
2070	12.25	0.95	8.14	13.22	2.62	8.43	54.31	41.23	41.03	6.68	17.96	42.99	249.80
2080	12.73	0.96	8.47	13.75	2.72	8.77	58.56	43.19	43.39	6.79	18.87	46.21	264.41
2090	13.23	0.97	8.81	14.30	2.84	9.12	63.19	45.30	45.92	6.90	19.85	49.68	280.10
2100	13.75	0.98	9.16	14.88	2.95	9.48	68.25	47.57	48.63	7.01	20.88	53.41	296.96

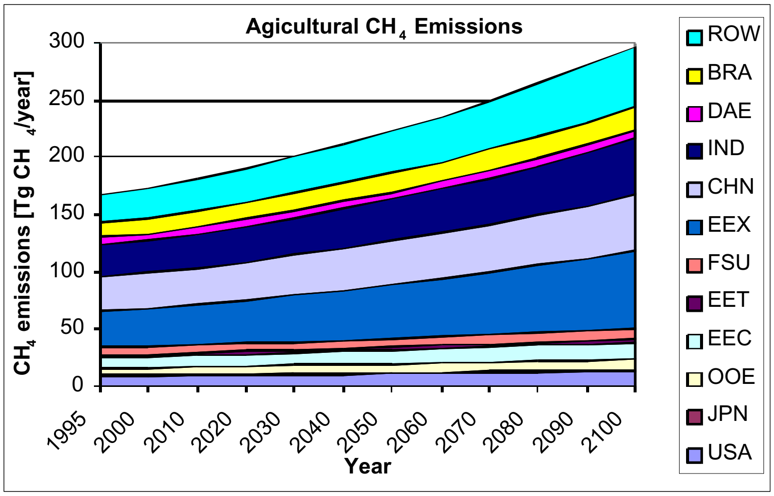

Figure 9: Total agricultural CH_4 emissions in Tg CH_4 per year

3. N_2O Emissions from Agriculture

Agricultural N_2O emissions (excl. biomass burning) have several sources (*Mosier and Kroeze* [1998]; Mosier et al. [1998]):

- Direct soil emissions: Synthetic fertilizer, animal waste, biological N_2 fixation, crop residue, cultivated histosols
- Animal production: Animal waste management systems
- Indirect emissions: Atmospheric deposition, nitrogen leaching and runoff, human sewage

In this study emissions were combined in the following 3 categories:

- soil emissions (N_2 fixation, crop residue, cultivated histosols)—related to harvested area
- direct and indirect emissions from N-fertilizer use—related to N-fertilizer use
- direct and indirect emissions from animals (from waste management systems, manure, leaching and runoff)—related to livestock

3.1. Soil Emissions

Soil emissions are calculated as follows:

$$N_2O_{soil} = \text{harvested area x emission coefficient} \qquad (7)$$

The emission coefficient is the same for all regions because no detailed data are available. The coefficient was calculated backwards from the global total for N_2 fixation, crop residue, cultivated histosols given by *Mosier and Kroeze* [1998]. It is 0.0015 Tg N_2O / 10^6 ha, constant through time.

Table 15: N_2O soil emissions in Tg N_2O per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	0.089	0.004	0.071	0.054	0.039	0.141	0.206	0.199	0.150	0.027	0.030	0.094	1.103
2000	0.089	0.004	0.071	0.054	0.039	0.141	0.214	0.199	0.150	0.027	0.030	0.097	1.117
2010	0.089	0.004	0.072	0.054	0.039	0.142	0.232	0.200	0.151	0.027	0.030	0.106	1.145
2020	0.089	0.004	0.073	0.054	0.039	0.143	0.251	0.200	0.152	0.028	0.030	0.115	1.176
2030	0.089	0.004	0.074	0.054	0.039	0.143	0.271	0.201	0.152	0.028	0.030	0.124	1.208
2040	0.089	0.004	0.074	0.054	0.039	0.144	0.293	0.201	0.153	0.028	0.030	0.135	1.244
2050	0.089	0.004	0.075	0.054	0.039	0.145	0.317	0.202	0.153	0.028	0.030	0.146	1.282
2060	0.089	0.004	0.076	0.054	0.039	0.146	0.342	0.203	0.154	0.028	0.031	0.158	1.323
2070	0.089	0.004	0.077	0.054	0.039	0.146	0.370	0.203	0.154	0.028	0.031	0.172	1.367
2080	0.089	0.004	0.077	0.054	0.039	0.147	0.400	0.204	0.155	0.028	0.031	0.186	1.414
2090	0.089	0.004	0.078	0.054	0.039	0.148	0.432	0.204	0.155	0.029	0.031	0.202	1.465
2100	0.089	0.004	0.079	0.054	0.039	0.149	0.468	0.205	0.156	0.029	0.031	0.219	1.521

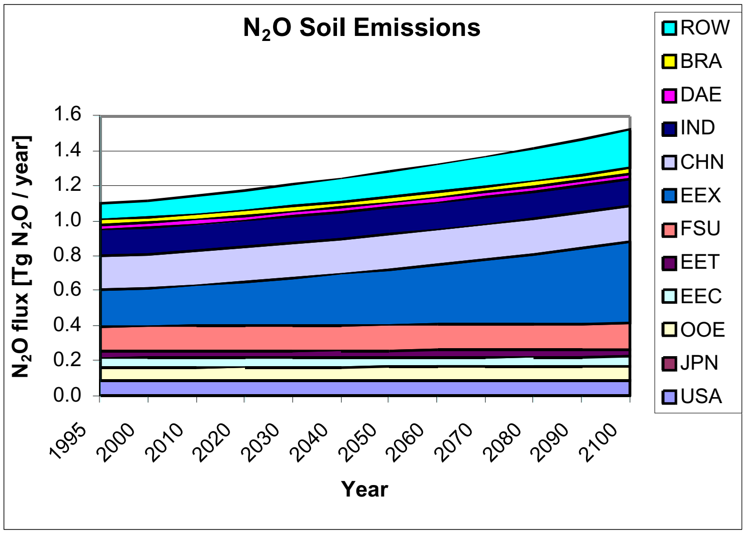

Figure 10: N_2O soil emissions in Tg N_2O per year

3.2. Direct and Indirect Emissions from N-Fertilizer Use

N_2O emissions from N-fertilizer are derived by the equation:

$$N_2O_{fert} = \text{N-fertilizer use x emission coefficient} \qquad (8)$$

Because of a lack of data (current and projections) N_2O emissions from N-fertilizer use are obtained by calculating backwards from the global total of those emissions given by *Mosier and Kroeze* [1998]. The coefficient is 0.04 Tg N_2O / mio ton N-fertilizer; it is not changed over time. The coefficient is in the possible range suggested by the IPCC 1996 guidelines. Direct nitrous oxide emissions are expected to be between 0.25 – 2.25% of the additional nitrogen input and for the indirect emissions between 0.2 – 12% of the lost nitrogen in fields (generally less than 70% of nitrogen applied, and frequently as little as 20%, is taken up by the crop, *Meisinger and Randall* [1991]). In this study N_2O emissions from N-fertilizer use account also for emissions from atmospheric deposition.

Table 16: Direct and indirect N_2O emissions from N-fertilizer use in Tg N_2O per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	0.446	0.021	0.146	0.381	0.081	0.106	0.285	0.935	0.393	0.066	0.046	0.211	3.118
2000	0.460	0.021	0.151	0.384	0.087	0.111	0.304	0.952	0.417	0.070	0.049	0.220	3.225
2010	0.488	0.022	0.162	0.390	0.099	0.121	0.346	0.986	0.470	0.079	0.054	0.238	3.456
2020	0.519	0.022	0.174	0.396	0.112	0.133	0.394	1.021	0.530	0.089	0.061	0.258	3.708
2030	0.551	0.022	0.186	0.402	0.128	0.145	0.449	1.057	0.598	0.101	0.068	0.279	3.986
2040	0.585	0.023	0.200	0.408	0.146	0.159	0.511	1.095	0.674	0.113	0.075	0.302	4.291
2050	0.621	0.023	0.214	0.414	0.166	0.174	0.582	1.134	0.760	0.128	0.084	0.327	4.628
2060	0.659	0.023	0.230	0.420	0.189	0.190	0.663	1.174	0.857	0.144	0.094	0.355	5.000
2070	0.700	0.024	0.246	0.427	0.215	0.208	0.755	1.216	0.966	0.163	0.105	0.384	5.410
2080	0.743	0.024	0.264	0.433	0.245	0.228	0.860	1.259	1.090	0.183	0.117	0.416	5.864
2090	0.789	0.024	0.284	0.440	0.279	0.249	0.980	1.304	1.228	0.207	0.131	0.451	6.366
2100	0.838	0.025	0.304	0.446	0.318	0.273	1.116	1.351	1.385	0.233	0.146	0.489	6.923

3.3. Direct and Indirect Emissions from Animal Manure

N_2O emissions from animals (ruminants + non-ruminants) are derived for each region by:

$$N_2O_{anim} = \text{animals(heads) x emission coefficient} \qquad (9)$$

The emission coefficient is an average for all animals and a combined coefficient for direct emissions form manure application on soils, direct emissions from animal waste management systems, and indirect emissions from manure deposition on soils. The coefficients are from the *IPCC* [1996]. Coefficients do not change over time.

Table 17: N_2O emission coefficient for livestock in Tg N_2O / mio heads

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
1995	0.0018	0.0012	0.0009	0.0014	0.0014	0.0014	0.0005	0.0007	0.0008	0.0007	0.0009	0.0006

The difference in the emission coefficients is caused by:

- Different ratio of cattle to other animals like sheep, pigs, etc.
- Different ratio of beef to dairy cattle; dairy cattle have the highest emission coefficient of all animals
- Different animal management systems – food, waste management, etc.
- Different ratio of grazing animals

Table 18: Direct and indirect N_2O emissions from animals in Tg N_2O per year

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	0.323	0.018	0.271	0.462	0.136	0.342	0.543	0.563	0.388	0.033	0.196	0.263	3.537
2000	0.329	0.019	0.276	0.470	0.139	0.349	0.568	0.585	0.402	0.034	0.202	0.272	3.646
2010	0.342	0.019	0.287	0.489	0.144	0.363	0.622	0.631	0.431	0.037	0.215	0.293	3.874
2020	0.355	0.020	0.299	0.508	0.150	0.378	0.681	0.681	0.463	0.040	0.229	0.315	4.118
2030	0.369	0.021	0.311	0.527	0.156	0.394	0.746	0.734	0.496	0.043	0.243	0.338	4.379
2040	0.383	0.022	0.324	0.548	0.163	0.410	0.818	0.792	0.532	0.046	0.259	0.364	4.659
2050	0.398	0.022	0.337	0.569	0.169	0.426	0.896	0.854	0.571	0.050	0.275	0.391	4.959
2060	0.414	0.023	0.350	0.592	0.176	0.444	0.981	0.921	0.613	0.054	0.293	0.421	5.280
2070	0.430	0.024	0.364	0.615	0.183	0.462	1.074	0.993	0.657	0.058	0.311	0.452	5.625
2080	0.447	0.025	0.379	0.639	0.191	0.481	1.177	1.071	0.705	0.062	0.331	0.486	5.994
2090	0.464	0.026	0.395	0.663	0.199	0.500	1.289	1.155	0.757	0.067	0.352	0.523	6.390
2100	0.482	0.027	0.411	0.689	0.207	0.521	1.412	1.246	0.812	0.072	0.375	0.562	6.816

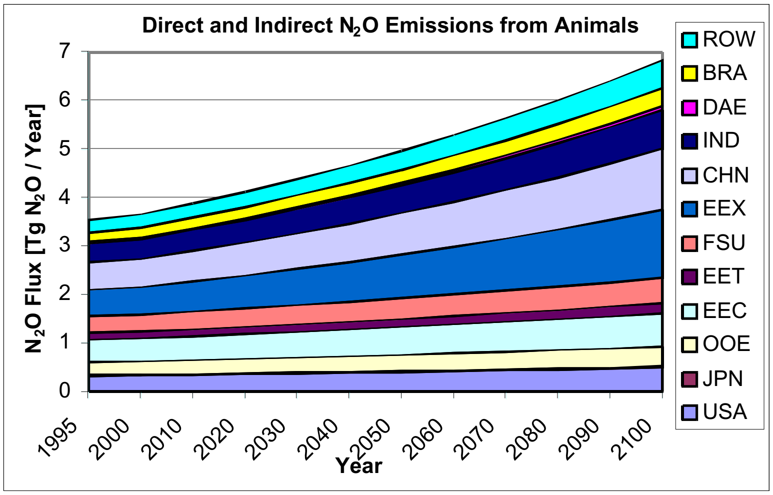

Figure 11: Direct and indirect N_2O emissions from animals in Tg N_2O per year

3.4. Total Agricultural N_2O Emissions (including Biomass Burning)

Total nitrous oxide emissions are the sum of emissions from soil, N-fertilizer, animal, and biomass burning (*Olivier et al.* [1995]) emissions. Biomass burning data are for 1990, they are kept constant through 2100.

Table 19: N_2O emissions from biomass burning, EDGAR 1990 in Tg N_2O per year.

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1990	0.000	0.000	0.000	0.000	0.000	0.000	0.409	0.008	0.021	0.025	0.119	0.082	0.664

Table 20: Total agricultural N_2O in Tg N_2O per year.

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	0.858	0.043	0.487	0.897	0.256	0.589	1.443	1.705	0.952	0.152	0.390	0.650	8.422
2000	0.878	0.043	0.498	0.909	0.265	0.601	1.495	1.744	0.990	0.157	0.399	0.672	8.651
2010	0.919	0.044	0.521	0.933	0.282	0.627	1.609	1.824	1.073	0.169	0.418	0.719	9.138
2020	0.962	0.046	0.545	0.958	0.302	0.654	1.735	1.909	1.165	0.182	0.438	0.769	9.665
2030	1.008	0.047	0.571	0.983	0.324	0.682	1.875	2.000	1.267	0.196	0.460	0.824	10.237
2040	1.057	0.048	0.598	1.010	0.348	0.713	2.031	2.096	1.380	0.213	0.483	0.883	10.858
2050	1.108	0.049	0.626	1.038	0.375	0.745	2.203	2.197	1.505	0.231	0.509	0.947	11.533
2060	1.162	0.050	0.656	1.066	0.405	0.780	2.395	2.305	1.644	0.251	0.536	1.016	12.266
2070	1.219	0.051	0.688	1.095	0.438	0.817	2.609	2.420	1.799	0.274	0.566	1.090	13.065
2080	1.279	0.052	0.721	1.126	0.475	0.856	2.846	2.542	1.971	0.299	0.598	1.171	13.936
2090	1.342	0.054	0.756	1.157	0.517	0.898	3.110	2.672	2.161	0.328	0.633	1.258	14.886
2100	1.409	0.055	0.794	1.190	0.564	0.942	3.404	2.810	2.374	0.359	0.671	1.352	15.923

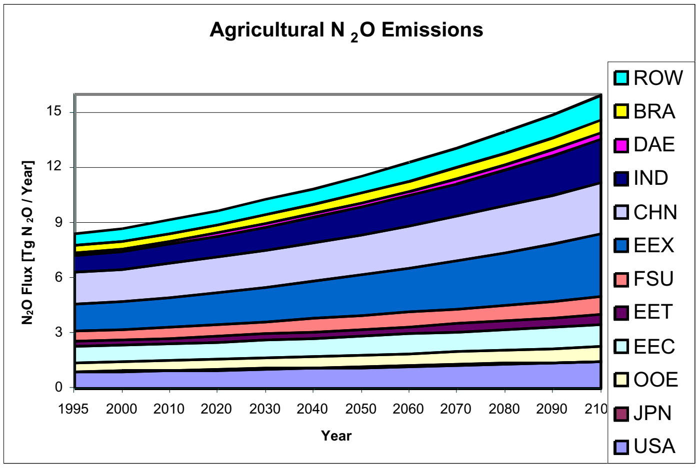

Figure 12: Total agricultural N_2O in Tg N_2O per year

4. Emissions Estimates for Other Sources of Non-CO_2 Greenhouse Gases

This section describes how the emissions inventories were constructed for non-agricultural sources of methane and nitrous oxide, and all sources of SF_6, HFCs, and PFCs.

4.1 Methane

For other sources of methane we were able to rely on existing inventories. For Annex B regions, *U.S. EPA* [2000] was used as the source for emissions from COAL (coal production), OIL (oil production), GAS (gas production), domestic sewage, and landfill emissions. For non-Annex B regions, estimates from ABARE (Brown et al. [1999]) were for emissions from COAL, OIL, and GAS. These estimates are based on production of these fuels by region.

Non-Annex B landfill emissions were assumed to be 32% of Annex B emissions (based on *IEA*, 1998). This total for non-Annex B nations was then distributed among the non-Annex B regions proportional to their share of global aggregate consumption.

Non-Annex B domestic sewage emissions were based on the difference between global domestic sewage emissions from IEA [1998] and the total for Annex B domestic sewage emissions (based on *U.S. EPA* [2000], as explained above). IEA gives a global total for domestic sewage emissions of 2 Tg methane/year. The difference between the global total and the Annex B domestic sewage emission total is distributed among non-Annex B regions proportional to their share of global aggregate consumption.

ENERINT and OTHERIND generate methane from industrial sewage. The major sources of methane in ENERINT are the pulp and paper industry and the chemical industry. For OTHERIND, the major source is food processing. For all regions, inventory data is from *IEA* [1998]. To translate the data from the IEA regional breakdown to the regions needed for EPPA, the IEA regional emissions estimates were aggregated into two regions: North America + Europe + Japan, and Asia + Africa + Rest of World. Then within these two groups, emissions were distributed to each EPPA region proportional to its share of GTAP sectoral output for the pulp/paper, chemical, and food processing industries. Similarly, the emissions were split between ENERINT and OTHERIND proportional to the GTAP monetary output of the pulp/paper, chemical, and food processing industries.

4.2 Nitrous Oxide

For N_2O emissions we were able to rely on existing inventories and emissions factors that could be applied directly to the physical energy quantity data in EPPA. For Annex B regions, *U.S. EPA* [2000] was used as the data source for emissions from ENERINT (due to adipic and nitric acid production). For non-Annex B regions, estimates from ABARE (Brown et al., [1999]) were used as the data source for ENERINT emissions.

COAL emissions of nitrous oxide are due to the combustion of coal. For all regions, emissions were estimated using the IPCC default coal combustion coefficient of 1.4 kg N_2O emitted per TJ of fuel (IPCC, 1996). This coefficient is multiplied by EPPA's coal consumption data for each region.

REFOIL emissions of nitrous oxide are due to the combustion of oil. For Annex B regions, emissions inventories were based on *U.S. EPA* [2000]. For non-Annex B regions, emissions were estimated using the IPCC default oil combustion coefficient of 0.6 kg N_2O emitted per TJ of fuel (*IPCC,* 1996). This coefficient is multiplied by EPPA's coal consumption data for each region.

Emissions of nitrous oxide due to the combustion of natural gas are minor and are not included in this version of EPPA.

4.3 HFC, PFC, SF-6:

In contrast to CH_4, N_2O and CO_2, these gases are manufactured compounds with no natural sources. Moreover they are long-lived and well-mixed in the atmosphere so that atmospheric measurements can be used to constrain estimates of global emissions. On the other hand, future emissions are highly uncertain. We thus explicitly develop a high and low scenario of future emissions. Baseline (1995) emissions were developed as follows:

- **PFCs:** Aluminum production is the only source included into the baseline (Table 21) and the projections. A constant emission factor for installed primary aluminum production capacity in 1994 was used. It reproduces the observed global emissions of CF_4 and C_2F_6 as reported in the *Harnisch et al*. [1996]. See also *Harnisch et al.* [1998] and *Harnisch et al.* [2000].

Table 21. PFC Reference-Emissions in 1995 [metric tons of CF_4-equivalents per year]

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW
E(1995)	4148.6	20.2	2320.7	4062.2	2607.9	1304.1	3516.2	599.4	607.0	0.0	1161.4	408.4

- **SF_6:** The sum of emissions from the electrical sector (E1) and from open applications (E2) (Table 22) are scaled to reproduce atmospheric observations as reported by *Maiss and Brenninkmeijer* [1998]. For the electrical sector, an effective leakage rate of 14% from a bank of 26,000 tons (1996) of SF_6 was assumed, thus accounting for real leakage and handling losses of SF_6 in the electrical sector. The banked amount of SF_6 was divided across regions according to shares of world electricity use in 1996. Emissions from open applications of SF_6 such as magnesium production are estimated to have been 2,400 tons of SF_6 in 1996. These emissions were distributed across regions according to shares of world GDP in 1996. See also, *Maiss and Brenninkmeijer* [1998].

Table 22. SF_6 Reference-Emissions in 1995 [metric tons of SF_6 per year]

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW
E1(1995)	921.0	282.1	519.5	355.8	242.4	275.0	396.7	103.5	124.4	81.2	56.9	176.5
E2(1995)	696.5	258.7	430.3	151.8	294.4	103.7	92.2	43.2	36.4	61.0	34.6	117.8

- **HFC:** Again global atmospheric observations were used to infer global emissions of HFCs. These are currently mainly HFC-23 and HFC-134a. Inferred global emissions were then divided across regions according to their respective shares of world GDP in 1995 (Table 23). Useful sources of information on HFCs are *Oram et al.* [1998] and *Simmonds et al.* [1998].

Table 23. HFC Reference-Emissions in 1995 [metric tons of HFC-134a-equivalents per year]

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW
E(1995)	34607.2	12853.7	21378.1	6943.0	4125.5	1042.2	4581.5	433.9	1447.1	1820.4	348.0	1183.8

High, reference and low scenarios (Figures 13-15; Tables 24-32) are intended to define the possible future range of emission trajectories at a 95% confidence level for the EPPA reference economic growth. The reference scenario is the emissions trajectory of greatest probability if no negative incentives are placed on emissions of greenhouse gases. Scenarios were developed based on reference GDP and energy use in EPPA using the following formulas. For PFCs (reported as emissions of CF_4):

$$E_i^{\Sigma}(t) = \frac{GDP_i(t)}{GDP_i(1995)}\varphi(t)E_i(1995) \tag{10}$$

For SF_6:

$$E_i^{\Sigma}(t) = \frac{ELEC_i(t)}{ELEC_i(1995)}\varphi(t,1)E_{i,1}(1995) + \frac{GDP_i(t)}{GDP_i(1995)}\varphi(t,2)E_{i,2}(1995) \tag{11}$$

$\varphi(t,1)=\varphi(t,2)$ was assumed.

For HFCs (reported as HFC134a):

$$E_i^{\Sigma}(t) = \frac{GDP_i(t)}{GDP_i(1995)}\varphi(t,i)E_i(1995) \tag{12}$$

i: regions
n: source type (1..2)
$\varphi(t,n,i)$: emission factor at time t, for process n and in region i
$E_{i,n}(t)$: emission type n in region i at time t,
$E_i^{\Sigma}(t)$: sum of emissions in region i at time t

For the reference scenarios it was assumed that modest improvements in terms of specific emissions per unit of activity take place. Usually observed trends were extrapolated for the reference scenario. For the use of HFCs it was assumed that eventually HFCs use per unit of GDP would be at 1/3 of the corresponding use of CFCs, HCFCs and HFCs in 1996.

The high scenarios are current technology scenarios. They assume that emissions per unit of activity remain constant while the economic activities such as GDP or ELEC consumption generally grow. The HFCs are an exception as emissions of HFCs are expected to grow significantly over the next decades when CFCs and HCFCs are phased out under the Montreal Protocol. The high scenario here implies that eventually the full 1996 demand of CFCs, HCFCs or HFCs will be met by HFCs. Demand again grows in time as GDPs expand. The low scenarios require an active policy to change technologies to abate emissions at a faster rate than in the case of undisturbed technological change. Under the low scenario the use of HFCs is considered to be an interim-solution for just a few decades.

The emission factors (Tables 33-38) in equations (10), (11), and (12) are used to relate changes of emissions relative to baseline emissions to changes of economic activity. They thus resemble economic elasticities. It is worthwhile noting that implicitly we assume unity for the actual economic elasticity of changes of demand (e.g. aluminum) relative to changes in economic activities (e.g. GDP). The actual emissions per unit of product or service such as aluminum or air-conditioning are projected to decline as in the case of primary aluminum or expand as in the case of mobile air conditioners. The emission factors were calculated based on specific assumptions about the technological development of source processes. The emission factors are chosen appropriately to account for the delay between sales and emissions of halocarbons.

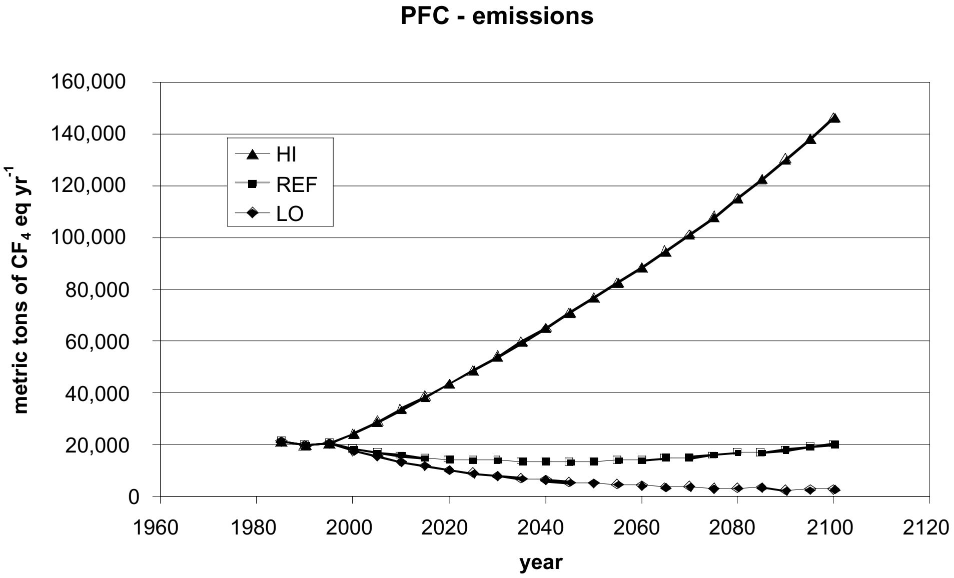

Figure 13: Projected emissions of PFCs

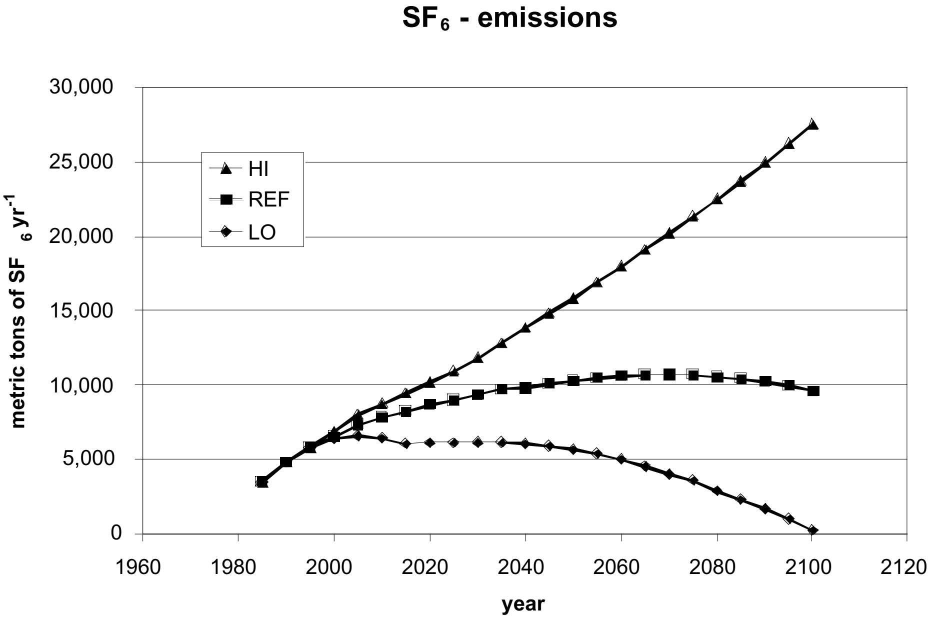

Figure 14: Projected emissions of SF_6

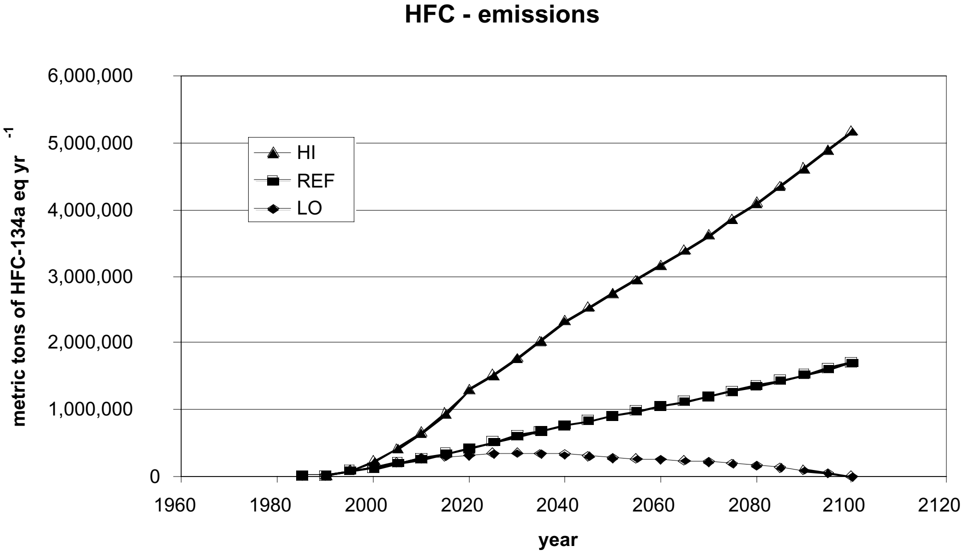

Figure 15: Projected emissions of HFCs

Table 24. PFC emissions in metric tons of CF_4 equivalents - high scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	4336.4	19.5	2364.8	4153.1	1829.5	1093.0	4795.4	497.5	780.1	0.0	1202.4	419.8	21492
1990	4012.1	18.8	2202.0	3885.7	2183.4	1139.7	3803.5	516.0	644.2	0.0	1110.1	386.0	19901
1995	4148.6	20.2	2320.7	4062.2	2607.9	1304.1	3516.2	599.4	607.0	0.0	1161.4	408.4	20756
2000	4678.2	23.7	2661.1	4623.6	3334.5	1590.5	4018.8	745.8	668.1	0.0	1434.4	485.8	24265
2005	5234.9	27.5	3023.4	5249.2	4190.0	1913.0	5226.5	916.3	917.7	0.0	1808.5	580.2	29087
2010	5824.2	32.1	3378.5	5958.8	4940.8	2307.2	6179.2	1120.6	1070.0	0.0	2203.0	681.9	33696
2015	6443.0	36.7	3749.9	6657.6	5754.2	2752.9	7306.8	1362.7	1246.3	0.0	2640.3	803.2	38754
2020	7098.5	40.9	4103.5	7361.8	6757.4	3252.7	8045.8	1610.4	1385.5	0.0	3114.6	931.7	43703
2025	7781.6	45.1	4447.8	8078.6	7835.4	3818.1	8707.2	1888.5	1525.5	0.0	3590.4	1067.5	48786
2030	8493.2	49.2	4781.9	8817.9	8951.7	4449.8	9419.2	2200.4	1674.1	0.0	4070.1	1211.5	54119
2035	9234.3	53.2	5104.8	9581.1	10086.9	5147.2	10129.3	2547.3	1830.3	0.0	4551.5	1363.1	59629
2040	10005.1	57.4	5438.0	10364.9	11183.9	5910.6	10745.0	2933.3	1990.7	0.0	5031.7	1526.9	65188
2045	10806.5	61.5	5757.7	11173.4	12248.2	6738.0	11335.0	3360.1	2160.5	0.0	5511.4	1693.5	70846
2050	11638.9	65.8	6069.2	12006.4	13269.0	7629.1	11912.6	3829.4	2341.1	0.0	5993.1	1864.6	76619
2055	12502.5	70.2	6377.0	12882.2	14252.9	8581.4	12486.7	4340.6	2532.7	0.0	6480.3	2040.6	82547
2060	13396.9	74.7	6681.5	13777.8	15225.7	9585.6	13067.9	4887.4	2734.2	0.0	6979.0	2220.9	88632
2065	14322.4	79.3	6988.5	14691.4	16194.1	10642.5	13668.3	5469.4	2946.7	0.0	7494.8	2407.1	94904
2070	15278.6	84.2	7305.4	15625.5	17135.6	11759.9	14299.2	6092.4	3173.0	0.0	8023.7	2603.1	101381
2075	16265.7	89.3	7626.4	16573.4	18153.3	12927.6	14967.9	6740.9	3407.4	0.0	8591.6	2804.1	108148
2080	17282.7	94.5	7956.8	17536.0	19210.6	14133.4	15684.0	7418.7	3652.0	0.0	9196.5	3012.7	115178
2085	18328.6	100.0	8301.6	18516.3	20289.0	15390.1	16486.4	8130.3	3910.4	0.0	9829.7	3231.9	122514
2090	19402.8	105.4	8662.1	19514.5	21398.7	16699.0	17393.0	8874.5	4188.8	0.0	10492.2	3462.6	130194
2095	20504.8	111.0	9022.1	20530.0	22534.4	18060.0	18377.1	9651.8	4474.8	0.0	11185.2	3705.8	138157
2100	21680.1	116.8	9375.2	21549.2	23651.9	19462.2	19285.5	10459.2	4762.8	0.0	11899.6	3960.1	146202

Table 25. PFC emissions in metric tons of CF_4 equivalents - reference scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	4336.4	19.5	2364.8	4153.1	1829.5	1093.0	4795.4	497.5	780.1	0.0	1202.4	419.8	21492
1990	4012.1	18.8	2202.0	3885.7	2183.4	1139.7	3803.5	516.0	644.2	0.0	1110.1	386.0	19901
1995	4148.6	20.2	2320.7	4062.2	2607.9	1304.1	3516.2	599.4	607.0	0.0	1161.4	408.4	20756
2000	3602.2	18.3	2049.0	3560.2	2567.5	1224.7	3094.4	574.2	514.5	0.0	1104.5	374.1	18684
2005	3088.6	16.2	1783.8	3097.0	2472.1	1128.7	3083.6	540.6	541.4	0.0	1067.0	342.3	17161
2010	2795.6	15.4	1621.7	2860.2	2371.6	1107.4	2966.0	537.9	513.6	0.0	1057.4	327.3	16174
2015	2512.8	14.3	1462.5	2596.5	2244.1	1073.6	2849.6	531.5	486.0	0.0	1029.7	313.3	15114
2020	2342.5	13.5	1354.1	2429.4	2229.9	1073.4	2655.1	531.4	457.2	0.0	1027.8	307.5	14422
2025	2256.7	13.1	1289.9	2342.8	2272.3	1107.2	2525.1	547.7	442.4	0.0	1041.2	309.6	14148
2030	2208.2	12.8	1243.3	2292.6	2327.4	1156.9	2449.0	572.1	435.3	0.0	1058.2	315.0	14071
2035	2123.9	12.2	1174.1	2203.7	2320.0	1183.9	2329.7	585.9	421.0	0.0	1046.8	313.5	13715
2040	2101.1	12.0	1142.0	2176.6	2348.6	1241.2	2256.4	616.0	418.1	0.0	1056.7	320.7	13689
2045	2053.2	11.7	1094.0	2123.0	2327.1	1280.2	2153.7	638.4	410.5	0.0	1047.2	321.8	13461
2050	2095.0	11.8	1092.4	2161.1	2388.4	1373.2	2144.3	689.3	421.4	0.0	1078.7	335.6	13791
2055	2125.4	11.9	1084.1	2190.0	2423.0	1458.8	2122.7	737.9	430.6	0.0	1101.7	346.9	14033
2060	2143.5	12.0	1069.0	2204.4	2436.1	1533.7	2090.9	782.0	437.5	0.0	1116.6	355.3	14181
2065	2291.6	12.7	1118.2	2350.6	2591.1	1702.8	2186.9	875.1	471.5	0.0	1199.2	385.1	15185
2070	2291.8	12.6	1095.8	2343.8	2570.3	1764.0	2144.9	913.9	476.0	0.0	1203.6	390.5	15207
2075	2439.9	13.4	1144.0	2486.0	2723.0	1939.1	2245.2	1011.1	511.1	0.0	1288.7	420.6	16222
2080	2592.4	14.2	1193.5	2630.4	2881.6	2120.0	2352.6	1112.8	547.8	0.0	1379.5	451.9	17277
2085	2566.0	14.0	1162.2	2592.3	2840.5	2154.6	2308.1	1138.2	547.5	0.0	1376.2	452.5	17152
2090	2716.4	14.8	1212.7	2732.0	2995.8	2337.9	2435.0	1242.4	586.4	0.0	1468.9	484.8	18227
2095	2870.7	15.5	1263.1	2874.2	3154.8	2528.4	2572.8	1351.2	626.5	0.0	1565.9	518.8	19342
2100	3035.2	16.4	1312.5	3016.9	3311.3	2724.7	2700.0	1464.3	666.8	0.0	1665.9	554.4	20468

Table 26. PFC emissions in metric tons of CF_4 equivalents - low scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	4336.4	19.5	2364.8	4153.1	1829.5	1093.0	4795.4	497.5	780.1	0.0	1202.4	419.8	21492
1990	4012.1	18.8	2202.0	3885.7	2183.4	1139.7	3803.5	516.0	644.2	0.0	1110.1	386.0	19901
1995	4148.6	20.2	2320.7	4062.2	2607.9	1304.1	3516.2	599.4	607.0	0.0	1161.4	408.4	20756
2000	3415.1	17.3	1942.6	3375.3	2434.2	1161.1	2933.7	544.4	487.7	0.0	1047.1	354.7	17713
2005	2826.8	14.8	1632.6	2834.5	2262.6	1033.0	2822.3	494.8	495.5	0.0	976.6	313.3	15707
2010	2329.7	12.8	1351.4	2383.5	1976.3	922.9	2471.7	448.2	428.0	0.0	881.2	272.8	13478
2015	1997.3	11.4	1162.5	2063.9	1783.8	853.4	2265.1	422.4	386.3	0.0	818.5	249.0	12014
2020	1703.6	9.8	984.8	1766.8	1621.8	780.7	1931.0	386.5	332.5	0.0	747.5	223.6	10489
2025	1478.5	8.6	845.1	1534.9	1488.7	725.4	1654.4	358.8	289.8	0.0	682.2	202.8	9269
2030	1274.0	7.4	717.3	1322.7	1342.8	667.5	1412.9	330.1	251.1	0.0	610.5	181.7	8118
2035	1108.1	6.4	612.6	1149.7	1210.4	617.7	1215.5	305.7	219.6	0.0	546.2	163.6	7155
2040	1000.5	5.7	543.8	1036.5	1118.4	591.1	1074.5	293.3	199.1	0.0	503.2	152.7	6519
2045	864.5	4.9	460.6	893.9	979.9	539.0	906.8	268.8	172.8	0.0	440.9	135.5	5668
2050	814.7	4.6	424.8	840.4	928.8	534.0	833.9	268.1	163.9	0.0	419.5	130.5	5363
2055	750.1	4.2	382.6	772.9	855.2	514.9	749.2	260.4	152.0	0.0	388.8	122.4	4953
2060	669.8	3.7	334.1	688.9	761.3	479.3	653.4	244.4	136.7	0.0	349.0	111.0	4432
2065	572.9	3.2	279.5	587.7	647.8	425.7	546.7	218.8	117.9	0.0	299.8	96.3	3796
2070	611.1	3.4	292.2	625.0	685.4	470.4	572.0	243.7	126.9	0.0	320.9	104.1	4055
2075	488.0	2.7	228.8	497.2	544.6	387.8	449.0	202.2	102.2	0.0	257.7	84.1	3244
2080	518.5	2.8	238.7	526.1	576.3	424.0	470.5	222.6	109.6	0.0	275.9	90.4	3455
2085	549.9	3.0	249.0	555.5	608.7	461.7	494.6	243.9	117.3	0.0	294.9	97.0	3675
2090	388.1	2.1	173.2	390.3	428.0	334.0	347.9	177.5	83.8	0.0	209.8	69.3	2604
2095	410.1	2.2	180.4	410.6	450.7	361.2	367.5	193.0	89.5	0.0	223.7	74.1	2763
2100	433.6	2.3	187.5	431.0	473.0	389.2	385.7	209.2	95.3	0.0	238.0	79.2	2924

Table 27. SF$_6$ emissions in metric tons - high scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	1027.4	301.7	601.4	299.2	243.6	147.0	418.9	63.0	131.5	72.3	57.0	187.6	3551
1990	1360.0	417.5	796.5	412.8	398.0	261.1	524.8	101.2	157.8	105.4	75.5	247.0	4858
1995	1617.5	540.8	949.7	507.7	536.8	378.7	488.9	146.7	160.8	142.1	91.5	294.4	5856
2000	1839.2	650.8	1086.8	597.7	690.1	492.9	525.5	200.0	178.8	187.4	113.5	350.4	6913
2005	2031.8	762.1	1213.2	681.5	848.6	588.0	621.2	258.7	246.0	239.2	141.4	409.8	8042
2010	2185.5	837.1	1318.4	728.7	979.2	641.3	597.8	304.7	268.0	294.8	171.9	471.5	8799
2015	2321.3	921.6	1412.3	779.8	1102.7	674.1	531.2	347.4	286.3	354.4	204.6	539.4	9475
2020	2426.4	997.9	1490.4	812.0	1232.9	762.3	536.1	400.3	301.7	422.0	241.5	613.2	10237
2025	2530.6	1068.0	1558.8	837.9	1374.9	844.4	544.2	458.4	315.1	487.3	278.2	684.5	10982
2030	2665.9	1142.8	1636.6	876.8	1524.8	947.3	563.9	528.9	333.7	560.4	319.9	761.9	11863
2035	2831.8	1222.9	1728.3	926.3	1677.5	1063.0	587.5	604.7	355.9	639.6	363.8	852.4	12854
2040	3011.3	1305.2	1826.6	979.8	1825.9	1190.3	612.7	685.8	380.2	711.0	410.1	921.4	13860
2045	3189.9	1385.3	1916.4	1030.0	1964.4	1321.7	642.0	770.2	405.7	784.0	455.7	998.6	14864
2050	3376.8	1462.9	2005.2	1081.6	2097.7	1460.7	671.6	857.2	432.0	858.1	502.3	1086.1	15892
2055	3570.0	1540.6	2093.2	1134.5	2229.5	1607.4	704.7	946.4	459.5	931.5	547.5	1178.2	16943
2060	3774.5	1620.4	2165.3	1191.3	2381.8	1761.7	739.7	1037.1	488.6	1003.4	590.7	1276.9	18031
2065	3994.6	1702.3	2234.8	1249.4	2521.0	1920.4	776.8	1129.2	518.4	1072.2	630.7	1379.2	19129
2070	4215.7	1787.4	2304.0	1305.4	2687.9	2084.2	816.2	1223.1	548.5	1138.3	667.6	1484.7	20263
2075	4439.1	1874.9	2374.5	1359.7	2849.0	2248.0	857.9	1317.6	578.1	1200.3	702.1	1592.8	21394
2080	4664.2	1965.3	2449.3	1412.5	2998.5	2415.7	902.0	1413.1	608.0	1263.4	735.9	1712.5	22540
2085	4891.7	2058.8	2528.9	1464.2	3151.0	2587.0	949.5	1510.0	638.5	1338.9	769.6	1850.4	23738
2090	5122.5	2151.9	2613.4	1515.6	3306.7	2763.2	1000.8	1608.3	670.3	1435.7	804.1	1985.0	24978
2095	5355.4	2247.1	2699.4	1566.1	3465.5	2943.1	1055.2	1707.9	702.5	1520.1	840.0	2147.4	26250
2100	5598.9	2344.4	2785.8	1615.7	3622.0	3126.4	1108.2	1808.5	735.1	1582.2	877.5	2324.2	27529

Table 28. SF$_6$ emissions in metric tons - reference scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	1027.4	301.7	601.4	299.2	243.6	147.0	418.9	63.0	131.5	72.3	57.0	187.6	3551
1990	1360.0	417.5	796.5	412.8	398.0	261.1	524.8	101.2	157.8	105.4	75.5	247.0	4858
1995	1617.5	540.8	949.7	507.7	536.8	378.7	488.9	146.7	160.8	142.1	91.5	294.4	5856
2000	1749.1	618.9	1033.5	568.4	656.2	468.8	499.8	190.2	170.0	178.2	107.9	333.2	6574
2005	1854.3	695.5	1107.2	622.0	774.5	536.7	566.9	236.1	224.5	218.3	129.1	374.0	7339
2010	1949.8	746.8	1176.2	650.1	873.6	572.2	533.4	271.8	239.1	263.0	153.4	420.6	7850
2015	2022.5	803.0	1230.5	679.5	960.8	587.4	462.8	302.7	249.4	308.8	178.3	470.0	8256
2020	2062.4	848.2	1266.9	690.2	1048.0	648.0	455.7	340.3	256.5	358.7	205.3	521.3	8701
2025	2075.1	875.7	1278.2	687.1	1127.4	692.4	446.2	375.9	258.4	399.5	228.1	561.3	9005
2030	2106.0	902.8	1292.9	692.7	1204.6	748.4	445.5	417.9	263.6	442.7	252.7	601.9	9372
2035	2152.2	929.4	1313.5	704.0	1274.9	807.9	446.5	459.6	270.5	486.1	276.5	647.8	9769
2040	2138.1	926.7	1296.9	695.7	1296.4	845.1	435.1	486.9	269.9	504.8	291.1	654.2	9841
2045	2169.1	942.0	1303.1	700.4	1335.8	898.7	436.5	523.7	275.9	533.1	309.9	679.1	10107
2050	2194.9	950.9	1303.4	703.0	1363.5	949.5	436.5	557.2	280.8	557.8	326.5	706.0	10330
2055	2213.4	955.2	1297.8	703.4	1382.3	996.6	436.9	586.7	284.9	577.5	339.4	730.5	10505
2060	2227.0	956.0	1277.5	702.8	1405.2	1039.4	436.4	611.9	288.3	592.0	348.5	753.3	10638
2065	2237.0	953.3	1251.5	699.7	1411.8	1075.4	435.0	632.4	290.3	600.4	353.2	772.3	10712
2070	2234.3	947.3	1221.1	691.8	1424.6	1104.6	432.6	648.2	290.7	603.3	353.8	786.9	10739
2075	2219.5	937.5	1187.2	679.8	1424.5	1124.0	429.0	658.8	289.1	600.1	351.0	796.4	10697
2080	2192.2	923.7	1151.2	663.9	1409.3	1135.4	424.0	664.1	285.8	593.8	345.9	804.9	10594
2085	2152.3	905.9	1112.7	644.3	1386.4	1138.3	417.8	664.4	280.9	589.1	338.6	814.2	10445
2090	2100.2	882.3	1071.5	621.4	1355.8	1132.9	410.3	659.4	274.8	588.6	329.7	813.9	10241
2095	2035.1	853.9	1025.8	595.1	1316.9	1118.4	401.0	649.0	267.0	577.7	319.2	816.0	9975
2100	1959.6	820.6	975.0	565.5	1267.7	1094.3	387.9	633.0	257.3	553.8	307.1	813.5	9635

Table 29. SF$_6$ emissions in metric tons - low scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	1027.4	301.7	601.4	299.2	243.6	147.0	418.9	63.0	131.5	72.3	57.0	187.6	3551
1990	1360.0	417.5	796.5	412.8	398.0	261.1	524.8	101.2	157.8	105.4	75.5	247.0	4858
1995	1617.5	540.8	949.7	507.7	536.8	378.7	488.9	146.7	160.8	142.1	91.5	294.4	5856
2000	1713.0	606.1	1012.2	556.6	642.7	459.1	489.5	186.2	166.5	174.5	105.7	326.3	6438
2005	1676.7	628.9	1001.2	562.4	700.3	485.3	512.7	213.5	203.0	197.4	116.7	338.2	6636
2010	1607.0	615.5	969.4	535.8	720.0	471.6	439.6	224.0	197.0	216.8	126.4	346.7	6470
2015	1493.9	593.1	908.9	501.9	709.7	433.9	341.9	223.5	184.3	228.1	131.7	347.2	6098
2020	1455.8	598.7	894.3	487.2	739.7	457.4	321.7	240.2	181.0	253.2	144.9	367.9	6142
2025	1417.1	598.1	872.9	469.2	769.9	472.9	304.7	256.7	176.5	272.9	155.8	383.3	6150
2030	1386.2	594.3	851.1	455.9	792.9	492.6	293.2	275.1	173.5	291.4	166.3	396.2	6169
2035	1359.3	587.0	829.6	444.6	805.2	510.3	282.0	290.3	170.8	307.0	174.6	409.1	6170
2040	1325.0	574.3	803.7	431.1	803.4	523.7	269.6	301.8	167.3	312.9	180.4	405.4	6099
2045	1276.0	554.1	766.6	412.0	785.8	528.7	256.8	308.1	162.3	313.6	182.3	399.5	5946
2050	1215.6	526.7	721.9	389.4	755.2	525.9	241.8	308.6	155.5	308.9	180.8	391.0	5721
2055	1142.4	493.0	669.8	363.0	713.4	514.4	225.5	302.8	147.0	298.1	175.2	377.0	5422
2060	1056.9	453.7	606.3	333.6	666.9	493.3	207.1	290.4	136.8	280.9	165.4	357.5	5049
2065	958.7	408.6	536.3	299.9	605.1	460.9	186.4	271.0	124.4	257.3	151.4	331.0	4591
2070	843.1	357.5	460.8	261.1	537.6	416.8	163.2	244.6	109.7	227.7	133.5	296.9	4053
2075	754.6	318.7	403.7	231.1	484.3	382.2	145.8	224.0	98.3	204.0	119.4	270.8	3637
2080	606.4	255.5	318.4	183.6	389.8	314.0	117.3	183.7	79.0	164.2	95.7	222.6	2930
2085	489.2	205.9	252.9	146.4	315.1	258.7	95.0	151.0	63.9	133.9	77.0	185.0	2374
2090	358.6	150.6	182.9	106.1	231.5	193.4	70.1	112.6	46.9	100.5	56.3	139.0	1748
2095	214.2	89.9	108.0	62.6	138.6	117.7	42.2	68.3	28.1	60.8	33.6	85.9	1050
2100	56.0	23.4	27.9	16.2	36.2	31.3	11.1	18.1	7.4	15.8	8.8	23.2	275

Table 30. HFC emissions in thousand metric tons of HFC-134a equivalents - high scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	5	2	3	1	0	0	1	0	0	0	0	0	13
1990	6	2	4	1	0	0	1	0	0	0	0	0	15
1995	35	13	21	7	4	1	5	0	1	2	0	1	91
2000	87	34	54	18	14	3	12	1	4	5	1	4	236
2005	146	58	93	30	31	8	23	4	8	11	3	9	424
2010	216	91	138	46	57	16	36	7	12	19	6	17	661
2015	299	129	192	65	89	27	53	12	18	29	10	28	950
2020	395	173	252	87	139	43	70	19	24	44	15	45	1305
2025	433	191	273	96	196	64	76	29	28	56	22	65	1528
2030	472	208	294	107	264	90	82	40	31	70	31	89	1778
2035	514	225	313	117	332	118	88	53	35	85	39	113	2032
2040	556	243	334	128	418	156	93	70	40	103	50	146	2337
2045	601	261	354	138	458	178	98	80	43	115	54	162	2542
2050	647	279	373	149	496	201	103	91	46	127	59	178	2750
2055	695	297	392	160	533	226	108	104	50	139	64	195	2963
2060	745	316	410	171	569	253	114	117	54	150	69	212	3180
2065	796	336	429	182	606	280	119	131	59	162	74	230	3403
2070	850	357	449	193	641	310	124	145	63	173	79	249	3633
2075	905	378	468	205	679	341	130	161	68	184	85	268	3871
2080	961	400	489	217	718	372	136	177	73	195	91	288	4118
2085	1019	423	510	229	759	405	143	194	78	206	97	309	4373
2090	1079	446	532	242	800	440	151	212	83	217	104	331	4637
2095	1140	470	554	254	843	476	160	230	89	229	110	354	4909
2100	1206	495	576	267	885	513	168	250	95	240	118	378	5188

Table 31. HFC emissions in thousand metric tons of HFC-134a equivalents - reference scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	5	2	3	1	0	0	1	0	0	0	0	0	13
1990	6	2	4	1	0	0	1	0	0	0	0	0	15
1995	35	13	21	7	4	1	5	0	1	2	0	1	91
2000	47	18	29	10	8	2	6	1	2	3	1	2	129
2005	61	24	39	13	16	5	10	2	3	5	2	5	184
2010	78	33	50	17	29	9	13	4	5	8	3	10	258
2015	97	42	62	22	48	16	17	7	6	12	6	17	352
2020	114	50	73	26	64	21	20	10	8	16	8	22	433
2025	134	59	85	31	80	27	23	12	9	20	10	28	518
2030	156	69	97	36	98	34	27	15	11	25	12	34	612
2035	169	74	103	39	118	42	29	19	12	29	14	40	689
2040	184	80	110	42	138	51	31	23	13	34	16	48	771
2045	198	86	117	46	151	59	32	26	14	38	18	53	839
2050	214	92	123	49	164	66	34	30	15	42	20	59	907
2055	229	98	129	53	176	75	36	34	17	46	21	64	978
2060	246	104	135	56	188	83	37	38	18	50	23	70	1049
2065	263	111	142	60	200	93	39	43	19	53	24	76	1123
2070	280	118	148	64	211	102	41	48	21	57	26	82	1199
2075	299	125	155	68	224	112	43	53	22	61	28	88	1277
2080	317	132	161	72	237	123	45	58	24	64	30	95	1359
2085	336	140	168	76	250	134	47	64	26	68	32	102	1443
2090	356	147	176	80	264	145	50	70	27	72	34	109	1530
2095	376	155	183	84	278	157	53	76	29	75	36	117	1620
2100	398	163	190	88	292	169	55	82	31	79	39	125	1712

Table 32. HFC emissions in thousand metric tons of HFC-134a equivalents - low scenario

	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW	WORLD
1985	5	2	3	1	0	0	1	0	0	0	0	0	13
1990	6	2	4	1	0	0	1	0	0	0	0	0	15
1995	35	13	21	7	4	1	5	0	1	2	0	1	91
2000	47	18	29	10	8	2	6	1	2	3	1	2	129
2005	61	24	39	13	16	5	10	2	3	5	2	5	184
2010	71	30	46	15	24	7	12	3	4	7	3	8	230
2015	86	37	55	19	34	11	15	5	5	9	4	12	293
2020	87	38	55	20	44	15	15	7	6	11	5	15	318
2025	87	38	55	20	56	19	15	9	6	13	7	19	343
2030	85	37	53	20	60	21	15	9	6	14	7	21	349
2035	82	36	50	19	60	22	14	10	6	15	7	21	342
2040	78	34	47	18	59	22	13	10	6	14	7	20	327
2045	72	31	42	17	55	21	12	10	5	14	7	19	305
2050	65	28	37	15	50	20	10	9	5	13	6	18	275
2055	63	27	35	14	48	20	10	9	5	12	6	18	267
2060	60	25	33	14	46	20	9	9	4	12	6	17	254
2065	56	24	30	13	42	20	8	9	4	11	5	16	238
2070	51	21	27	12	38	19	7	9	4	10	5	15	218
2075	45	19	23	10	34	17	7	8	3	9	4	13	194
2080	38	16	20	9	29	15	5	7	3	8	4	12	165
2085	31	13	15	7	23	12	4	6	2	6	3	9	131
2090	22	9	11	5	16	9	3	4	2	4	2	7	93
2095	11	5	6	3	8	5	2	2	1	2	1	4	49
2100	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 33. PFC emissions factor (ø) values

YEAR	HI	REF	LO
1985	1.37	1.37	1.37
1990	1.10	1.10	1.10
1995	1.00	1.00	1.00
2000	1.00	0.77	0.73
2005	1.00	0.59	0.54
2010	1.00	0.48	0.40
2015	1.00	0.39	0.31
2020	1.00	0.33	0.24
2025	1.00	0.29	0.19
2030	1.00	0.26	0.15
2035	1.00	0.23	0.12
2040	1.00	0.21	0.10
2045	1.00	0.19	0.08
2050	1.00	0.18	0.07
2055	1.00	0.17	0.06
2060	1.00	0.16	0.05
2065	1.00	0.16	0.04
2070	1.00	0.15	0.04
2075	1.00	0.15	0.03
2080	1.00	0.15	0.03
2085	1.00	0.14	0.03
2090	1.00	0.14	0.02
2095	1.00	0.14	0.02
2100	1.00	0.14	0.02

Table 34. SF_6 phi (ø) values

YEAR	LO	REF	HI
1985	0.82	0.82	0.82
1990	0.96	0.96	0.96
1995	1.00	1.00	1.00
2000	0.95	0.97	1.02
2005	0.85	0.94	1.03
2010	0.75	0.91	1.02
2015	0.65	0.88	1.01
2020	0.60	0.85	1.00
2025	0.56	0.82	1.00
2030	0.52	0.79	1.00
2035	0.48	0.76	1.00
2040	0.44	0.71	1.00
2045	0.40	0.68	1.00
2050	0.36	0.65	1.00
2055	0.32	0.62	1.00
2060	0.28	0.59	1.00
2065	0.24	0.56	1.00
2070	0.20	0.53	1.00
2075	0.17	0.50	1.00
2080	0.13	0.47	1.00
2085	0.10	0.44	1.00
2090	0.07	0.41	1.00
2095	0.04	0.38	1.00
2100	0.01	0.35	1.00

Table 35. HFC indirect global ø (calculated from sum of regional emissions and world GDP)

	HIGH	REF	LOW
1985	0.20	0.20	0.20
1990	0.19	0.19	0.19
1995	1.00	1.00	1.00
2000	2.22	1.21	1.21
2005	3.40	1.48	1.48
2010	4.61	1.80	1.60
2015	5.80	2.15	1.79
2020	7.07	2.34	1.72
2025	7.41	2.51	1.66
2030	7.77	2.67	1.52
2035	8.06	2.73	1.36
2040	8.47	2.79	1.19
2045	8.47	2.79	1.02
2050	8.47	2.79	0.85
2055	8.47	2.79	0.76
2060	8.47	2.79	0.68
2065	8.47	2.79	0.59
2070	8.47	2.79	0.51
2075	8.47	2.79	0.42
2080	8.47	2.79	0.34
2085	8.47	2.79	0.25
2090	8.47	2.79	0.17
2095	8.47	2.79	0.08
2100	8.47	2.79	0.00

Table 36. HFC ø values HIGH scenario

YEAR	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW
1985	0.2	0.2	0.2	0.2	0.1	0.0	0.2	0.0	0.2	0.2	0.0	0.0
1990	0.2	0.2	0.2	0.2	0.1	0.0	0.2	0.0	0.2	0.2	0.0	0.0
1995	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2000	2.2	2.2	2.2	2.2	2.6	2.7	2.2	2.7	2.3	2.3	2.7	2.7
2005	3.3	3.3	3.3	3.4	4.7	5.5	3.3	5.5	3.5	3.7	5.5	5.5
2010	4.4	4.4	4.4	4.5	7.2	8.8	4.4	8.8	4.7	5.2	8.8	8.8
2015	5.6	5.6	5.6	5.7	9.8	12.1	5.6	12.1	6.0	6.7	12.1	12.1
2020	6.7	6.7	6.7	6.9	13.0	16.5	6.7	16.5	7.3	8.3	16.5	16.5
2025	6.7	6.7	6.7	7.0	15.8	20.9	6.7	20.9	7.6	9.1	20.9	20.9
2030	6.7	6.7	6.7	7.1	18.7	25.3	6.7	25.3	7.8	9.8	25.3	25.3
2035	6.7	6.7	6.7	7.1	20.8	28.6	6.7	28.6	8.0	10.4	28.6	28.6
2040	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2045	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2050	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2055	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2060	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2065	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2070	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2075	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2080	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2085	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2090	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2095	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0
2100	6.7	6.7	6.7	7.2	23.6	33.0	6.7	33.0	8.3	11.1	33.0	33.0

Table 37. HFC ø values REF scenario

YEAR	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW
1985	0.2	0.2	0.2	0.2	0.1	0.0	0.2	0.0	0.2	0.2	0.0	0.0
1990	0.2	0.2	0.2	0.2	0.1	0.0	0.2	0.0	0.2	0.2	0.0	0.0
1995	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2000	1.2	1.2	1.2	1.2	1.5	1.6	1.2	1.6	1.2	1.3	1.6	1.6
2005	1.4	1.4	1.4	1.4	2.4	3.0	1.4	3.0	1.5	1.7	3.0	3.0
2010	1.6	1.6	1.6	1.7	3.8	4.9	1.6	4.9	1.8	2.2	4.9	4.9
2015	1.8	1.8	1.8	1.9	5.3	7.3	1.8	7.3	2.1	2.7	7.3	7.3
2020	1.9	1.9	1.9	2.1	6.0	8.2	1.9	8.2	2.3	3.0	8.2	8.2
2025	2.1	2.1	2.1	2.2	6.5	8.9	2.1	8.9	2.5	3.2	8.9	8.9
2030	2.2	2.2	2.2	2.4	7.0	9.6	2.2	9.6	2.7	3.4	9.6	9.6
2035	2.2	2.2	2.2	2.4	7.4	10.2	2.2	10.2	2.7	3.5	10.2	10.2
2040	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2045	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2050	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2055	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2060	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2065	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2070	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2075	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2080	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2085	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2090	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2095	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9
2100	2.2	2.2	2.2	2.4	7.8	10.9	2.2	10.9	2.7	3.7	10.9	10.9

Table 38. HFC ø values LOW-scenario

YEAR	USA	JAP	EEC	OOE	EEX	CHN	FSU	IND	EET	DAE	BRA	ROW
1985	0.2	0.2	0.2	0.2	0.1	0.0	0.2	0.0	0.2	0.2	0.0	0.0
1990	0.2	0.2	0.2	0.2	0.1	0.0	0.2	0.0	0.2	0.2	0.0	0.0
1995	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2000	1.2	1.2	1.2	1.2	1.5	1.6	1.2	1.6	1.2	1.3	1.6	1.6
2005	1.4	1.4	1.4	1.4	2.4	3.0	1.4	3.0	1.5	1.7	3.0	3.0
2010	1.5	1.5	1.5	1.5	3.1	4.0	1.5	4.0	1.6	1.9	4.0	4.0
2015	1.6	1.6	1.6	1.7	3.8	4.9	1.6	4.9	1.8	2.2	4.9	4.9
2020	1.5	1.5	1.5	1.6	4.1	5.6	1.5	5.6	1.7	2.2	5.6	5.6
2025	1.3	1.3	1.3	1.4	4.5	6.3	1.3	6.3	1.6	2.2	6.3	6.3
2030	1.2	1.2	1.2	1.3	4.3	5.9	1.2	5.9	1.5	2.0	5.9	5.9
2035	1.1	1.1	1.1	1.2	3.8	5.3	1.1	5.3	1.3	1.8	5.3	5.3
2040	0.9	0.9	0.9	1.0	3.3	4.6	0.9	4.6	1.2	1.6	4.6	4.6
2045	0.8	0.8	0.8	0.9	2.8	4.0	0.8	4.0	1.0	1.3	4.0	4.0
2050	0.7	0.7	0.7	0.7	2.4	3.3	0.7	3.3	0.8	1.1	3.3	3.3
2055	0.6	0.6	0.6	0.7	2.1	3.0	0.6	3.0	0.7	1.0	3.0	3.0
2060	0.5	0.5	0.5	0.6	1.9	2.6	0.5	2.6	0.7	0.9	2.6	2.6
2065	0.5	0.5	0.5	0.5	1.7	2.3	0.5	2.3	0.6	0.8	2.3	2.3
2070	0.4	0.4	0.4	0.4	1.4	2.0	0.4	2.0	0.5	0.7	2.0	2.0
2075	0.3	0.3	0.3	0.4	1.2	1.6	0.3	1.6	0.4	0.6	1.6	1.6
2080	0.3	0.3	0.3	0.3	0.9	1.3	0.3	1.3	0.3	0.4	1.3	1.3
2085	0.2	0.2	0.2	0.2	0.7	1.0	0.2	1.0	0.2	0.3	1.0	1.0
2090	0.1	0.1	0.1	0.1	0.5	0.7	0.1	0.7	0.2	0.2	0.7	0.7
2095	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.3	0.1	0.1	0.3	0.3
2100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

5. Emission Estimates for Criteria Pollutants NO_x, SO_2, CO, and NMVOC, Particulate Emissions of Black Carbon (BC) and Organic Carbon (OC) as well as Ammonia (NH_3) Emissions in 1995

Main data sources used to derive the 1995 emissions are:

- EDGAR 2.0 emissions inventory for 1990 (*Olivier et al*. [1995])
- Energy use for coal, gas, and oil as specified in EPPA (in heat units – EJ)
- IEA data for 1996 for consumption of refined petroleum products
- *Cooke et al*.[1999]; *Liousse et al*. [1996] for black and organic carbon aerosol emissions

5.1 1995 Emissions from Fossils Fuel Combustion

$$\text{Emissions} = \text{emission coefficient x heat units} \qquad (13)$$

Heat units as used in EPPA for 1995. The emission coefficients are fuel, source, and pollutant (NO_x, SO_2, CO, NMVOC, BC, OC) specific. The emission coefficients for different fuel types (coal, refined oil, and gas) and different sources are taken from EDGAR and for BC and OC from *Cooke et al*. [1999]. For BC and OC we use the coefficient for bulk emissions rather than for submicron particulate emissions. *Cooke et al*. [1999] provide for each fuel and source type one emission factor for developed, semideveloped, and underdeveloped countries. We use for our estimate the emission factor for developed countries for the EPPA regions USA, JPN, EEC, and OOE, the emission factor for semideveloped for EET and FSU and the emission factor for underdeveloped countries for the remaining EPPA regions. In the case of the EDGAR emission factors the following attribution was made for the EPPA regions:

USA: USA-EDGAR value
JPN: Japan -EDGAR value
OOE: (2x Canada + Oceania)EDGAR/3
EEC: W Europe-EDGAR value
EET: E Europe-EDGAR value
FSU: CIS EDGAR value
EEX: (Latin Am + Africa + Middle East + East Asia)EDGAR/4
CHN: China region –EDGAR value
IND: India region - EDGAR value
DAE: East Asia – EDGAR value
BRA: Latin Am –EDGAR value
ROW: (Latin Am + Africa + East Asia)EDGAR/3

Based on IEA data on consumption of refined petroleum products for 1996, the partitioning between gasoline and diesel use was determined for each EPPA region (IEA data are on a country level). This allowed us to estimate a single emission coefficient for each region for emissions from refined oil combustion in road transportation. Transportation is part of the EPPA sector OTHERIND and HOUSEHOLD. For each region we assume (based on Melanie Bautista’s work for the USA) that 85% of the heat units in the OTHERIND sector are used in transportation, whereas in the HOUSHOLD sector 90% of the heat units are consumed in the transportation sector. This ratio is the same for all future projections, as well as the partitioning for gasoline and diesel consumption.

5.2 Emissions from Other Sources for 1995

These are emissions from: refining, industrial processes/solvent use, landuse and waste treatment, and biofuel combustion. EDGAR emissions of several sources were aggregated (if necessary) and then attributed to EPPA sectors. All data are therefore for 1990.

Table 39: Non fossil fuel combustion related emission sources.

EPPA sector	Sources from EDGAR	NO_x	SO_x	CO	NMVOC	NH_3	BC	OC
Oil refining	Refining process	x	x	x	x			
Otherind	Manufacturing of building materials, other industrial processes, solvents				x			
Energint	Iron & steel, chemicals, non-ferro, cement	x	x	x	x			
Agric	Biofuel (industry), waste treatment, biomass burning	x	x	x	x	x	x	x
Household	Biofuel housholds, waste burning	x	x	x	x	x	x	x

EPPA sector related to EDGAR sources (for criteria pollutants and NH_3). BC and OC estimates are based on Liousse et al. [1996] and Crutzen and Andreae [1990], though the allocation of the biomass burning emission was done by employing EDGAR maps.

5.3 EPPA emissions for 1995 for Criteria Pollutants (Fossil Fuel and Other), BC, and OC Particulates

Our 1995 emission estimates which were obtained with the EDGAR emission coefficients were compared to EDGAR (*Olivier et al*. [1995]) and other inventories by EPA's (*U.S. EPA* [1997], European Environment Agency (*EEA* [1995, 1997]), papers (*van Aardenne et al*. [1999], *Streets and Waldhoff* [2000], *Cooke et al.* [1999], *Liousse et al.* [1996]), national communications to the FCCC, and emission caps of the "Convention on Long-Range Transboundary Air Pollution" (*CLRTAP*). The more detailed and more recent studies were used to revise our 1995 data.

The following tables list for each species EPPA 1995 estimates (revised data) compared to other studies for 1995 as well as emission estimates for 1990. The comparison is not possible for all EPPA regions because of a lack of data.

Table 40: NO_x estimates (in Gg NO_2)[*,1]

	EPPA 1995	1995		1990		
USA	24859		21713[a]	24065[e]		21586[a]
JPN	3137	2818[c]		2751[e]	2468[c]	
EEC	15740		13827[b]	13171[e]		13590[d]
CHN	14827	12039[c]	11991[f]	10785[e]	9038[c]	9540[f]
IND	6207	4548[c]		5947[e]	3481[c]	
FSU	10132			10883[e]		

[1] NO_x EDGAR emission factors (transportation, power plants US) were down scaled for the US and Europe to be consistent with past development in that areas

Table 41: CO estimates (in Gg CO)[*,2]

	EPPA 1995	1995	1990	
USA	82330	81394[a]	95100[e]	87576[a]
JPN	10749		11800[e]	
EEC	59959	49695[b]	68500[e]	52928[d]
CHN	114465	114640[f]	111500[e]	99423[f]
IND	105807		110000[e]	
FSU	58128		65600[e]	

[2] EDGAR CO emissions from iron & steel and from waste burning were scaled down for USA, JPN, OOE, and EEC (based on *U.S. EPA* [1997], *EEA* [1997]). CHN and IND emissions of AGRIC PROD sector were scaled up based on *Streets and Waldhoff* [2000].

Table 42: NMVOC estimates (in Gg NMVOC)[*,3]

	EPPA 1995	1995	1990	
USA	20197	18675[a]	19000[e]	19037[a]
JPN	5027		5400[e]	
EEC	17256	13866[b]	17700[e]	17760[d]
CHN	18448		18200[e]	
IND	19064		18700[e]	
FSU	15134		17000[e]	

[3] The AGRIC PROD sector emissions were scaled down for USA, JPN, OOE, EEC (following *U.S. EPA* [1997]) and scaled up for CHN and IND.

Table 43: SO_2 estimates (in Gg SO_2)[*]

	EPPA 1995	1995	1990	
USA	16828	16830[a]	21826[e]	20989[a]
JPN	893		1904[e]	
EEC	10739	13280[b]	22506[e]	17059[d]
CHN	25051	25178[f]	28292[e]	23011[f]
IND	5771		4866[e]	
FSU	19625		23007[e]	

Table 44: Caps (or projections for USA, CHN) for SO_2 emissions[*]

	1995	2000	2005	2010	2020
USA	16830[a]	15295[a]	15675[a]	15357[a]	
JPN	850[g]				
OOE	4169[i]				
EEC	10684[h]	9598[h]	7460[h]	6791[h]	
EET	6557[h]	6030[h]	5917[h]	5836[h]	
CHN	25178[f]				30600[f]

Table 45: SO_2 caps in EPPA to reflect policies in place or expected to be in place in the future

Year	Regional caps, Tg SO_2					
	USA	JPN	OOE	EEC	EET	CHN
1995	16830	850	4169	10684	6557	25178
2000	15295	850	4169	9598	6030	25178
2005	15676	850	4169	7460	5917	25178
2010-2020	15358	850	4169	6791	5836	25178
2020-2100	15358	850	4169	6791	5836	30600

[*] References for Tables 22, 23, 24, 25, and 26 are: [a] *U.S. EPA* [1997]; [b] *EEA* [1997]; [c] *van Aardenne et al.* [1999]; [d] *EEA* [1995]; [e] *Olivier et al.* [1995]; CHN and IND region definition in EDGAR slightly different; [f] *Streets and Waldhoff* [2000]; does not include emissions from land-use and industrial processes (about 210 Gg NO_2); [g] *FCCC Japanese 2nd National Communication*; [h] *CLTRAP*; [i] OOE: New Zealand, Turkey missing, Australia -> FCCC for 1995; CLRTAP: CH, Norway, Iceland, Canada.

5.4 Ammonia (NH_3) EPPA Emissions

NH3 emission estimates for 1995 are based on *Bouwman et al*. [1997]. The underlying activity levels for agricultural sources are the same as for CH_4 and N_2O. NH_3 emissions are so far only used as an input to the urban model, where they are needed to calculate nitrate aerosol.

Agricultural sources of NH_3 include ruminant livestock, non-ruminant livestock, crops, synthetic fertilizer, and humans and pets. Ruminant livestock emissions are related to ruminant population projections (Table 5), non-ruminant emissions to non-ruminant population projections (Table 6), crop emissions to harvested crop area projections (Table 1), synthetic fertilizer emissions to nitrogen fertilizer use (Table 4), and human and pet emissions to the EPPA human population projections (Table 46). Table 47 shows the emissions coefficients for each of these sources. Table 48 shows total NH_3 projections.

Table 46: EPPA human population projections (millions of people)

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
1995	267.3	125.4	123.8	371.5	100.6	294.8	1233.6	1226.1	941.5	179.6	161.6	677.8
2000	278.7	126.7	131.3	374.0	103.0	302.9	1383.1	1285.3	1020.6	193.3	173.4	766.5
2010	298.7	127.6	144.3	375.5	106.7	317.0	1695.5	1385.9	1170.2	218.9	194.4	932.4
2020	315.6	126.5	155.0	373.4	109.6	328.3	2017.4	1465.5	1307.6	242.2	212.2	1082.8
2030	329.9	124.2	163.6	368.8	112.2	336.7	2338.5	1527.1	1432.2	263.2	226.7	1216.9
2040	342.2	121.1	170.2	363.0	115.2	342.3	2648.6	1573.6	1543.5	281.9	237.8	1334.2
2050	353.2	118.0	175.1	357.2	119.1	345.1	2937.6	1608.0	1640.8	298.3	245.8	1434.1
2060	363.4	115.3	178.4	352.6	124.5	345.0	3195.2	1633.4	1723.6	312.4	250.4	1515.9
2070	373.5	113.7	180.2	350.4	132.1	342.1	3411.3	1652.7	1791.2	324.1	251.7	1579.2
2080	384.0	113.9	180.8	351.7	142.5	336.3	3575.6	1668.9	1843.0	333.6	249.8	1623.2
2090	395.6	116.3	180.4	357.8	156.1	327.8	3678.0	1685.1	1878.5	340.8	244.6	1647.4
2100	408.8	121.7	179.1	370.0	173.7	316.3	3708.2	1704.2	1897.0	345.7	236.1	1651.2

Table 47: Emissions coefficients for NH_3

		Emissions coefficient											
Source	**Units**	**USA**	**JPN**	**OOE**	**EEC**	**EET**	**FSU**	**EEX**	**CHN**	**IND**	**DAE**	**BRA**	**ROW**
Ruminants	Tg N / million animals	0.0065	0.006	0.003	0.0065	0.0065	0.0065	0.0035	0.005	0.006	0.0041	0.0055	0.0055
Non-rumin.	Tg N / million animals	0.008	0.008	0.005	0.005	0.005	0.005	0.001	0.0035	0.007	0.007	0.007	0.007
Crops	Tg N / 10^6 ha	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Fertilizer	% N converted to NH3	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.17	0.17	0.17	0.1	0.1
Humans	Tg N / million people	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005

Table 48: Total NH_3 emissions (Tg N)

	USA	JPN	OOE	EEC	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	TOT
1995	2.13	0.21	1.32	2.73	0.79	2.20	5.26	8.35	5.37	0.68	1.51	3.53	34.09
2000	2.18	0.21	1.35	2.78	0.81	2.25	5.57	8.58	5.61	0.71	1.56	3.70	35.31
2010	2.28	0.22	1.41	2.86	0.85	2.35	6.21	9.04	6.14	0.79	1.67	4.04	37.84
2020	2.37	0.22	1.48	2.95	0.89	2.45	6.91	9.53	6.70	0.86	1.78	4.39	40.52
2030	2.47	0.22	1.54	3.04	0.94	2.55	7.67	10.03	7.30	0.95	1.90	4.76	43.36
2040	2.58	0.23	1.60	3.13	0.99	2.66	8.48	10.55	7.96	1.04	2.02	5.13	46.37
2050	2.69	0.23	1.67	3.23	1.04	2.77	9.35	11.10	8.67	1.14	2.16	5.53	49.57
2060	2.80	0.24	1.74	3.33	1.10	2.89	10.28	11.68	9.43	1.24	2.30	5.95	52.97
2070	2.92	0.24	1.81	3.44	1.17	3.02	11.27	12.29	10.27	1.36	2.44	6.38	56.61
2080	3.04	0.25	1.89	3.55	1.24	3.15	12.33	12.94	11.18	1.49	2.60	6.84	60.49
2090	3.18	0.25	1.97	3.66	1.32	3.29	13.46	13.63	12.18	1.63	2.77	7.32	64.66
2100	3.31	0.26	2.05	3.79	1.41	3.43	14.67	14.37	13.27	1.79	2.95	7.82	69.13

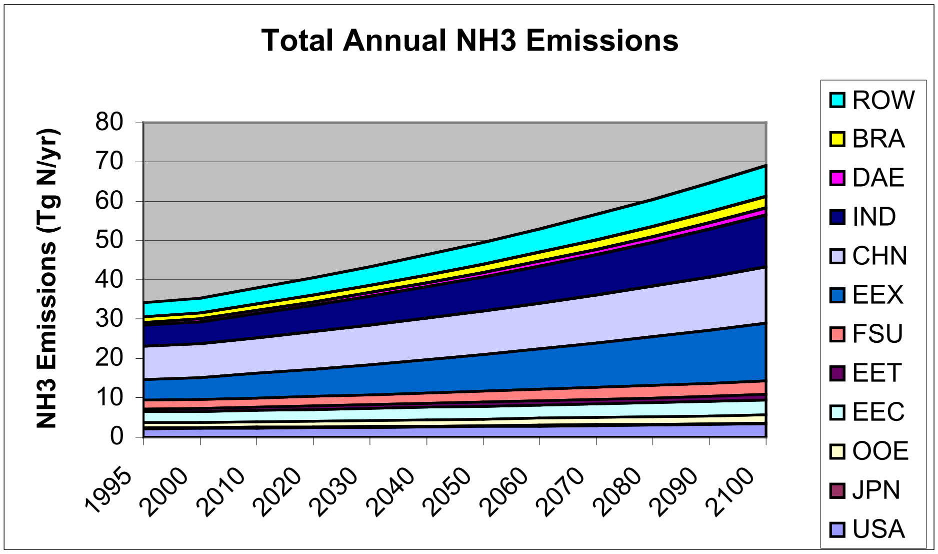

Figure 16: Total NH_3 emissions (Tg N)

6. Time Trends in Emission Coefficients

A key additional consideration for projecting future emissions is the way in which these emission coefficients are likely to change over time, independent of climate policy. In our approach we classify emission coefficients into two categories. The first and more straightforward of these relate to emissions that result from fossil fuel combustion. For these, EPPA forecasts the physical quantities of each fuel and the coefficients are based on measured data that is widely available. Unlike CO_2, however, there are various technological and policy reasons why emissions per unit of fuel differ substantially across countries and over time. We follow an approach based on the observation (e.g. *Seldon and Song*, 1994; *Grossman and Krueger*, 1995) that emissions are related, negatively, to per capita income. The particular reasons behind this relationship have not been explained but it may reflect changes in the composition of the economy, technological sophistication, or a preference for less pollution embodied either in the market choices individuals make or in regulation at various levels of government.

Our approach is somewhat more disaggregated, to be consistent with the EPPA model structure. We estimate relationships between emissions per unit of energy use and per capita GDP for different sectors. We estimate a cross-section relationship for 1995 using the emissions coefficients we developed for the EPPA regions as discussed in previous sections and GDP per capita data from EPPA. The resulting emission coefficients decline with increasing GDP per capita. These relationships were estimated by fitting power series or exponential functions. We estimated separate relationships for each pollutant by fuel and for three different combustion situations. These three combustion situations were: large stationary point source combustion (applied in EPPA to electric power generation, energy intensive industry, and for coal use, other industry) shown in Figure 17 and 18, sectors where fuels are combusted at relatively small scales (household consumption, agriculture) shown in Figures 19 and 20, and refined oil combustion in other industry shown in Figure 19. Much of this latter category is fuel used in transportation. These three different combustion situations result in quite different emissions and different technological and policy options for reducing emissions. The estimated equations for each sector and fuel are given in Table 49.

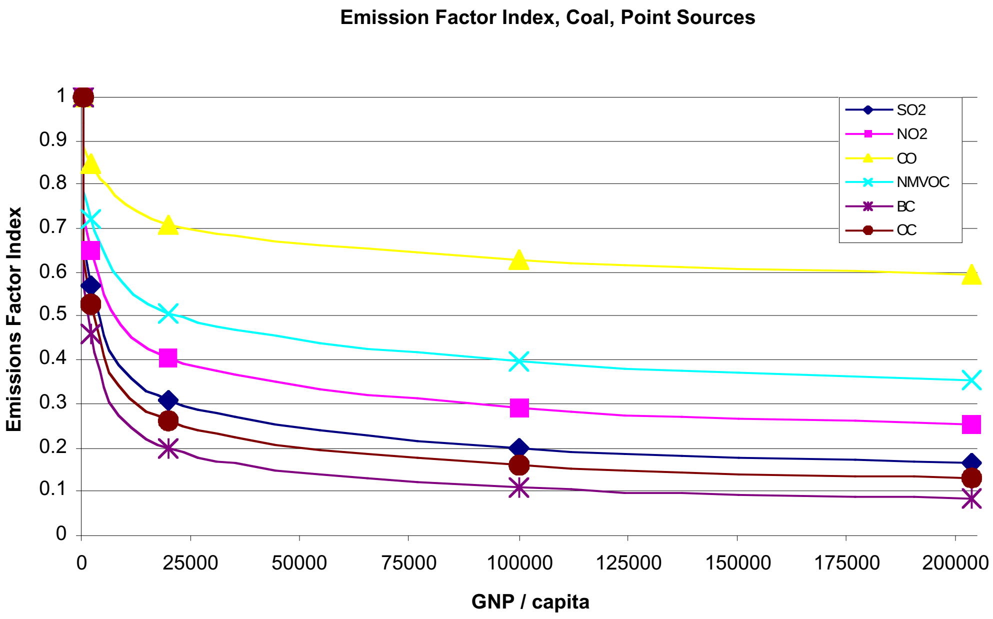

Figure 17: Emission Factor Index, Coal, Large Point Source Combustion

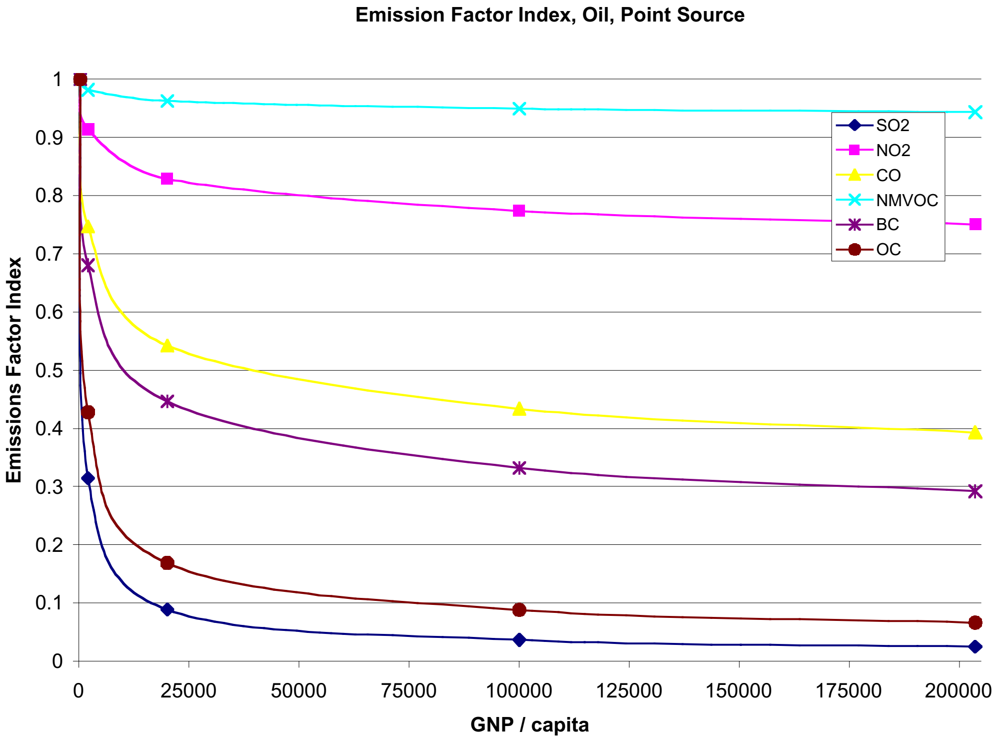

Figure 18: Emission Factor Index, Oil, Large Point Source Combustion

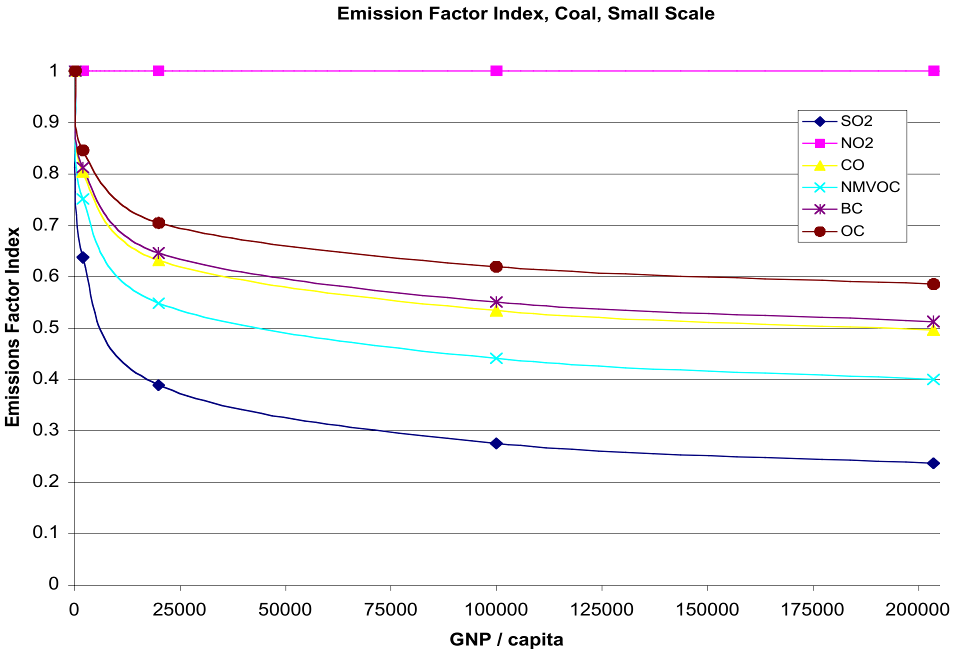

Figure 19: Emission Factor Index, Coal, Small Scale Combustion

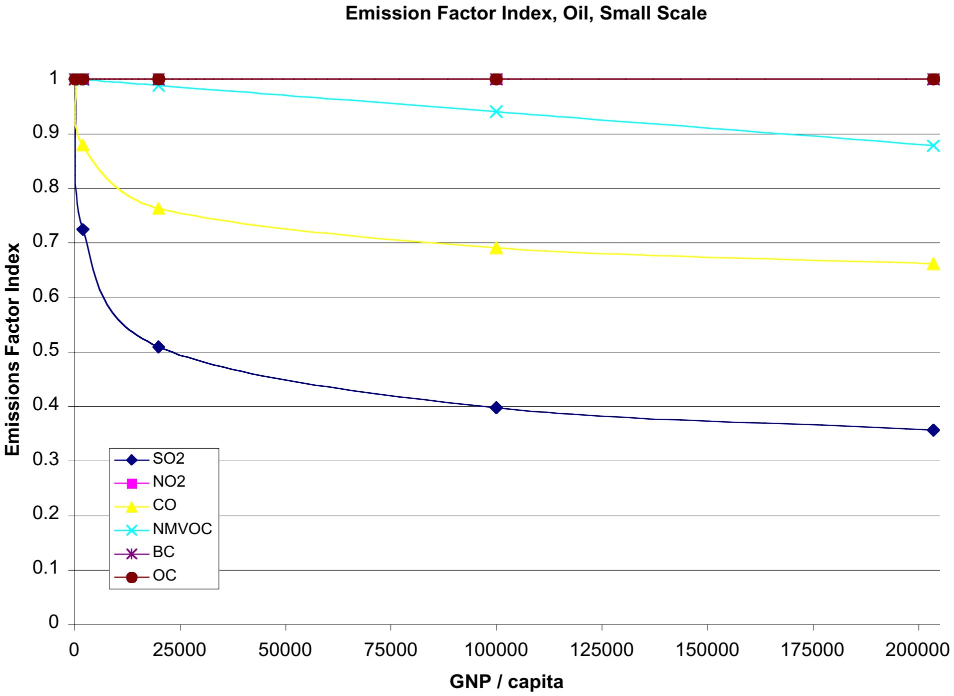

Figure 20: Emission Factor Index, Oil, Small Scale Combustion

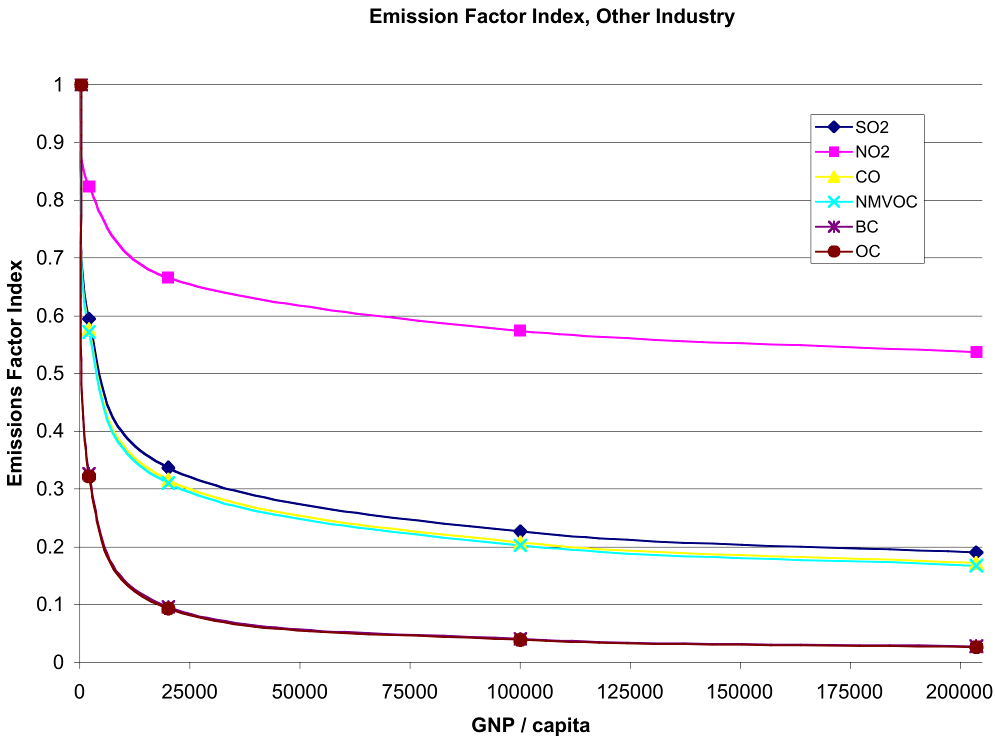

Figure 21: Emission Factor Index, Oil, Other Industry—Applicable to Transportation

Table 49: Regression Estimates of Emissions Factors on GDP/capita

	Estimated emissions factors as a function of GDP/ capita					
	SO_2	**NO_2**	**CO**	**NMVOC**	**BC**	**OC**
Coal,	y = 4.78x^(-0.27)	y = 3.66x^(-0.21)	y = 1.68x^(-0.08)	y = 2.64x^(-0.15)	y = 9.00x^(-0.37)	y = 5.50x^(-0.30)
large scale	R2 = 0.42	R2 = 0.59	R2 = 0.79	R2 = 0.26	R2 = 0.67	R2 = 0.57
Coal,	y = 3.26x^(-0.21)	y = constant	y = 1.88x^(-0.10)	y = 2.35x^(-0.14)	y = 1.54x^(-0.10)	y = 1.68x^(-0.08)
small scale	R2 = 0.31		R2 = 0.41	R2 = 0.36	R2 = 0.33	R2 = 0.15
Oil,	y = 34.47x^(-0.55)	y = 0.88x^(-0.04)	y = 2.35x^(-0.14)	y = 0.53x^(-0.01)	y = 3.13x^(-0.18)	y = 11.08x^(-0.40)
large scale	R2 = 0.72	R2 = 0.10	R2 = 0.37	R2 = 0.01	R2 = 0.71	R2 = 0.58
Oil,	y = 1.45x^(-0.15)	y = constant	y = 0.71x^(-0.06)	y = -6E-07x^(+ 1)	y=constant	y=constant
small scale	R2 = 0.36		R2 = 0.04	R2 = -0.0872		
Oil,	y = 2.29x^(-0.25)	y = 1.65x^(-0.09)	y = 5.03x^(-0.26)	y = 3.06x^(-0.27)	y = 24.72x^(-0.53)	y = 27.46x^(-0.54)
Otherind	R2 = 0.46	R2 = 0.55	R2 = 0.89	R2 = 0.66	R2 = 0.75	R2 = 0.76
Otherind				y = 18.40x^(-0.59)		
solvents				R2 = 0.81		
energint	y = 0.24e-0.0002x					
	R2 = 0.78					

The second category of emission coefficients is used to derive emissions from sources other than fossil fuel use. Here EPPA lacks the physical process detail to project tons of ore smelted, hectares of rice paddies, head of ruminant animals, or other relevant physical indicators of the emissions. We make this category of emission coefficients time dependent in order to reflect the fact that over time there has tended to be a decrease in material outputs of the economy relative to the quantity of output measured in economic terms. For energy, this stylized fact has been represented by the AEEI parameter.

There are a number of phenomena that permit the economy's dollar-value of output to grow relative to physical output such as head of livestock or numbers of microprocessors. The first is a shift in the composition of production at the sectoral level, such that the mix of products within each sector tends toward higher quality, higher priced goods. For example, to get the physical output of the aggregate agriculture sector (AGRIC) one literally needs to add together apples and oranges (and wheat, rice, beef, lumber, and hundreds of other products). In the energy-intensive industry sector (ENERINT) a changing array of chemicals is being aggregated with cement, steel, and aluminum production. And even within a relatively homogeneous subset of this industry like ferrous and non-ferrous metals, trends toward (for example) increased recycling and the manufacture of high-performance steel has tended over time to reduce the material intensity of the economic output of the sector. The EPPA model does not contain the level of detail necessary to directly represent these kinds of changes. A consistent change in the product mix over time can lead to a trend in emissions coefficients attached to aggregate sector production even if, for example, emissions per ton of iron ore, head of livestock, or per hectare of rice are not changing. Even in the case of energy use where EPPA contains physical quantity data, technological changes can lead to changes in emissions per unit of energy.

To capture both of the above types of trends we assessed historical and cross-section data as well as detailed forecasts of physical quantities relative to GDP and sector output that are directly indicative of processes that lead to emissions of GHGs and other pollutants. We used these trends and relationships to establish trends in emissions coefficients that would correct for the fact that EPPA, itself, did not capture the changes in product mix and structural change in the economy below the scale of resolution of the model.

For CH_4, N_2O, and NH_3 agricultural emissions are quite important, particularly in developing countries. We evaluated projections of growth in world and regional rice production and area, harvested area, nitrogen fertilizer use, and livestock production, making assumptions about population and yield growth to extend these projections through 2100, and applying emissions coefficients from *IPCC* [1996] and *Bouwman et al.* [1997] to generate a reference emissions projection as already described in Sections 1 through 3 We used these reference forecasts of emissions with our reference EPPA projections to produce time-varying emissions coefficients.

NMVOC emissions from solvent use is related to OTHERIND. As for emission coefficients from fossil fuel combustion we fit the dependence of the coefficient on GDP per capita with a power series. For biofuel use in households we based our reference projections on population growth and for. Agricultural waste and savannah burning emissions are assumed constant through time. Emissions from deforestation decline, assuming that in 2100 only 10% non-sustainable use occurs. We used emissions coefficients per unit of oil and gas applicable to electric power generation from oil and coal for shale oil and coal gas, respectively, on the basis that the centralized production of these fuels would be subject to similar emissions controls. In the BAU scenario these fuel sources begin to enter after 2030 as fossil fuel prices from conventional sources rise.

6.1 ENERINT Time Trends

6.1.1 Relationships of Physical Output to Value Of Output

ENERINT output in EPPA is measured in value terms rather than physical units of production such as tons of iron ore or cement produced. Production in value terms is a price weighted index of physical units. A trend over time towards higher value output may mean that the number of tons of iron ore or cement does not increase as rapidly as the value index of production. Emissions of pollutants are more directly related to physical tons rather than output in value terms. We use long-term historical data on the change in physical tons and compare this growth rate to growth in output in value terms to derive an trend in the emission coefficient over time. This index is applied to all ENERINT emissions, including CO_2 emissions from cement production.

To derive this index, steel output was used as a proxy for all ENERINT production as these data are most consistently available. GDP data were from the Penn World Tables (*Center for International Comparisons*, 1995) to tons of crude steel output (*Mitchell*, 1998a,b,c). The trends differed for high-income, middle-income, and low-income regions and we thus grouped EPPA regions into these three categories (Table 50).

Historical data was then collected for the largest countries within those regions for which data were available. For high-income countries the period of analysis was 1960-1989 and for low- and middle-income nations it was 1980-1989. GDP and tons of steel for representative countries within each region was summed to represent the region.

Table 50: Regional Groupings

Income Grouping	EPPA Regions	**Countries used**
High (Annex B)	USA	USA
	JPN	Japan
	OOE	None
	EEC	France, West Germany, UK
	EET	Czechoslovakia, East Germany, Poland
	FSU	USSR
Middle	BRA	Brazil
	DAE	South Korea
	ROW	Argentina
Low	CHN	China
	IND	India
	EEX	Indonesia, Mexico

Table 51 and Figures 22 -24 show the aggregate data. Steel output grows more slowly than GDP in the high-income nations (47% as fast). In middle-income countries, steel output grows slightly faster (116%). In low-income nations, steel output grows significantly faster than GDP (219%). These results intuitively make sense. As developing nations move from agrarian to industrial economies, their industrial output will increase faster than their economy as a whole. As their economies mature, however, they move into less energy-intensive industries and eventually develop more of a service-orientation. Then, the energy-intensive sector should grow more slowly than the economy.

Before using these rates in the EPPA model, the results needed to be scaled because ENERINT dollar output does not increase at the same rate as GNP in the model. In other words, the trends described above were already reflected in the model to a small degree, but not as large an effect as historical data suggest. In EPPA, ENERINT dollar output grows 96.9% as fast as GNP for high-income regions, 107.9% as fast as GNP for middle income regions, and 111.5% as fast as GNP for low income regions. Therefore, the rates determined from historical steel output and GDP were scaled to adjust for this. Thus, after adjustment, we wanted the initial rates to be that ENERINT emissions grow 48.4% as fast as ENERINT dollar output for high income regions, 107.3% as fast for middle income regions, and 196.2% as fast for low income regions.

Table 51: Steel Output vs GDP

Income Grouping	5-year Growth Rate, Steel Output	5-year Growth Rate, GDP	Steel Growth Rate / GDP Growth Rate
High	10.0%	21.3%	0.47
Middle	31.1%	26.8%	1.16
Low	30.3%	13.9%	2.19

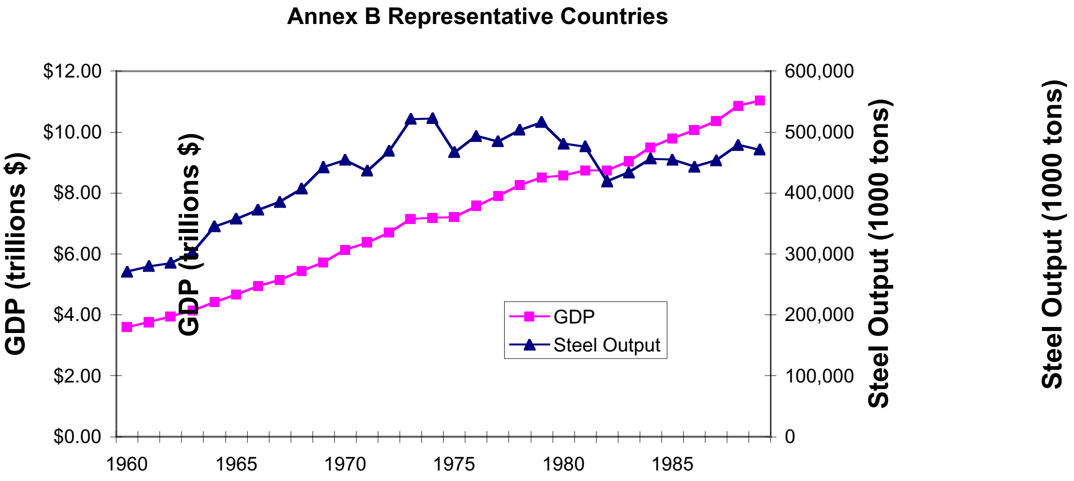

Figure 22: GDP (1985 $) and Steel Output, Annex B Countries

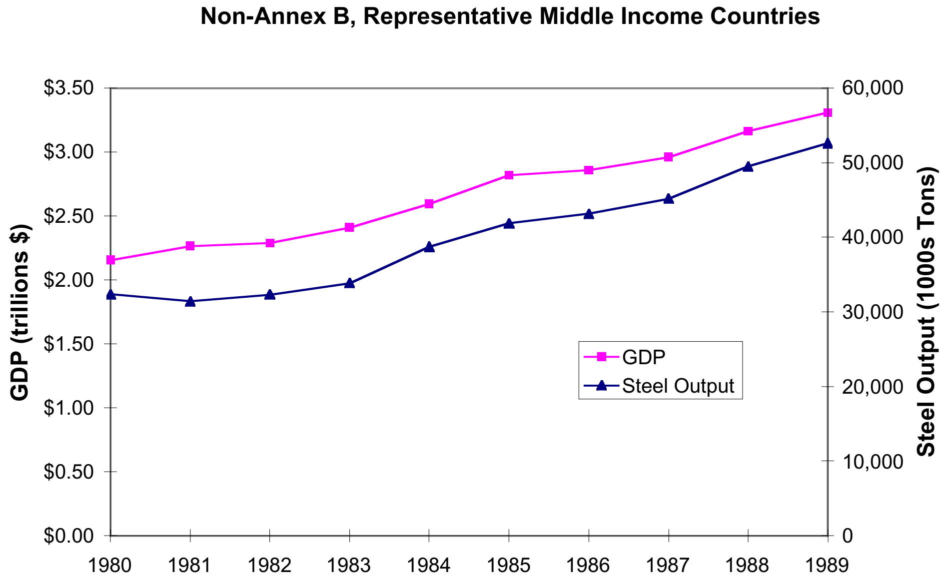

Figure 23: GDP and Steel Output, Middle Income

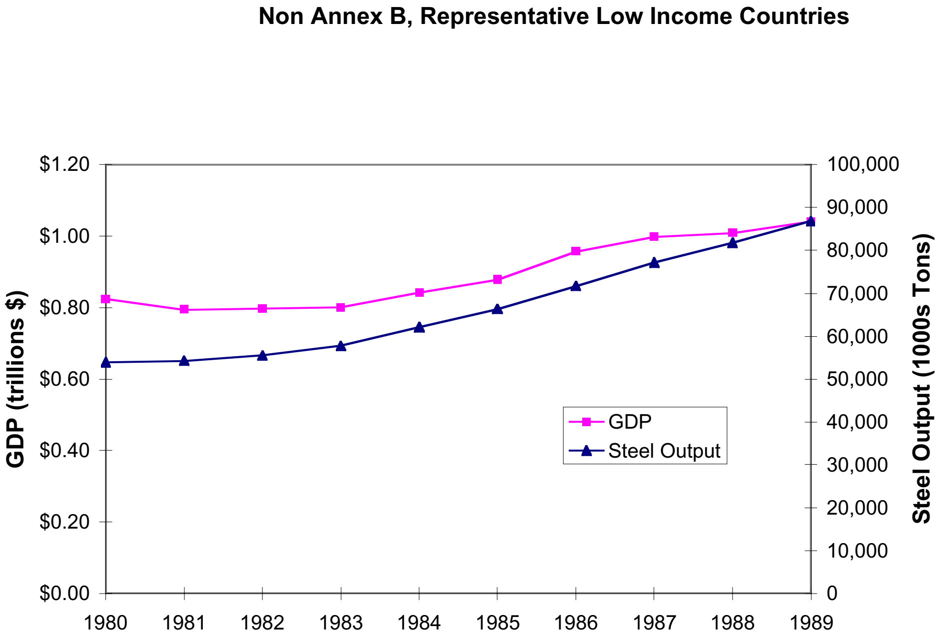

Figure 24: GDP and Steel Output, Low Income Countries

Finally, it was assumed that the emission coefficient trends for low and middle-income nations would converge to that of high-income nations by the year 2100. Thus, the rates shown above for low and middle income nations decrease until they have reached 48.4% in the year 2100.

Following is the functional form for calculating the emission coefficient index over time:

$$\text{Hi:} \quad \exp(-0.05389*t) \tag{14}$$

Middle: exp((1.00961 - exp(0.00293*t)*t) (15)

Low: exp((1.13980 - exp(0.00843*t))*t) (16)

where t = time in 5 year increments (from 0 to 21)

6.1.2 Time dependence of emissions factor for SO_2 emissions from ENERINT industry

The iron and steel industry was used as a proxy for ENERINT industry. SO_2 emissions from ferrous metal processing reported by *U.S. EPA* [1997] were divided by the physical output of iron and steel as reported by *Mitchell* [1998b]. Data from 1960 though 1995 were fitted with an analytical function. This index is applied only to SO_2 emissions from ENERINT. (The index contained in EPPA for SO_2 emissions from ENERINT is this index multiplied by the ENERINT value adjustment index discussed above).

There was no evidence of a trend in emission factors for CO in US data. Therefore, no time trends were created.

6.2 Synthetic Flourinated Compounds

HFC, PFC, and SF_6 projections are taken from *Harnisch* [1999]. EPPA reference case emissions for these gases were set equal to Harnisch's reference case scenario. Time-trends for the emissions coefficients were calculated for each year by dividing emissions for that year by the dollar output of the relevant EPPA activity (the adjusted output in the case of ENERINT, see above).

6.3 Agriculture

Agriculture emissions projections for methane, nitrous oxide, and ammonia were described earlier in this document. Time-trends for the emissions coefficients were calculated for each year by dividing these emission estimates for a given year by the dollar output of AGRIC.

NO_x, SO_2, CO, NMVOC, OC, and BC emissions from agriculture are an aggregate of agricultural waste, savannah burning, and deforestation emissions. We assume that agricultural waste and savannah burning emissions are constant through time, and emissions from deforestation decline, assuming that in 2100 only 10% non-sustainable use occurs. This leads to a decline in total agricultural emissions over time. The emissions are tied to agricultural output of EPPA. The time dependent emission coefficients were derived by dividing the externally projected agricultural emissions by the output of agriculture (in $) calculated by EPPA and creating an index.

CO_2 emissions from deforestation are also related to agricultural output of EPPA. As for NO_x, SO_2, CO, and NMVOC, we assume that in 2100 only 10% non-sustainable use occurs. The time dependent emissions coefficient was obtained the same way as for NO_x, SO_2, CO, and NMVOC.

6.4 Household Emissions (HOUSE)

Household emissions of SO_2, CO, NO_x, and NMVOCs (generally from biofuel burning) are assumed to grow 80% as fast as population. Emissions are calculated as such using the UN population growth tables ("un_pop(t,r)") found in the file eppatrend.gms.

6.5 Methane Emissions from Landfill and Domestic Sewage

In the reference case, methane emissions from landfill and domestic sewage (which are tied to final demand in the EPPA model) are assumed to increase as fast as population.

7. Summary and Uncertainties

The principal objective of this report has been to document the development of reference emissions inventories and reference forecasts of emissions. These have been implemented in the EPPA model as described in Babiker et al. (2001). The inventories and forecasts were developed by applying consistent methods and using the data and technical information that was available at the time the report was prepared. This is an active area of research and data and methods for estimating emissions are improving rapidly. The detail provided here offers a means to update the inventory we developed as new data and measurements become available. There remain substantial uncertainties in current global and regional emissions of most of these substances because of incomplete monitoring and measurement as shown in **Table 52** and as already discussed for the PFCs, HFCs, and SF_6 in earlier sections of this report. Uncertainties in current emissions extend to result in uncertainties in future forecasts. Examining the implications of these uncertainties for the climate change issue is a major focus of our ongoing research.

Table 52: Uncertainty in annual global total emission estimates

	Natural		Anthropogenic		Total	
CH_4 [Tg CH_4]	160	(110 – 210)	375	(300 – 450)	535	(410 – 600)
N_2O [Tg N]	9	(4.3 – 14.7)	7.2	(2.1 – 19.7)	16.2	(6.4 – 34.4)
NO_x [Tg N]	19.3	(6 – 35)	31.1	(16 – 46)	50.4	(22 – 81)
SO_2 [Tg S]	32	(25 – 40)	70	(69 – 76)	102	(95 – 116)
CO [Tg CO]	370	(280 – 960)	925	(600 – 1250)	1295	(880 – 2210)
BC [Tg C]		—	6.5	*fossil fuel* (1.8 – 13)	13.7	(3.8 – 26)
			7.2	*biomass* (2 – 13)		
OC [Tg mass]	7.8	(??)	7.5	*fossil fuel* (0.75 – 15)	59.3	(5.2 – 95)
			44	*biomass* (4.4 – 80)		

Source: Summarized from Olivier *et al*. (1995), Seinfeld and Pandis (1998), and Mosier and Kroeze (1998).

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