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ASIA-WIDE EMISSIONS OF GREENHOUSE GASES

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CONTENTS

ABSTRACT

Emissions of principal greenhouse gases (GHGs) from Asia are increasing faster than those from any other continent. This is a result of rapid economic growth, as well as the fact that almost half of the world's population lives in Asian countries. In this paper, we provide estimates of emissions of the two principal greenhouse gases, carbon dioxide (CO_2) and methane (CH_4), from individual countries and areas. Recent literature has been reviewed for emission estimates for individual sources, such as carbon dioxide from cement manufacture, and methane from rice fields. There are very large uncertainties in many of these estimates, so several estimates are provided, where available.

The largest anthropogenic source of CO_2 emissions is the use of fossil fuels. Energy consumption data from 1992 have been used to calculate estimated

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emissions of CO_2 from this source. In view of the ongoing negotiations to limit future greenhouse gas emissions, estimates of projected CO_2 emissions from the developing countries of Asia are also provided. These are likely to be 3 times their 1986 levels by 2010, under "business as usual" scenarios. Even with the implementation of energy efficiency measures and fuel switching where feasible, the emissions of CO_2 are likely to double within the same time period.

INTRODUCTION

The rapid rate of industrialization and population growth in much of Asia has been accompanied by large increases in emissions of greenhouse gases from the region. During the past few decades, Asia's share of global emissions has increased rapidly. Carbon dioxide emissions caused by the use of fossil fuels, for example, now exceed those from North America and from the European Union, as shown in Figure 1. (Asia, as defined in this paper, includes the central Asian republics of the former Soviet Union, the Middle East, and Turkey). On a per capita basis, emissions from the developing countries of Asia are still only a fraction of those from the more industrialized countries (Figure 2). Therefore, increasing emissions from the Asian countries are to be expected for several decades.

The Framework Convention on Climate Change (FCCC) has been signed by more than 160 countries, and took effect in early 1994. The signatories are required to inventory greenhouse gases (GHGs) and identify policy options for stabilizing or reducing future emissions. The signatories to the FCCC met

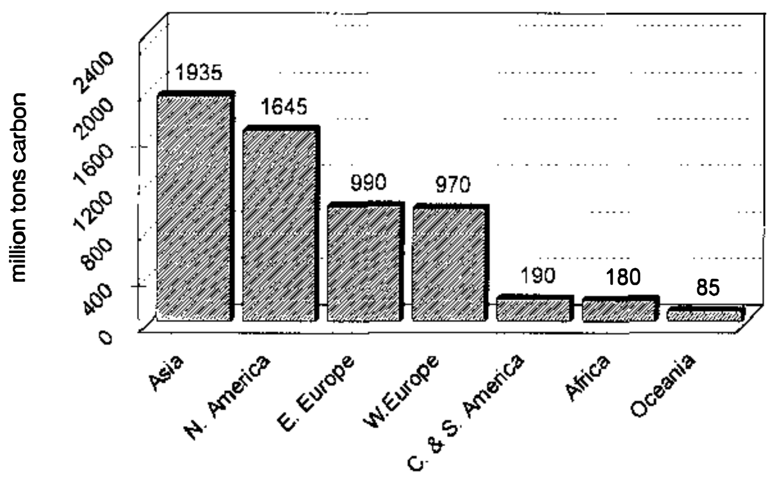

Figure 1 Carbon dioxide emissions from fossil fuels by world region, 1992.

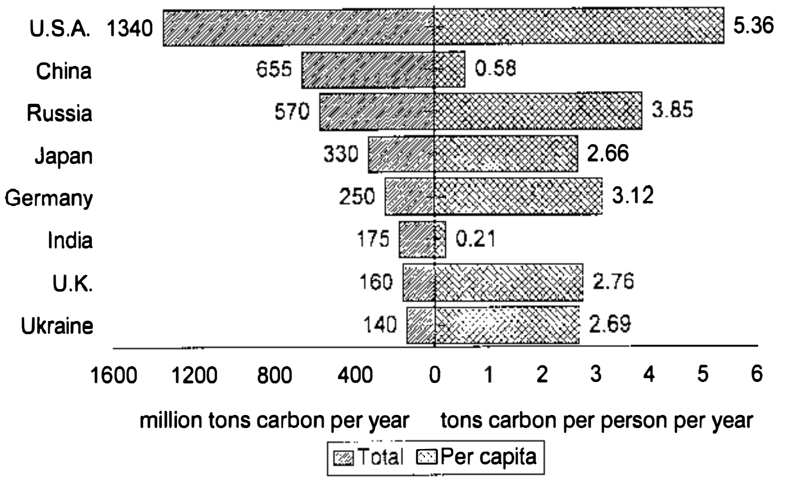

Figure 2 Total and per capita emissions of carbon dioxide from fossil fuel use for countries with the largest total emissions, 1992.

in Berlin in March and April, 1995, but were unable to agree on emission limits or a timetable to achieve them. This situation is different from the one that resulted in the Montreal Protocol for reducing emissions of substances that reduce the ozone layer, where it was possible to agree on a complete phase-out of such substances by the industrialized countries by 1997, and by the developing countries a decade later.

A number of factors make the setting of emission limits for GHGs difficult. These factors include:

1. The current recessions in many industrialized countries and the concern that limits on greenhouse gas emissions would exacerbate economic problems;
2. The concern by developing countries that emission limits would lower their economic growth rates;
3. The disparity in per capita emissions between industrialized and developing countries, and the fact that most anthropogenic greenhouse gas emissions result from activities undertaken by industrialized countries;
4. The view in some industrialized countries that most emissions increases will come from developing countries and that stabilizing or reducing their own emissions is pointless as long as developing countries give no indication of doing so.

The economic and political aspects of limiting greenhouse gas emissions have been discussed in a number of excellent reviews (1–5), and we shall not pursue that subject further here.

This paper presents current estimates of the emissions of greenhouse gases, principally carbon dioxide (CO_2) and methane (CH_4), from the countries of Asia, the continent with the most rapid increase in such emissions. For many of the countries, detailed estimates are under way, and the results will be available within a year or two. For other countries, particularly Japan, China, India, and the Republic of Korea, several estimates have already been made. These are summarized in the relevant sections below.

Each of the greenhouse gases has many anthropogenic sources of emissions (6–8), and the uncertainty in emissions estimates varies greatly with each source. Whereas emissions of CO_2 from the combustion of fossil fuels can usually be accurately estimated to within 5%, uncertainties exceeding 50% are not uncommon for other sources. Uncertainties in estimates of methane emissions from rice fields or coal mines, for example, often exceed 50%. A great deal of additional research is needed to reduce these uncertainties. Some research has begun, but a major effort needs to be made to reduce the uncertainties at a country-specific level. This would assist the countries greatly in assessing the potential for reducing emissions from different sectors, and designing reduction strategies that are cost-effective.

CARBON DIOXIDE EMISSIONS

Carbon dioxide is the largest contributor to greenhouse warming, and the combustion of fossil fuels is the largest anthropogenic source of CO_2 (9). The Carbon Dioxide Information Analysis Center (CDIAC) publishes annual data indicating trends in atmospheric concentrations, as well as emissions from industrial use from various regions of the world, as well as from the larger emitting countries (10). We begin our discussion with CO_2 emissions from fossil fuel use in Asia.

Fossil Fuel Combustion

Annual estimates of CO_2 emissions from fossil fuel combustion and cement manufacturing, since 1950, for several Asian subregions, as well as for many individual countries, are provided in CDIAC reports (11) and are now available on computer disk. Estimates of emissions in more recent years are provided in the biennial reports published by the World Resources Institute (12). More detailed information on several countries is provided in a number of conference proceedings (13–15).

A study commissioned by the Economic and Social Commission for Asia and the Pacific (ESCAP, 16, 17) was the first to provide not only estimated emissions for a base year (1986), but also projected future emissions under alternate scenarios for each of the developing countries in Asia and the Pacific (excluding the Middle East and the central Asian republics that were a part of

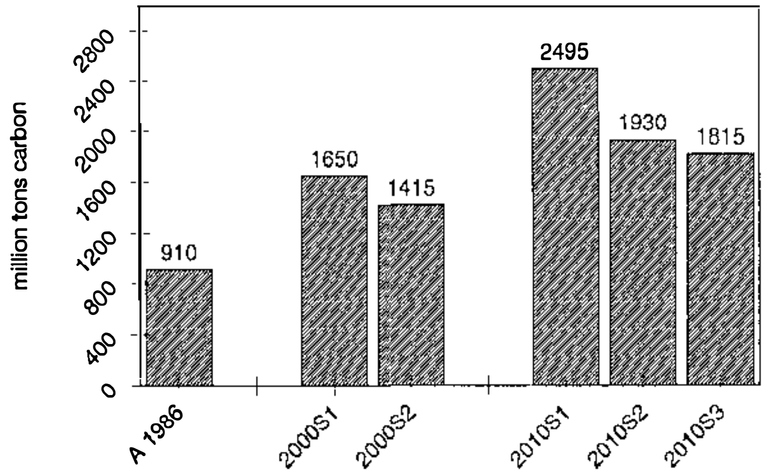

Figure 3 **Recent and projected emissions of carbon dioxide from Asian developing countries.**

alternate scenarios for each of the developing countries in Asia and the Pacific (excluding the Middle East and the central Asian republics that were a part of the USSR at that time). The study used the following scenarios to estimate future emissions:

1. Business As Usual, meaning no special efforts to reduce future emissions;
2. Conservation, meaning efforts to reduce emissions by improving the efficiency of energy use and thereby reduce the actual amount of energy used;
3. Conservation + Fuel Switching, meaning that, in addition to the measures taken in scenario 2, the use of coal and oil would be reduced wherever feasible and replaced by natural gas, hydro- or nuclear power, and renewable energy sources.

The estimated CO_2 emissions from the use of fossil fuels for 1986 for developing Asian countries that were members of ESCAP are shown in Figure 3. The projections for 2000 and 2010 are also shown in Figure 3 for the different scenarios. Because of the long lead time required for fuel switching, scenario 3 was not included for the year 2000. The totals in Figure 3 include emissions from the Pacific islands, but not from Japan, the Middle East, and the central Asian republics. The contribution of the Pacific islands to global emissions of CO_2 is small, amounting to 2.1 million metric tons carbon (MtC) in 1986, 3.0–3.5 MtC in 2000, and 3.4–4.9 MtC in 2010.

The ESCAP study showed that CO_2 emissions from the developing countries of Asia could almost double between 1986 and 2000 and reach three times the

1986 emissions by 2010 under the Business As Usual scenario. Even with the implementation of measures to improve the efficiency of energy use and fuel switching, the 2010 emissions would be almost double those of 1986. Most of the absolute increase would result from anticipated continued growth in coal use in China and India, which derive most of their energy from this source, and where alternate sources of energy could not replace the large amounts required in the 20-year time horizon.

The present author has also estimated the emissions of CO_2 from fossil fuel use in each of the Asian countries during 1992 (Table 1). The energy consumption data are from the United Nations (18), except for Taiwan (19). The data contain some ambiguities regarding the extent to which the coal, oil, and natural gas are used for purposes other than combustion, such as the production of lubricants or tar. Therefore, the estimated emissions shown in Table 1 may be somewhat high, but the overestimation is not expected to exceed 5% in most cases.

The factors for converting energy supplied by coal, oil, and natural gas into carbon emitted into the atmosphere vary somewhat from country to country (11, 20). Since separate emission factors for each of the Asian countries are not available, the emission factors for China (21), the country with the highest emissions, have been used for all the countries in Asia, except for Japan, the second largest emitter, for which a somewhat larger emission factor for coal (26.2 gC Gj^{-1}) has been used, based on the OECD Pacific estimate by the International Energy Agency (IEA) (20).

For all countries except India, 98% of the fuel's carbon content is assumed to be emitted into the atmosphere as carbon dioxide. The Central Fuel Research Institute of India has estimated (22) that an average of 90% of carbon in the coals is converted into CO_2 [this low value may be a result of the very large ash content (30–40%) in Indian coals], and this estimate was used to calculate India's CO_2 emissions from coal in Table 1.

Some of the other estimates (23–29) for CO_2 emissions for countries with substantial emissions are shown in Table 2. A number of additional estimates are expected to become available during the next year.

Cement

In Asia as a whole, cement manufacturing contributes about 4% of the total CO_2 emissions from industrial processes (12), the remainder coming from the use of fossil fuels and gas flaring. The total CO_2 emissions due to cement manufacturing from the Asian countries, excluding the central Asian republics of the former USSR, amounted to 77 million tons (Mt) in 1991 out of a world total of 162 Mt. China is by far the largest emitter, with Japan, India, and the Republic of Korea also contributing substantially. The emissions of CO_2 from cement manufacturing in the major emitting countries in Asia are given in Table 3.

Biomass Combustion

The uncertainties in estimating emissions of CO_2 from biomass combustion are much larger than those for fossil fuels or cement manufacturing. Uncertainties about the amount of biomass burned, as well as the conditions under which it is burned, are relatively large. Biomass usually includes fuelwood, agricultural wastes, and animal wastes. The actual amounts of these items that undergo combustion in each country are not known accurately. The amount burned in stoves, the efficiency of combustion of the stoves, and the amounts burned in the open are also subject to large uncertainties.

The United Nations has compiled estimated amounts of fuelwood and bagasse (from sugarcane) used for energy purposes in the Asian countries (18). These estimates have been converted into energy supplied, in terms of million metric tons of coal equivalent (Mtce), using the conversion factors given in Reference 18. The energy supplied by these sources is given in Table 4 for the subregions and for the countries where the total amount of energy supplied by these biomass sources exceeds 100 thousand metric tons (100 ktce or 0.1 Mtce). Figures given separately for charcoal are included in the fuelwood column, with a conversion value of 0.986 tce/ton of charcoal.

The total amount of biomass in all forms used for energy, as well as that used as fuelwood, has been estimated for most countries in a report published by the Food and Agriculture Organization of the United Nations (FAO) (28). These estimates are based on FAO's own database, as well as data from the UN Statistical Office and detailed studies by the Biomass Users Network. For developing countries with no published data, FAO assumed that the annual per capita consumption of biomass is 1 ton of wood equivalent (twe) for rural inhabitants and 0.5 twe for urban inhabitants.

Estimates of the amount of energy derived from all forms of biomass in several developing countries during 1987 have been compiled by Hall (29). These estimates were converted into tons of carbon emitted as CO_2 using the conversion factor of 0.636 metric tons of carbon per ton of coal equivalent (20), with the usual provisos regarding large uncertainties in the estimates. The results for the Asian countries are given in Table 5.

Estimates of biofuels consumption in several Asian countries have also been provided by Myers and Leach (30). Recent studies on China (21) and India (22) estimate the total amount of energy supplied by biomass at 266 and 176 million tons coal equivalent respectively during 1990.

Many countries have not made estimates of the emissions of CO_2 from biomass combustion because they maintain that these figures are about equal

Table 1 Carbon dioxide emissions from fossil fuel consumption in Asia (1992)[a]

		Fossil fuel consumption (Mtoe)			Carbon dioxide emissions from fossil fuels[b] (million tons carbon)			
Subregion	Country/area	Coal and lignite	Oil	Nat. gas and LNG	Coal and lignite	Oil	Nat. Gas and LNG	Total
East Asia	China	544.5	109.8	14.7	594.0	96.2	9.0	699.2
	Hong Kong	5.5	4.2		6.0	3.7	0.0	9.7
	Japan	81.4	209.9	52.5	94.4	183.9	32.1	310.4
	Korea, DPR	60.7	4.6		66.2	4.0	0.0	70.3
	Korea, Rep. of	25.3	78.5	5.7	27.5	68.8	3.5	99.8
	Macao		0.4		0.0	0.3	0.0	0.3
	Mongolia	1.9	0.6		2.1	0.5	0.0	2.6
	Taiwan[c]	16.5	28.6	2.0	18.0	25.1	1.2	44.3
						Total for Subregion		1236.6
Southeast Asia	Brunei		0.8	2.4	0.0	0.7	1.5	2.2
	Cambodia	0.0	0.2		0.0	0.1	0.0	0.1
	Indonesia	3.9	27.2	19.2	4.2	23.8	11.8	39.8
	Lao PDR	0.0	0.1		0.0	0.1	0.0	0.1
	Malaysia	1.6	14.6	7.0	1.8	12.8	4.3	18.9
	Myanmar	0.0	0.6	0.9	0.0	0.5	0.6	1.1
Philippines		1.3	11.8		1.5	10.4	0.0	11.8
	Singapore	0.0	16.5		0.0	14.4	0.0	14.4
	Thailand	4.1	23.2	7.2	4.5	20.3	4.4	29.2
	Vietnam	2.4	2.9	0.0	2.6	2.6	0.0	5.2
						Total for Subregion		122.9
South Asia	*Afghanistan*	0.0	0.3	0.2	0.0	0.3	0.1	0.4
	Bangladesh	0.2	2.1	4.7	0.2	1.8	2.9	4.9
	Bhutan	0.0	0.0		0.0	0.0	0.0	0.0
	India	143.9	52.8	10.9	144.2	46.2	6.7	197.1
	Iran, Isl. Rep.	1.4	46.3	23.3	1.6	40.6	14.3	56.4
	Maldives		0.0		0.0	0.0	0.0	0.0
	Nepal	0.1	0.3		0.1	0.3	0.0	0.3

	Pakistan	2.2	10.8	11.2	2.4	9.5	6.8	18.7
	Sri Lanka	0.0	1.6		0.0	1.4	0.0	1.4
						Total for Subregion		279.2
Central Asia	Armenia	0.1		1.7	0.1	0.0	1.1	1.2
	Azerbaijan	0.0	0.4	10.8	0.0	0.4	6.6	7.0
	Kazakhstan	52.6	6.0	17.2	57.4	5.2	10.5	73.1
	Kyrgyzstan	1.7	1.5	1.8	1.9	1.3	1.1	4.3
	Tajikistan	0.1	0.0	1.7	0.1	0.0	1.0	1.1
	Turkmenistan	0.2	0.5	10.4	0.2	0.5	6.4	7.1
	Uzbekistan	4.8	5.1	38.5	5.3	4.5	23.5	33.3
						Total for Subregion		127.0
Middle East and West Asia	Bahrein	0.0	0.7	4.8	0.0	0.6	3.0	3.6
	Cyprus	0.0	1.4		0.0	1.3	0.0	1.3
	Iraq	0.0	14.0	2.8	0.0	12.2	1.7	14.0
	Israel	3.5	8.3	0.0	3.8	7.3	0.0	11.0
	Jordan	0.0	3.4		0.0	3.0	0.0	3.0
	Kuwait[d]	0.0	3.1	2.4	0.0	2.7	1.5	4.2
	Lebanon	0.0	3.5	0.0	0.0	3.1	0.0	3.1
	Oman	0.0	1.6	1.7	0.0	1.4	1.4	2.4
	Qatar	0.0	1.8	10.7	0.0	1.6	6.6	8.2
	Saudi Arabia[d]	0.0	35.9	32.1	0.0	31.4	19.6	51.1
	Syrian Arab R.	0.0	9.6	1.8	0.0	8.4	1.1	9.5
	Turkey	15.4	20.7	4.2	16.8	18.1	2.6	37.5
	United Arab E.	0.0	6.7	23.8	0.0	5.9	14.5	20.4
	Yemen	0.0	2.9	0.0	0.0	2.5	0.0	2.5
						Total for Subregion		171.7
						Total for Asia		1937.4

[a] Sources: The energy data are for 1992, and taken from the *United Nations' Energy Statistics 1992* (18) unless indicated otherwise.
Mtoe = million metric tons oil equivalent.

[b] The carbon dioxide emissions were calculated by the present author using the following conversion factors: Coal: g-C Gj − 1, 24.8; tons-C toe − 1, 1.091. Petroleum products: kg-C Gj − 1, 19.9; tons-C toe − 1, 0.876. Natural Gas: kg-C Gj − 1, 13.9; tons-C toe − 1, 0.612. Please see the text for a discussion of these.

[c] From Reference 19.

[d] Includes part of Neutral Zone.

Table 2 Carbon dioxide emissions estimates from fossil fuel consumption in selected Asian countries

Country	Emissions (Mt-C)	Estimate for Year	Reference
China	660.5	1991	23
China	614.5	1990	21
India	182.2	1991	23
India	153.0	1989–1990	22
India	167.5	1989–1990	24
Indonesia	32.9	1990	22
Iran, Isl. Rep. of	52.9	1991	23
Japan	285.7	1991	23
Japan	322.7	1992	25
Korea, DPR	64.2	1991	23
Korea, Rep. of	67.7	1991	23
Korea, Rep. of	63.0	1990	26
Pakistan	17.6	1990–1991	27
Philippines	10.1	1990	22
Saudi Arabia	53.0	1991	23
Thailand	23.2	1991	27
Vietnam	5.3	1990	22

Table 3 Carbon dioxide emissions estimates from cement production in selected Asian countries

Country	Emissions (Mt-C)	Estimate for Year	Reference
China	33.7	1991	23
China	25.5	1990	21
India	6.8	1991	23
India	6.3	1989–1990	22
Indonesia	1.7	1990	22
Iran, Isl. Rep. of	2.0	1991	23
Iraq	0.7	1991	12
Israel	0.4	1991	12
Japan	12.1	1991	23
Korea, DPR	2.2	1991	23
Korea, Rep. of	4.6	1991	23
Malaysia	1.0	1991	12
Pakistan	1.0	1991	12
Philippines	0.6	1991	12
Saudi Arabia	1.6	1991	23
Thailand	2.5	1991	12
Turkey	3.5	1991	12
Vietnam	0.9	1990	22

Table 4 Carbon dioxide emissions from selected[a] biomass consumption in some Asian countries, 1992

		Fuelwood		Bagasse		Subtotal	CO_2
Subregion	Country/Area	million m3	million tce[b]	million tons	million tce[b]	biomass (Mtce)	emissions[c] (Mt-C)
East Asia	China	203.77	67.24	23.11	6.10	73.35	46.65
	Japan	0.17	0.15	0.44	0.12	0.27	0.17
	Korea, Dem. P.R.	4.18	1.38			1.38	0.88
	Korea, Rep. of	2.40	0.79			0.79	0.50
	Mongolia	1.35	0.45			0.45	0.28
Southeast Asia	Cambodia	5.71	1.88			1.88	1.20
	Indonesia	146.28	48.27	7.66	2.02	50.29	31.99
	Lao Peop. Dem. Rep.	4.13	1.36			1.36	0.87
	Malaysia	9.16	3.02	0.34	0.09	3.11	1.98
	Myanmar	18.63	6.15	0.36	0.10	6.24	3.97
	Philippines	35.04	11.56	6.03	1.59	13.16	8.37
	Thailand	60.84	20.08	10.43	2.75	22.83	14.52
	Vietnam	25.16	8.30	1.28	0.34	8.64	5.50
South Asia	Afghanistan	5.67	1.87			1.87	1.19
	Bangladesh	5.90	1.95	3.35	0.88	2.83	1.80
	India	257.79	85.07	45.22	11.94	97.01	61.70
	Iran, Islamic Rep. of	2.51	0.83	0.72	0.19	1.02	0.65
	Nepal	17.11	5.65	0.07	0.02	5.66	3.60
	Pakistan	24.38	8.05	8.15	2.15	10.20	6.49
	Sri Lanka	9.10	3.00	0.22	0.06	3.06	1.95
Central Asia	Kazakhstan	0.55	0.18			0.18	0.12
Middle East	Lebanon	0.48	0.16			0.16	0.10
	Turkey	9.75	3.22			3.22	2.05
	Yemen	0.32	0.11			0.11	0.07
				Total for Asia		309.26	169.69

[a] Data on agricultural and animal wastes are not included here.
[b] Conversion factors (18): Fuel wood: 0.33 tce/m3; Bagasse: 0.264 tce/t; tce = tons of coal equivalent.
Sources: The biomass energy data are from the United Nations (18).
[c] The carbon dioxide emissions have been calculated by the present author using the conversion factor: 0.636 t-C/tce (20).

Table 5 Energy derived from all biomass in selected Asian countries, 1987

Country	Biomass energy[a] (Mtoe)	CO_2 emissions[b] (Mt-C)
Bangladesh	36.3	33.9
China	221.1	206.2
India	203.4	189.7
Indonesia	63.2	59.0
Malaysia	15.8	14.7
Nepal	10.4	9.7
Pakistan	29.7	27.7
Philippines	20.4	19.0
Sri Lanka	4.3	4.0
Thailand	4.9	4.6

[a] The energy data are from Hall (29)
[b] The carbon dioxide emissions have been calculated by the present author using the conversion factor: 0.636 t-C/tce (20).

balance for each country is to be calculated. India is one of the few countries where detailed estimates have been made (24), and such emissions amounted to about 148 MtC during 1989–90.

Land Use Changes

Changes in land use such as the switch from forests to agriculture have been a major source of carbon dioxide emissions for centuries (31). The pace of such change has accelerated in Asia during the past several decades, owing to population increases, as well as demand for fuelwood, timber, and residential land. The rate at which land conversions have been taking place in individual countries and regions is the source of much controversy. Thus the available data should be considered very tentative. Table 6 shows estimated CO_2 emissions (12) caused by land use changes in 1991 in several Asian countries. Estimates of such emissions in a few Asian countries are also provided in Reference 22.

METHANE EMISSIONS

Global anthropogenic methane emissions rank second only to carbon dioxide emissions in their contribution to greenhouse warming. The Asian countries (excluding the central Asian republics of the former USSR) are estimated to have emitted about 120 million tons (Mt) of methane from human activities, out of a global total of about 250 Mt emitted in 1991 (12). More than half of

Table 6 Estimated emissions of carbon dioxide due to land use changes in selected Asian countries, 1991

Country	Emissions (Mt-C)
Bangladesh	1.9
Bhutan	1.1
Cambodia	9.3
India	5.7
Indonesia	89.9
Lao PDR	9.8
Malaysia	30.0
Myanmar	32.7
Nepal	2.1
Pakistan	2.6
Philippines	30.0
Sri Lanka	1.0
Thailand	24.8
Vietnam	9.0

Source: World Resources Institute (12)

this figure is attributed to rice production, with other major contributions coming from livestock, coal mining, solid wastes, and oil and gas production. The estimates compiled by the World Resources Institute (WRI) (12) for the Asian countries are shown in Table 7. As mentioned earlier, estimates of methane emissions are subject to very large uncertainties (6, 32), particularly for emissions from rice production, coal mines, and natural gas distribution. These are discussed in the relevant sections that follow.

Rice Fields

The flux of methane (defined as milligrams of methane per square meter per hour, $mg/m^{-2}\ h^{-1}$) varies enormously, depending on several factors such as agricultural practices, soil conditions, time of day and year, and rice varieties. Thus the estimates of methane emissions from entire countries, and from the world as a whole, are subject to very large uncertainties. The Intergovernmental Panel on Climate Change (IPCC) (6) estimates global methane emissions from rice paddies range from 20–150 Mt (recently revised to a range of 20–100 Mt). Their report also gives revised estimates of methane fluxes in several Asian countries, which range (in units of $mg/m^{-2}\ h^{-1}$) from 0.1–27.5 for India, 7.8–60.0 for China, 0.4–16.2 for Japan, and 3.7–19.6 for Thailand.

An earlier review by Khalil and Rasmussen (32) of 11 global methane budgets found a range of 18–280 teragrams (Tg). Estimates by Bachelet &

Table 7 Estimated emissions of methane from anthropogenic sources in selected Asian countries, 1991

Country	Methane emissions (teragrams or million metric tons methane per year)					
	Rice production	Livestock	Solid waste	Coal mining	Oil & Gas production	Total
Afghanistan	0.1	0.2	0.0	0.0	0.0	0.3
Bangladesh	5.0	1.0	0.2		0.1	6.2
China	19.0	5.4	0.9	14.0	0.3	39.5
India	19.0	12.0	2.3	1.8	0.2	35.3
Indonesia	5.1	0.7	0.5	0.1	0.7	7.0
Iran, Islamic Rep.	0.3	0.6	0.3	0.0	0.4	1.6
Iraq	0.1	0.1	0.3		0.0	0.5
Japan	1.4	0.3	1.9	0.1	0.0	3.7
Korea, DPR	0.3	0.1	0.1	0.8		1.3
Korea, Rep. of	0.6	0.1	0.3	0.3		1.2
Lao PDR	0.2	0.1	0.0			0.3
Malaysia	0.3	0.0	0.1		0.3	0.6
Mongolia		0.3	0.0	0.0		0.3
Myanmar	3.0	0.4	0.1	0.0	0.0	3.5
Nepal	0.6	0.4	0.0		0.2	3.2
Pakistan	1.1	1.9	0.0	0.0	0.2	3.2
Philippines	1.5	0.2	0.2			1.9
Saudi Arabia		0.1	0.2		0.6	0.9
Sri Lanka	0.5	0.1	0.0			0.6
Syrian Arab Rep.		0.1	0.1			0.2
Thailand	5.3	0.4	0.1	0.0	0.1	5.9
Turkey	0.0	0.7	0.3	0.0	0.0	1.1
United Arab Emr.		0.0	0.1		0.4	0.5
Vietnam	3.4	0.3		0.1	0.0	3.7

Source: World Resources Institute (12).
[a] Many of these estimates are subjected to very large uncertainties. For example, for the two largest emitting countries, China and India, other estimates (21, 22) give total emissions of 28 and 16 Tg per year respectively.

Neue (33) of methane emissions from rice fields in Asia using several techniques suggest total emissions of about 60 Tg.

Perhaps the best known example of the wide differences in estimates in the Asian context is for emissions from rice fields in India. The US Environmental Protection Agency (USEPA) (34) estimates that India's emissions of methane amounted to 16 Tg (=Mt) during 1990, whereas the Indian Agricultural Research Institute has estimated (22, 24) these emissions at 4.0 Tg and Sinha (35) at 0.83–1.22 Tg. In the case of China, scientists at the Chinese Academy of Agricultural Sciences have estimated (36) total CH_4 emissions from rice fields in China at 11.3 Tg, whereas the USEPA estimate is 21 Tg. All of these studies suggest that extrapolations of fluxes from Europe and North America to specific Asian countries may not be useful, and that detailed measurements in different parts of larger countries would be required to improve the accuracy of the estimates.

Enteric Fermentation and Animal Wastes

Livestock are a major source of methane, owing directly to enteric fermentation, as well as manure emissions. Global emissions from the former source are estimated (34) to be in the range of 65–100 Tg, and 10–18 Tg from the latter. According to the WRI estimate (12), about one third of all methane emissions from livestock is from Asian countries.

The USEPA (34) has estimated China's emissions of CH_4 from enteric fermentation at 6 Tg, and from livestock manure at 2 Tg. The former number is fairly close to the 5.5 Tg estimated in the study for the Asian Development Bank and the State Science and Technology Commission of China (ADB/SSTC) (21), which includes estimates of animal populations in individual provinces, as well as emission factors for the different animals.

For India, the Council for Scientific and Industrial Research (CSIR) estimate (24) for CH_4 emissions from enteric fermentation from all animals is 6.9 Tg, about 30% less than the 10 Tg estimated by USEPA (34). The differences in the estimates for China and India are considerably smaller than for emissions from rice fields.

Coal Mines

Coal mines are a substantial source of methane emissions in the major coal-producing countries of the world. China and India are the largest coal producers in Asia, the former producing about 1,100 Mt per year. Estimates of CH_4 emissions from China's coal mines vary by a factor of about 3. The review by IEA (37) discusses the assumptions underlying estimates of 5.3, 7.6, 15.3, and 16.1 Tg per year made during the 1990–1992 period. The ADB/SSTC study estimated (21) the emissions at 5.3 Tg, based on the methane content of seams in the major coal fields. This is lower than the range of 9.5–16.6 Tg estimated by USEPA (34). Their estimate of India's emissions of 0.4 Tg agrees with the ADB study (22).

Oil and Gas

The natural–gas and oil production and distribution system is believed to be the largest source of anthropogenic methane in Russia (34), but its contribution to emissions in the Asian countries is estimated at only about 3.2 Tg (12). Estimates of contributions from the major emitting countries are provided in Table 7. The largest source of uncertainty in these estimates, owing to lack of

Table 8 Estimated emissions of methane from anthropogenic biomass combustion in selected Asian countries[a]

Country/Region	Emissions (Tg/year)
Bangladesh	0.8
China	7.3
India	2.6
Indonesia	2.9
Mayanmar	1.0
Pakistan	0.7
Thailand	0.9
Vietnam	0.8
Other Asia	2.9

[a] Source: USEPA (34)

data, is leakage from natural–gas pipeline systems, which can reach 5% of the throughput in some of the older systems.

Biomass Burning

Worldwide anthropogenic emissions of methane from biomass combustion are estimated in the range of 20–80 Tg per year. Estimates for many of the countries in Asia are not available, but those provided by USEPA (34) for several countries for 1990 are summarized in Table 8.

Solid Wastes

Urban wastes are the largest source of methane emissions in many industrialized countries, including the US (34) and Japan (38). They are of growing importance in the larger and more developed countries of Asia, including China and India. Emissions in China are estimated (21) in the range of 0.6–2.0 Tg per year, in India at 2.4 Tg per year (22), and in Thailand at 0.3 Tg per year (34). Japan's emissions are estimated in the range of 0.4–0.8 Tg per year (38).

In many Asian countries, agricultural wastes are likely to contribute more to methane emissions than urban wastes. In China, for example, emissions from agricultural wastes are estimated at 2–4 Tg per year (21), about 2–3 times the emissions from urban wastes.

OTHER GREENHOUSE GASES

The other major (6) long-lived greenhouse gases are nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and carbon tetrachloride (CCl_4). Anthropogenic sources are estimated to contribute about 1–6 Tg of nitrogen per year in the form of N_2O. Combustion of fossil fuels and biomass is the largest source of N_2O. Estimated emissions from individual countries are not yet available in most cases, but initial estimates have been made for a few, including China, India and Japan (38). The estimated emissions for China (21) lie in the range of 0.2–0.6 Tg- Nitrogen (N) per year. Approximately one third to one half this amount is estimated to be from fossil fuel combustion. The total for India is estimated (22) at approximately 0.04 Tg - N per year. Most of these emissions are from fossil fuel combustion, with fertilizer use also contributing approximately 20% of the total. Again, these estimates are subject to very large uncertainties.

Almost all the Asian countries have signed the Montreal Protocol for the elimination of ozone-depleting substances, and are committed to the phaseout of CFCs during the next 12 years. In the interim period, emissions from Asia have become a significant part of the global total because the industrialized countries are phasing out the use of these substances by 1997 and their current emissions are declining rapidly.

While the total amounts of the various CFCs used in each country are fairly well known, the amount that actually escapes into the atmosphere in any country is less well determined. CFCs are used for various purposes, principally refrigeration, foams, and aerosols. For some uses, such as aerosols, the release into the atmosphere is instantaneous. For other uses, the release may be delayed several years. Taking these variations into account, emissions of CFC-11, CFC-12, and HCFC-22 from India are estimated at 1308, 8, and 1020 metric tons respectively during 1989–1990 (24).

Estimates of CFC emissions by countries that have not reported them have been calculated (39) using a linear relationship between Gross Domestic Product and total consumption of CFCs. The uncertainties based on this method are only one half as large as those using the relationship between CFC consumption and electric power use. Estimates of CFC use for all Asian countries are provided for the year 1986.

CONCLUSION

Emissions of greenhouse gases from the Asian countries are already a large fraction of anthropogenic global emissions, and their share is expected to increase in the years ahead. Thus any international agreement to slow down the rate of increase, eventually stabilize, and even reduce greenhouse gas emissions would require the commitment and cooperation of the developing countries of Asia, as well as the industrialized nations on all continents, if it is to be effective.

For the formulation of longer-term strategies for addressing global climate change concerns, needed inputs include estimates of current emissions of greenhouse gases in each of the major emitting countries, technological and policy options for reducing future emissions, and the economic, social, and environmental costs of implementing such options. Several regional and national studies to undertake these estimates have been initiated during the past few years by international and regional organizations such as the Global Environment Facility (40), the United Nations Development Programme (41), the World Bank (42), and the Asian Development Bank (21, 22). Some of the work is also supported by individual countries such as the US (43), various European countries, Australia, Canada, and Japan.

The results from some of these studies became available during 1994 (21, 22), and others will be available soon. Many of the Asian countries have also initiated their own research and analysis programs to address global climate change issues. All these efforts will assist in defining the full scope of the problem and the options available for addressing it. The negotiations that preceded and followed the United Nations Conference on Environment and Development (UNCED) conference (44) in Rio de Janeiro and the First Conference of the Parties to FCCC made clear that financial resources will be a major constraint in the implementation of strategies for reducing emissions of greenhouse gases. An equitable arrangement between the industrialized and developing countries of the world is essential for mobilizing resources.

In some countries, infrastructure development, including the establishment of organizations with the needed scientific and technical capabilities, is also required for the successful implementation of policies to reduce future emissions of greenhouse gases. The needed institutions and the pool of technically qualified persons are growing at a fast rate in most Asian countries. Consequently, even though these factors are important at present, they are not expected to be long-term constraints on the Asian countries' ability to cooperate actively with the rest of the international community in addressing the challenges and opportunities presented by global climate change.

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