

## SULFUR DIOXIDE EMISSIONS IN ASIA

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### *Abstracts*

This paper presents a review of energy use in 22 selected countries of Asia and estimates the anthropogenic emission of sulfur dioxide (SO<sub>2</sub>) for the selected countries both at national and disaggregated sub-country regional levels. The paper also makes a comparative assessment of the Asian countries in terms of SO<sub>2</sub> emission intensity (i.e. emission per GDP), emission per capita, and emission density (i.e. emission per unit area).

The total SO<sub>2</sub> emission in the region is estimated to be about 38 million tons in 1990. Five countries i.e. China, India, South Korea, Japan and Thailand accounted for over 91 per cent of the regional SO<sub>2</sub> emission. Coal use had the dominant share (81 per cent) in the total emission from the region. Among the economic sectors, industry sector contributed the largest share (49 per cent) in the total emissions of the selected countries as a whole followed by power sector (30 per cent). These findings suggest the need for mitigation strategies focussed to industry and power sectors of the major emitting countries in Asia.

*Keywords:* energy use; emission inventory; sulfur dioxide emissions; Asian emissions.

### **1. Introduction**

Although, until recently acidification of the environment was regarded as a problem only in Europe and North America, the problem has started emerging in parts of Asia as well. Most of the air pollution problems identified in the Asian countries are confined to localized areas of high emissions (usually associated with the densely populated cities of the region) such as Beijing, Bombay, Calcutta, Shenyang, Seoul, Bangkok, Hong Kong, Manila, and Kuala Lumpur (Rodhe *et al.*, 1988; Bhatti *et al.*, 1989; World Bank Report, 1991; IIASA, 1993). Pollutant concentrations in most of these cities regularly exceed the World Health Organization (WHO) recommended limits for SO<sub>2</sub>. The Asian region comprises many of the fastest growing economies in the world. During the period of 1971-1991, the average total primary energy consumption in Asia has been growing at the rate of 5.9 per cent per annum as compared to the world average of 2.4 per cent (OECD/IEA, 1993). The demand of electricity is growing even faster. In particular, electricity generation from thermal plants in 16 developing member countries of the Asian Development Bank (ADB) taken as a whole, was growing at the annual rate of 8.9 per cent during 1973-1990 (ADB, 1992). Thus, from the regional environmental perspective, the growth of energy in Asia is likely to assume an increasingly important

role in the future.

As is well known, the anthropogenic emission of SO<sub>2</sub> is the major precursor of acid rain. Reliable estimation of anthropogenic emissions of acid rain precursors is important in order to understand the geographical origins of acid rain precursors. Furthermore, assessment of region specific emissions by economic sector and fuel type is necessary in order to be able to formulate effective strategies for the mitigation of acid rain precursors.

There exist a limited number of studies that have estimated the inventories of SO<sub>2</sub> emissions in Asian countries (NISTEP, 1993; Kato and Akimoto, 1992; Foell and Green, 1990; Bhatti *et al.*, 1989). Except Kato and Akimoto (1992); and NISTEP (1993), the studies are based on national level data and thus fail to provide the spatial distribution of emissions across different regions of individual countries. The studies by Kato and Akimoto (1992); and NISTEP (1993) have provided emission estimates only at the national level except for China and India. The distinctive features of the present paper are that the emission levels are estimated at sub-country regional levels for all major countries of Asia using region specific data that clearly accounts for variation in fuel qualities. The study also analyses sectoral contributions to total emissions and assesses emissions from the selected countries in terms of indicators such as per capita emissions, emission intensity (defined as emission per unit of GDP) and emission density (defined as emission per unit of area). Furthermore, the emission inventory in our study is for the more recent year (i.e. 1990) as compared to the previous studies.

This study covers 22 countries in Asia i.e. China, Japan, Hong Kong, South Korea, Mongolia and Taiwan in North-East Asia; Bangladesh, Bhutan, India, Myanmar, Pakistan, Nepal and Sri Lanka in South Asia; and Brunei, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand and Vietnam in South-East Asia. The national level emission estimates were derived from estimates of the emissions at the sub-country regional levels. Altogether the 22 countries were disaggregated into 92 sub-country regions for this purpose.

## 2. Methodology

Total anthropogenic emission of SO<sub>2</sub> in a country or region comprises emissions from two sources i.e. combustion of fuels and non-energy use of fuels in industrial processes. The emission of SO<sub>2</sub> from fuel combustion is estimated by taking into account sulfur content and heat value of fuels as well as the efficiency of emission control (wherever applicable) and sulfur retained in ash.

To present the underlying methodology for calculation of SO<sub>2</sub> emission, first the following symbols are defined:

$S_{ijk}(t)$	=	SO <sub>2</sub> emission by fuel type <i>i</i> used in sector <i>j</i> of country <i>k</i> in year <i>t</i> ;
$E_{ijk}(t)$	=	Consumption of fuel type <i>i</i> used in sector <i>j</i> of country <i>k</i> in year <i>t</i> ;
$SC_{ijk}$	=	Sulfur content of fuel type <i>i</i> used in sector <i>j</i> of country <i>k</i> ;
$hv_{ij}$	=	Heat value of fuel type <i>i</i> used in sector <i>j</i> ;

$$\begin{aligned}
 sr_{jk} &= \text{Fraction of SO}_2 \text{ emissions retained in ash in sector } j \text{ of country } k; \\
 x_{jk} &= \text{Fraction of emissions removed by pollution control in sector } j \text{ of country } k; \text{ and} \\
 S_i^P(t) &= \text{SO}_2 \text{ emissions from industrial non-combustion processes of fuel type } i \text{ in year } t.
 \end{aligned}$$

SO<sub>2</sub> emission through the use of fuel *i* in sector *j* of country *k* can be expressed as:

$$S_{ijk}(t) = \sum_i E_{ijk}(t) * (sc_{ijk}/hv_{ij}) * (1-sr_{jk}) * (1-x_{jk}) \quad (1)$$

The total emission in country *k* is given by:

$$S_k(t) = \sum_i \sum_j S_{ijk}(t) + \sum_i S_i^P(t) \quad (2)$$

SO<sub>2</sub> emissions were estimated both at the country and sub-country regional levels. In all, 17 kinds of fuels and 5 major economic sectors were considered for the emission analysis.

## 2.1. DATA SOURCES

The estimation of SO<sub>2</sub> emission in the present study is based on a spatially disaggregated energy and socio-economic database which was established at Asian Institute of Technology (AIT) in the framework of a regional project entitled "Acid Rain and Emissions Reduction in Asia" funded by the ADB. The database has been created on the basis of data supplied by national collaborating institutes/experts of countries as well as data from published sources such as ADB (1992), ADB (1993), OECD/IEA (1993), NISTEP (1993), AEEMTRC (1993) and relevant country specific publications.

## 3. Energy Use in Asia

In recent years, the Asian region has recorded the highest growth rate of total primary commercial energy (TPCE) Consumption (BP, 1994). The region accounted for about 23.5 per cent of the TPCE consumption in the world in 1993 (*ibid*). About 84 per cent of the total TPCE consumption in Asia was accounted for by four countries i.e. China, India, Japan and South Korea combined.

Currently, energy use in Asia as a whole is heavily dependent on fossil fuels (almost 93 per cent of the TPCE consumption was from fossil fuel in 1993). About 46 per cent of the TPCE consumption in 1993 was in the form of coal (mainly due to high coal consumption in China and India) followed by oil (39 per cent), natural gas (7.5 per cent) and primary electricity (7.5 per cent). Thus coal and oil contribute significantly to the emission of acid rain precursors in Asia.

In per capita terms, commercial energy consumption in the Asian region as a whole was about 0.5 ton of oil equivalent (toe) (which was less than one tenth of that in OECD) in 1990. However, the average per capita energy consumption in the region has been growing rapidly as it almost doubled during 1973-1990 (ADB, 1992). Although the average energy consumption per capita figure is relatively low, the evolutions of energy sector in Asia have important environmental implications

mainly for two reasons: First, in many Asian countries, energy use is growing at a higher rate than in most countries in other parts of the world. Secondly, most Asian countries have experienced significant changes in their energy use pattern in the recent years. In particular, with rapid industrialization in many countries, there has been an increasing switch from traditional to modern fuels. Furthermore, as can be seen from Table 1, fossil fuels (i.e. coal, oil, natural gas) have registered faster growth rates than in the rest of the world.

**TABLE 1. Average Annual Growth Rate of Fossil Fuels, Primary Electricity and Total Primary Energy Consumption (TPEC) during 1983-93, %.**

Region	Coal	Oil	Gas	Nuclear Hydro	TPEC	
World	1.1	1.2	3.0	8.0	2.0	1.9
Asia	4.4	4.7	9.3	9.9	4.4	5.0
North America	2.0	1.1	2.0	7.5	0.0	1.9
Latin America	3.4	1.8	2.2	13.5	4.1	2.9
OECD Europe*	(1.6)	1.0	3.6	8.1	0.9	1.6
Non OECD Europe*	(3.3)	(4.0)	2.2	6.5	2.6	(1.1)
Rest of the World	1.7	2.6	6.3	6.9 <sup>§</sup>	4.0	3.2

\* Figures in the parenthesis indicate negative growth rate.

<sup>§</sup> During the year 1984-1993.

Source: BP (1994).

### 3.1. SECTORAL SHARES

Sectoral shares of total energy use are largely determined by the extent of industrialization and urbanization in a country. Table 2 presents the sectoral shares in total primary energy consumption in the Asian countries in 1990. Note here that the "domestic" sector in the table consists of residential, commercial and agricultural sectors. As can be seen from the table, the share of industrial sector in total primary energy consumption was the highest in the selected countries as a whole, followed by domestic, power generation and transport sectors. However, this was not always the case at the individual country or sub-country regional levels: Industrial sector is found to have the largest share in total energy consumption in North-East Asia while the domestic sector dominated in emissions from South- and South-East Asian regions. The value of industrial sector share also varied widely across the countries: It was the highest in China with over 60 per cent of total energy consumption in that country while it was in the range of 30 to 44 per cent in Japan, South Korea, Malaysia, Philippines, Singapore and Taiwan.

**TABLE 2. Sectoral Shares in Total Primary Energy Consumption of Asian Countries in 1990, %**

Country/Region Industry	Domestic*	Transport	Power	Non Energy	
<b>North East Asia</b>	<b>50.5</b>	<b>19.2</b>	<b>8.8</b>	<b>17.6</b>	<b>3.8</b>
China	60.3	18.7	3.5	15.3	2.2
Hong Kong	13.7	22.3	22.7	41.3	0.0
Japan	37.1	19.4	16.3	19.9	7.3
Mongolia	9.2	35.2	5.0	49.7	0.8
South Korea	37.7	25.9	16.5	19.9	0.0
Taiwan	41.7	13.7	13.7	23.5	7.4
<b>South Asia</b>	<b>30.4</b>	<b>39.2</b>	<b>9.4</b>	<b>19.7</b>	<b>1.3</b>
Bangladesh	20.9	56.2	3.6	9.7	9.6
Bhutan	0.8	95.2	0.6	3.4	0.0
India	33.6	35.2	9.6	21.6	0.0
Myanmar	5.8	79.9	4.7	8.3	1.3
Nepal	2.8	93.8	1.7	1.8	0.0
Pakistan	26.6	35.5	12.4	18.5	6.0
Sri Lanka	11.2	59.4	17.3	10.3	1.8
<b>South East Asia</b>	<b>23.7</b>	<b>44.3</b>	<b>17.5</b>	<b>13.2</b>	<b>1.3</b>
Brunei	7.9	14.4	31.2	45.7	0.9
Cambodia	19.8	52.5	15.8	11.9	0.0
Indonesia	18.1	60.0	14.5	7.0	0.4
Laos	4.7	88.6	1.6	5.1	0.0
Malaysia	32.2	18.4	22.5	19.3	7.6
Philippines	29.8	16.6	24.6	27.6	1.3
Singapore	43.9	9.8	17.7	28.6	0.0
Thailand	25.8	34.2	23.8	16.0	0.1
Vietnam	21.6	64.1	5.7	8.2	0.6
<b>Asia</b>	<b>44.2</b>	<b>25.4</b>	<b>9.8</b>	<b>17.5</b>	<b>3.1</b>

\* Comprises residential, commercial and agricultural sectors.

The share of domestic sector in total energy consumption ranged from 9 to 95 per cent. The share is found to be relatively high (in the range of 34 to 95 per cent) in Bangladesh, Bhutan, India, Indonesia, Laos, Myanmar, Nepal, Sri Lanka, Thailand and Vietnam. Power sector had the largest share in total primary energy consumption in Brunei, Hong Kong and Mongolia and the second largest in Japan, Singapore and Taiwan. Transport sector shares were relatively small except in Thailand, Hong Kong, Brunei, Philippines and Malaysia.

### 3.2. ENERGY MIX

Table 3 presents the fuel shares in TPCE in the Asian countries in 1990. The energy mix in the selected countries as a whole is dominated by coal followed by oil, primary electricity and gas. Coal had the largest share in fuel mix in both North-East- and South- Asia regions.

TABLE 3. Fuel Shares in TPCE of Asian Countries in 1990, %.

Country/Region	Coal	Oil	Gas	Primary Electricity	
<b>North East Asia</b>	<b>55.5</b>	<b>29.7</b>	<b>6.3</b>	<b>8.5</b>	
China	84.0	10.4	1.7	3.9	
Hong Kong	64.4	32.0	3.5	-	
Japan	12.2	56.6	15.4	15.8	
South Korea	26.4	52.4	3.9	17.4	
Mongolia	58.3	22.5	19.2	-	
Taiwan	28.2	65.1	2.4	4.3	
<b>South Asia</b>	<b>50.0</b>	<b>28.8</b>	<b>11.7</b>	<b>9.6</b>	
Bangladesh	5.8	30.2	60.0	3.9	
Bhutan	3.7	27.5	68.8	-	
India	58.1	27.8	5.5	8.6	
Myanmar	1.6	34.9	46.8	16.7	
Nepal	11.2	54.9	-	33.9	
Pakistan	8.0	31.8	44.8	15.4	
Sri Lanka	0.1	63.1	-	36.8	
<b>South East Asia</b>	<b>9.9</b>	<b>72.5</b>	<b>13.2</b>	<b>4.4</b>	
Brunei	-	40.5	59.5	-	
Cambodia	44.2	46.2	-	9.6	
Indonesia	8.1	77.0	12.4	2.4	
Laos	-	43.4	-	56.6	
Malaysia		5.9	71.3	18.8	4.0
Philippines	8.0	72.3	10.4	9.3	
Singapore	0.1	99.1	0.9	-	
Thailand		14.2	64.8	17.0	4.0
Vietnam	32.0	52.0	0.1	16.0	
<b>Asia</b>	<b>51.1</b>	<b>33.1</b>	<b>7.6</b>	<b>8.3</b>	

It is interesting to note that the share of oil in South-East Asia is much higher (more than 72 per cent) than in the other parts of the region, partly due to the oil consumption in the Association of Southeast Asian Nation (ASEAN) countries (i.e., Brunei, Indonesia, Malaysia, Philippines, Singapore and Thailand). Four countries i.e. China, India, South Korea and Japan accounted for over 80 per cent of total coal consumption in the Asian region as a whole in 1990. Furthermore, the shares of these countries in total regional oil and gas consumption were more than 70 and 74 per cent respectively.

### 3.3. ENERGY INTENSITIES

Energy intensities (defined as energy used per unit of GDP) of selected Asian countries are shown in Table 4 along with those of some western industrialized economies. The intensity is found to have an

increasing trend in countries like Indonesia, Malaysia and a decreasing trend in China, Japan, South Korea, Philippines, and Thailand during 1980-1990. As can be seen from the table, energy intensity varies widely across the countries. It ranged from 0.258 toe/thousand US\$ in Japan to 1.659 toe/thousand US\$ in China in 1990. The energy intensities of some major countries like China, India, South Korea, Indonesia, Malaysia, Philippines and Thailand are found to be higher than the average intensity of OECD countries.

**TABLE 4. Energy Intensity of Selected Asian Countries and Western Industrialized Economies, toe/thousand US\$ at 1985 price.**

Country/Region 1973	1980	1985	1990	
Bangladesh*	0.245	0.293	0.331	0.450
China*	-	2.388	1.867	1.659
India*	0.570	0.638	0.656	0.673
Japan <sup>§</sup>	0.370	0.310	0.269	0.258
Indonesia*	0.283	0.394	0.440	0.459
South Korea*	0.596	0.688	0.602	0.605
Malaysia*	0.375	0.376	0.394	0.414
Myanmar*	0.355	0.323	0.318	0.279
Nepal*	0.296	0.116	0.139	0.148
Pakistan*	0.529	0.588	0.633	
0.744				
Philippines*	0.458	0.390	0.366	0.400
Singapore*	0.497	0.433	0.781	0.427
Sri Lanka*	0.337	0.282	0.305	0.299
Thailand*	0.480	0.433	0.424	0.479
United States <sup>§</sup>	0.563	0.511	0.441	0.419
France <sup>§</sup>	0.417	0.393	0.384	0.364
North America <sup>§</sup>	0.570	0.521	0.450	0.428
OECD Europe <sup>§</sup>	0.525	0.472	0.446	0.403

\* The GDP figures are based on IMF (1993) and IMF (1994); and energy consumption figures are based on ADB (1993) and OECD/IEA (1993).

<sup>§</sup> The figures are based on OECD/IEA (1994).

#### 4. Emission of SO<sub>2</sub> in Asia

##### 4.1. EMISSIONS BY COUNTRY AND SUB-COUNTRY REGIONS

Table 5 presents the estimated emissions of SO<sub>2</sub> in Asia both at national and sub-country regional levels in 1990. The total emissions of SO<sub>2</sub> in the region was estimated to be about 38 million tons in 1990 almost 56 per cent higher than that of North America (i.e. United States and Canada). With the high growth of fossil fuel use in Asia, total SO<sub>2</sub> emission is expected to be significantly larger in the coming

decades. As can be seen from Table 5, countries in North-East Asia as a group (i.e. China, Hong Kong, Japan, South Korea, Mongolia and Taiwan) contributed almost 78 per cent of total emissions of SO<sub>2</sub> in Asia, followed by South Asia region (15 per cent) and South East Asia region (7 per cent). The SO<sub>2</sub> emissions are found to be relatively high in most of the coal dominated countries. China has the highest share (69 per cent) in the total Asia region emission, while China, India, South Korea, Thailand and Japan together accounted for over 91 per cent of the total SO<sub>2</sub> emission in the region.

**TABLE 5. Emission of SO<sub>2</sub> in Asian and Selected Western Countries in 1990, thousand tons.**

Country	Region	Emission
<b>Bangladesh</b>		<b>87.4</b>
	Dhaka	13.4
	Rest of Country	74.1
<b>Bhutan</b>	<b>Whole Country</b>	<b>2.1</b>
<b>Brunei</b>	<b>Whole Country</b>	<b>3.9</b>
<b>Cambodia</b>	<b>Whole Country</b>	<b>19.6</b>
<b>China<sup>§</sup></b>		<b>26,373.9</b>
<b>India<sup>§</sup></b>		<b>4,951.5</b>
<b>Hong Kong</b>	<b>Whole Country</b>	<b>138.5</b>
<b>Indonesia</b>		<b>691.1</b>
	Jakarta	23.1
	Java	411.4
	Rest of the Country	122.8
	Sumatra	133.8
<b>Japan</b>		<b>852.1</b>
	Chugoku-Shikoku	161.1
	Chubu	162.3
	Hokkaido-Tohoku	109.8
	Kanto	178.8
	Kinki-Kyoto	134.3
	Kyushu-Okinawa	105.9
<b>South Korea</b>		<b>1,770.2</b>
	North	257.0
	Pusan	661.3
	Seoul-Inchon	526.9
	South	325.0
<b>Laos</b>	<b>Whole Country</b>	<b>4.2</b>
<b>Malaysia</b>		<b>214.3</b>
	Kuala Lumpur	11.7
	Peninsular Malaysia	168.6
	Sarawak-Sabah	34.0
<b>Mongolia</b>	<b>Whole Country</b>	<b>46.7</b>
<b>Myanmar</b>	<b>Whole Country</b>	<b>22.1</b>
<b>Nepal</b>	<b>Whole Country</b>	<b>28.0</b>

Country	Region	Emission
<b>Pakistan</b>		<b>620.6</b>
	Karachi	105.5
	Lahore	21.9
	North and West Plateau	103.5
	Punjab	289.0
	Sind	100.8
<b>Philippines</b>		<b>414.9</b>
	Central Island-Mindanao	93.2
	Luzon	176.0
	Metro Manila	145.7
<b>Singapore</b>	<b>Whole Country</b>	<b>190.9</b>
<b>Sri Lanka</b>	<b>Whole Country</b>	<b>30.5</b>
<b>Taiwan</b>	<b>Whole Country</b>	<b>512.6</b>
<b>Thailand</b>		<b>1,036.9</b>
	Bangkok	298.1
	Central Valley	129.6
	North-East Plateau	58.9
	North Highlands	490.9
	South Peninsula	59.3
<b>Vietnam</b>		<b>134.4</b>
	North Vietnam	62.8
	South Vietnam	71.6
<b>Asia</b>		<b>38,146.2</b>
	North-East Asia	29,694.0
	South Asia	5,742.2
	South-East Asia	2,710.0
Canada*		3,326.0
Germany*		5,679.0
United Kingdom*		3,780.0
United States*		21,060.0

\* These figures are based on WRI (1994).

§ Refer to Table 8 for sub-country regional emissions of SO<sub>2</sub>.

Low SO<sub>2</sub> emission (below 30 thousand tons in 1990) from Bhutan, Cambodia, Laos, Myanmar and Nepal can be attributed mainly to the predominance of traditional (i.e. biomass) fuels whose sulfur contents are much lower than that of the fossil fuels. High dependence on traditional fuels was also partly responsible for relatively low SO<sub>2</sub> emissions in Bangladesh, Indonesia, Mongolia, Myanmar,

Philippines, Sri Lanka and Vietnam.

Some regions of China (i.e. Hebei-Anhui-Henah; Jiangsu; Sichuan; and Heilongjiang-Jilin-Liaoning) emitted more than two million tons of SO<sub>2</sub> in 1990 -a figure much higher than that of other Asian countries except India and South Korea (refer Table 8). Among the regions in China, the emission was the largest in Jiangsu accounting for 13 per cent of the total emissions from the Asian region as a whole.

Table 6 presents emission intensity, emission per capita and emission density for countries/regions in 1990. Emission intensity was found to vary from 0.3 kg per thousand US\$ (1990) in Japan to 71 kg per thousand US\$ in China. Emission intensities were particularly high in China and Mongolia among countries in North-East Asia; India and Pakistan among in South Asia; and Thailand and Vietnam in South-East Asia. As can be seen from the table, emission intensities in most Asian countries are higher than those in industrialized countries. These higher values in most Asian countries reflect partly low efficiency in energy use in most of the major countries. For example, as can be seen from Table 7, specific energy consumption figures (defined as energy consumption per ton of output) of major energy intensive industries in China and India were significantly higher than those in Japan, Sweden, and USA.

**TABLE 6. SO<sub>2</sub> Emission Intensity, Emission Per Capita and Emission Density in Asian and Selected Western Countries in 1990.**

Country/Region	Emission Intensity (kg/thousand US\$) (1990 Price)	Emission Per Capita (kg)	Emission Density (tons/km <sup>2</sup> )
<b>North East Asia</b>	<b>7.88</b>	<b>22.03</b>	<b>2.58</b>
China	71.35	22.86	2.79
Hong Kong	3.45	23.88	138.50
Japan	0.29	6.90	2.25
South Korea	6.98	41.29	17.88
Mongolia	24.99	21.93	0.03
Taiwan	3.35	25.38	14.24
<b>South Asia</b>	<b>14.39</b>	<b>5.07</b>	<b>1.11</b>
Bangladesh	4.10	0.77	0.61
Bhutan	7.23	1.33	0.04
India	16.29	5.99	1.50
Myanmar	0.96	0.53	0.03
Nepal	9.05	1.48	0.20
Pakistan	15.74	5.54	0.78
Sri Lanka	3.79	1.79	0.46
<b>South East Asia</b>	<b>8.18</b>	<b>6.63</b>	<b>0.71</b>
Brunei	1.87	15.26	0.64
Cambodia	12.22	2.35	0.11

Indonesia	6.51	3.85	0.36
Laos	4.84	1.01	0.02
Malaysia	5.02	12.07	0.65
Philippines	9.40	6.78	1.38
Singapore	5.23	70.44	190.89
Thailand	12.93	18.49	2.02
Vietnam	10.37	2.03	0.41
<b>Asia</b>	<b>8.47</b>	<b>13.19</b>	<b>1.86</b>
United States	3.81	84.27	2.25
Germany	3.76	89.96	15.96
France	1.00	21.15	2.17
United Kingdom	3.84	65.84	15.43

Sources: World Tables (1992), ADB (1993), IMF (1994), and AIT (1995).

Furthermore, efficiency of electricity generation from coal-fired power plants was significantly lower in China (31.3 per cent) and India (28.4 per cent) as compared to 38.8 per cent in Japan and 36.9 per cent OECD countries as a whole (ADB, 1993; OECD/IEA, 1994). They also partly reflect the relatively high shares of energy intensive production sector, and lack of emission controls. The emission intensities in China, India, Thailand, Pakistan and Vietnam have most likely been increasing over time during 1980-1990 since overall energy intensities and the share of coal have been increasing in these countries during the period.

**TABLE 7. Specific Energy Consumption of Industries in Selected Countries, million kCal/ton.**

Country	Steel	Cement	Pulp and Paper	Fertilizer
China	6.87	2.24	-	15.60
India	9.50	2.00	11.13	11.25
Japan	4.18	1.20	-	-
Germany	5.21	0.82	-	-
Italy	4.03	0.89	-	9.92
Sweden	5.02	1.40	7.56	-
United Kingdom	6.07	1.30	7.62	12.23
USA	6.06	0.95	9.70	11.32

Source: Chen *et al.* (1994).

In per capita terms, SO<sub>2</sub> emission varied from 0.5 kg in Myanmar to 70 kg Singapore. In most of the countries the figure was below 25 kg which was less than the corresponding figures in industrialized countries like the USA, United Kingdom and Germany (WRI, 1994). The relatively low emission per capita figures for most Asian countries reflect the relatively lower level of industrialization

in these countries.

The average SO<sub>2</sub> emission density of the Asian region as a whole was estimated to be 1.86 tons per km<sup>2</sup>. Although the Asian regional average intensity appears low as compared to industrial countries like France, Germany, USA and United Kingdom, there are wide variations (i.e. from 0.17 tons to 190 tons/km<sup>2</sup>) across countries/regions in the region. Eight countries viz. China, Hong Kong, Japan, South Korea, Philippines, Singapore, Taiwan and Thailand were found to have emission densities above the average. These countries had higher emission densities than those of the United States, United Kingdom, Japan, Germany and France. Given the high economic growth rates of most countries in the region, it can be expected that the emission density would be significantly higher in the coming decades, if the present structure of production were to continue. The emission density figures at the national level could, however, be misleading in that it could mask the large variations in the densities that exist across regions within a particular country. This is illustrated in Table 8, in cases of China and India. Although the national level emission densities of China and India appear relatively low (2.8 and 1.5 tons/km<sup>2</sup> respectively), there were at least 11 sub-country regions in China and 4 in India for which the emission density was above 3 tons/km<sup>2</sup>. These figures were higher than those of all other countries and sub-country regions of Asia, except Singapore, Hong Kong, Taiwan and South Korea.

#### 4.2. SECTORAL EMISSIONS

Table 9 presents the sectoral emission of SO<sub>2</sub> in 1990 in Asian countries. Industrial sector accounted for the greatest share (55 per cent) in total emission of SO<sub>2</sub> in Asia as a whole followed by power generation (22 per cent), domestic (18 per cent) and transport (5 per cent) sectors respectively. At the individual country level, industrial sector had the largest share in total national SO<sub>2</sub> emissions in China, Japan, South Korea, Taiwan, Indonesia, Pakistan, Sri Lanka, Cambodia and Laos. Power generation had the largest share in national emissions in India, Hong Kong, Malaysia, Philippines, Thailand, Singapore, Brunei and Mongolia. Together, industrial and power generation sectors contributed about 77 per cent of the total SO<sub>2</sub> emission in Asia.

**TABLE 8. Emission Density of SO<sub>2</sub> in selected Sub-country Regions of China and India in 1990.**

Country	Region	SO <sub>2</sub> Emission (thousand tons)	Area* (thousand km <sup>2</sup> )	Emission Density (tons/km <sup>2</sup> )
China		<b>26,373.9</b>	<b>9,444.3</b>	<b>2.8</b>
	Beijing	313.2	16.8	18.6
	Chongqing	1,023.5	-	-
	Fujian	316.4	120.0	2.6
	Guangdong-Hainan	838.5	210.0	4.0
	Guangxi	935.3	230.0	4.1
	Guangzhou	196.9	-	-
	Guiyang	272.6	-	-
	Guizhou	895.2	170.0	5.3
	Hebei-Anhui-Henah	3,147.4	470.0	6.7
	Hubei	610.1	180.0	3.4

	Hunan	422.6	160.0	2.6
	North East Mongolia-Ningxia	744.9	1,200.0	0.6
	Jiangsu	5,030.3	100.0	50.3
	Jiangxi	312.7	160.0	2.0
	Heilongjiang-Jilin-Liaoning	2,591.8	780.0	3.3
	Shanghai	504.7	6.2	81.6
	Shenyang	170.6	-	-
	Shaanxi-Gansu	892.7	640.0	1.4
	Shandong	947.2	150.0	6.3
	Shanxi	754.4	150.0	5.0
	Sichuan	3,031.5	570.0	5.3
	Taiyuan	208.0	-	-
	Tianjin	237.7	11.3	21.0
	Tibet-Qinghai-Xinjiang Uygur	350.3	2,800.0	0.1
	Wuhan	160.3	-	-
	Yunan	919.5	390.0	2.4
	Zhejiang	545.9	100.0	5.5
<b>India</b>		<b>4,951.5</b>	<b>3,288.0</b>	<b>1.5</b>
	Andhra Pradesh	213.0	275.0	0.8
	West Bengal	278.5	88.7	3.1
	Bihar	316.3	173.8	1.8
	Bombay	207.1	0.2	345.2
	Calcutta	62.2	0.2	311.0
	Delhi	73.5	1.5	49.0
	North East Highlands-Assam	455.9	254.8	1.8
	Gujarat	167.3	196.0	0.9
	Haryana	193.9	44.2	4.4
	Karnataka-Goa	160.7	195.5	0.8
	Kerala	106.3	38.8	2.7
	Madras	13.1	0.2	77.0
	Maharashtra-Daman-Diu	320.4	307.7	1.0
	Madhya Pradesh	378.3	443.4	0.9
	Orissa	219.0	155.7	1.4
	Punjab-Chandigarh	160.2	50.4	3.2
	Rajasthan	130.0	342.2	0.4
	Tamil Nadu-Pondichery	227.1	130.0	1.7
	Uttar Pradesh	460.5	294.4	1.6
	Jammu-Kashmir-Himachal	808.2	-	-

\* Sources: Kaplan *et al.* (1982) and GOI (1993).

**TABLE 9. Sectoral Emission of SO<sub>2</sub> in Asian Countries / Regions in 1990.**

Country/Region	Sectoral Shares (%)				Total Emission (tons)
	Industrial	Domestic	Power	Transport	
<b>North-East Asia</b>	<b>52.4</b>	<b>18.3</b>	<b>26.0</b>	<b>3.3</b>	<b>29,694.0</b>
China	53.7	18.7	26.2	1.4	26,373.9
Hong Kong	4.6	3.3	87.0	19.2	138.5
Japan	30.8	9.6	23.7	35.8	852.1

South Korea	45.5	21.2	25.3	8.0	1,770.2
Mongolia	1.3	3.2	94.9	0.6	46.7
Taiwan	69.7	8.6	9.1	12.6	512.6
<b>South Asia</b>	<b>38.1</b>	<b>11.5</b>	<b>42.1</b>	<b>8.3</b>	<b>5,742.2</b>
Bangladesh	32.3	43.0	10.1	14.6	87.4
Bhutan	9.5	85.7	-	4.8	2.1
India	36.4	10.2	45.8	7.5	4,951.5
Myanmar	3.6	93.7	1.4	1.4	22.1
Nepal	9.6	82.2	3.9	4.3	28.0
Pakistan	55.3	9.6	22.1	13.0	620.6
Sri Lanka	37.3	31.4	0.7	30.7	30.5
<b>South-East Asia</b>	<b>29.6</b>	<b>11.6</b>	<b>46.8</b>	<b>12.0</b>	<b>2,710.0</b>
Brunei	5.1	7.7	51.3	35.9	3.9
Cambodia	45.4	21.9	26.5	6.1	19.6
Indonesia	33.5	22.9	26.9	16.7	691.1
Laos	41.4	51.7	3.4	3.4	4.2
Malaysia	27.6	7.1	59.7	5.4	214.3
Philippines	36.8	4.7	53.1	5.5	414.9
Singapore	34.3	0.2	59.7	5.4	190.9
Thailand	22.9	7.0	55.6	14.5	1,036.9
Vietnam	33.9	36.5	18.1	11.5	134.4
<b>Asia</b>	<b>48.6</b>	<b>16.8</b>	<b>29.9</b>	<b>4.7</b>	<b>38,146.2</b>

#### 4.3. EMISSIONS BY FUEL TYPES

Fuel shares in total emission of SO<sub>2</sub> are shown in Table 10. Coal (of different varieties i.e. brown coal, hard coal and derived coke) was the largest source of emission in 1990 accounting for about 81 per cent of the total emission in the region, followed by oil (17 per cent). At the individual country level, coal use was the biggest source of emissions in China, India, Hong Kong, Thailand, Cambodia, and Mongolia while it was oil in Japan, South Korea, Taiwan, Pakistan, Sri Lanka, Indonesia, Malaysia, Philippines, Singapore and Vietnam.

**TABLE 10. Emissions of SO<sub>2</sub> by Fuel Types in Asian Countries / Regions in 1990.**

Country/Region	Share by Fuel Type (%)				Total Emission (tons)
	Coal	Oil	Gas	Other Solids*	
<b>North-East Asia</b>	<b>89.6</b>	<b>10.3</b>	-	-	<b>29,694.0</b>
China	96.9	3.1	-	-	26,373.9
Hong Kong	75.1	24.8	-	0.1	138.5
Japan	23.7	76.3	-	0.1	852.1

South Korea	32.2	67.7	-	0.2	1,770.2
Mongolia	90.8	7.1	-	2.1	46.7
Taiwan	37.8	62.1	0.1	-	512.6
<b>South-East Asia</b>	<b>81.4</b>	<b>16.7</b>	<b>0.1</b>	<b>1.8</b>	<b>2,710.0</b>
Bangladesh	14.2	34.6	1.3	49.9	87.4
Bhutan	4.8	9.5	-	85.7	2.1
India	69.2	23.4	0.5	6.9	4,951.5
Myanmar	1.8	5.4	0.9	91.9	22.1
Nepal	3.6	16.4	-	80.0	28.0
Pakistan	41.2	54.5	0.3	4.1	620.6
Sri Lanka	0.3	69.5	-	30.2	30.5
<b>South-East Asia</b>	<b>81.4</b>	<b>16.7</b>	<b>0.1</b>	<b>1.8</b>	<b>2,710.0</b>
Brunei	-	44.7	55.3	-	3.9
Cambodia	52.0	26.0	-	21.9	19.6
Indonesia	6.6	74.9	-	18.5	691.1
Laos	-	31.0	-	69.0	4.2
Malaysia	7.1	90.0	0.4	2.5	214.3
Philippines	24.3	75.7	-	-	414.9
Singapore	0.1	99.9	0.1	-	190.9
Thailand	49.0	46.8	-	4.2	1,036.9
Vietnam	20.8	47.6	-	31.6	134.4
<b>Asia</b>	<b>81.4</b>	<b>16.7</b>	<b>0.1</b>	<b>1.8</b>	<b>38,146.2</b>

\* The other solids includes fuelwood and biomass fuels (such as plant residue and animal waste).

## 5. Conclusion and Final Remarks

From the present analysis, total emission of SO<sub>2</sub> in Asia was estimated to be about 38 million tons in 1990. About 78 per cent of these emissions originated from countries in North-East Asia (China, Hong Kong, Japan, Mongolia, South Korea and Taiwan). Coal use accounted for over 80 per cent of the total emission in Asia as a whole and about 90 per cent of the total emission in North-East Asia. Due to rapid economic growth and high share of coal in energy system, SO<sub>2</sub> emissions are expected to be much larger in the coming decades if effective mitigation measures are not adopted.

In terms of sectoral contributions to SO<sub>2</sub> emissions, industrial sector was predominant in total emissions from Asia as a whole and that from North-East Asia while it was power sector in South and South-East Asian regions. Clearly, the finding shows that in terms of mitigation strategies, industrial sector options deserve more attention in North-East Asia while the power sector options may be more important in South- and South-East Asia.

There seems to exist a large potential for mitigation of SO<sub>2</sub> emissions through efficiency improvements in industrial and power sectors of big emitting countries like China and India. However, these remain mostly untapped, as substantial investments are needed for the purpose. Financing of the

additional investment for emission control, and associated pricing implications are the problems confronted by the policy makers in most countries in the region. We intend to examine the mitigation potential of various energy efficiency and emission control options as well as the associated costs in a subsequent paper.

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