ENVIRONMENTAL IMPLICATIONS OF FOSSIL-FUEL BASED ELECTRICITY GENERATION IN SOUTH-EAST ASIA COUNTRIES

1. INTRODUCTION

Electricity constitutes a critical input in sustaining the Nation's economic growth and development and the well-being of its inhabitants. To meet customer demand in 1992, total electricity generation in South-East Asia (SEA) totaled nearly 150 TWh using over 39 mtoe of fossil fuels. However, there are by-products of electricity generation that have an undesirable effects on the environment. Most of these are emissions introduced by the combustion of fossil fuels, which accounts for nearly 80% of total electricity generated in SEA countries in 1992.

The use of fossil fuels for electricity generation is intimately linked to their availability. Coal, oil, and gas are, and will continue to be, readily available throughout the world. Oil and gas however, are premium products whose value as a chemical fedstock or as premium fuels for transport with their limited reserves mitigate against their profligate use purely for electricity production. Coal remains the dominant fuel which will be used for electricity generation in virtually every part of the world for the foreseeable future.

In the past two decades, studies of energy technologies increasingly have focused on quantifying environmental effects. In particular, many studies have attempted to estimate the environmental cost of different electricity generating technologies - the monetary value of the environmental effects so that environmental concerns can be incorporated more easily into public and private decision making. There are a number of options available to SEA countries to reduce emissions of SO_2 and to certain extent NO_x and CO_2. The purpose of this paper is to examine some of the issues related to acid-rain control technologies in SEA and to suggest ways to include technology options for future power generation expansion planning in these countries.

2. METHODOLOGY

This section describes methods used to develop emission estimates and other data for significant anthropogenic sources of, and CO_2 from fossil-fuel use in power generation sector. This study covers the following 8 countries of SEA: Brunei, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam.

Emission Factors

The emission factors developed in this paper represent the uncontrolled emissions from each source by fuel types. The factors are presented on a mass of pollutant per unit of energy input basis. Emission factor estimates were derived based primarily on data available in various EPA and IPCC documents. Emission data for NO_x and CO_2 were available from IPCC (1995) and Radian (1990). Typically, other emission data for NO_x were available from AP-42, background information documents for new source performance standards, environmental assessment studies

for various sources and from the source test reports. CO_2 emission factors were calculated from fuel properties and a carbon balance by assuming that, in many cases, all fuel carbon is transformed into CO_2 , CO, and CH_4 . Non methane hydrocarbons were not included in the carbon balance. ***Table 2.1*** summarizes the emission factors for NO_x and CO_2 . Actual heat value and carbon content will, however, vary from one country to another for various fuels. The total anthropogenic emission of NO_x ($N_{ik}(t)$) and CO_2 ($C_{ik}(t)$) from combustion of fossil fuels for power generation for each country in year t are estimated as

$$N_{ik}(t) = \Sigma_i E_{ik}(t) * EF_i (NO_x); \text{ and} \quad (1)$$

$$C_{ik}(t) = \Sigma_i E_{ik}(t) * EF_i (CO_2), \quad (2)$$

where, $E_{ik}(t)$ is the consumption of fuel type i of country k in year t and EF_i is the emission factor for fuel type i.

Table 2.1 Emissions Factors of NO_x and CO_2 for Electricity Generation (tons/thousand toe of energy input) by Type of Generation Technology Used.

Source	Efficiency at Busbar (%)	NO_x	CO_2 *
Natural Gas - Boiler	35.2	11.18	2034.84
Gas Turbine Combined Cycle	45.4	7.83	2115.47
Gas Turbine Simple Cycle	28.5	7.87	2115.63
Residual Oil - Boiler	35.2	8.42	3120.08
Diesel Oil - Boiler	35.2	2.85	2984.42
Spreader Stoker - Coal	33.7	13.65	4412.99
Pulverized Coal	34.0	35.88	4321.65

*. The carbon weight in percent and heat value in MJ/kg for natural gas, diesel oil, fuel oil, and coal are 70.6, 87.2, 85.6, and 65.0 and 51.1, 45.2, 43.0, and 23.2 respectively. Carbon is not generally retained in ash.
Sources: Radian (1990) and IPCC (1995).

Similarly, the total anthropogenic emission of SO_2 from combustion of fossil fuels for power generation 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_2 emission, first the following symbols are defined:

$S_{ik}(t)$ = SO_2 emission by fuel type i of country k in year t;
SC_{ik} = Sulfur content of fuel type i of country k;
hv_{ik} = Heat value of fuel type i used of country k;
sr_k = Fraction of sulfur retained in ash of country k; and
x_k = Fraction of emissions removed by pollution control of country k.

SO_2 emission through the use of fuel i of country k can be expressed as:

$$S_{ik}(t) = 2 * E_{ik}(t) * (sc_{ik}/hv_i) * (1-sr_k) * (1-x_k) \quad (3)$$

The total emission of SO_2 in country k from electricity generation is given by:

$$S_k(t) = \Sigma_i S_{ik}(t) \quad (4)$$

The fuel properties required for this study include heating value and weight percent of sulfur in the fuels. ***Table 2.2*** summarizes the heat value, sulfur content used, and the emission factors for SO_2 from different fuels in each country considered in this study.

Table 3.2 Heat Value, Sulfur Content, and the Emission Factors for SO_2 by Fuel Types in SEA Countries.

Country	Fuel Type	HV (toe/ton)	SC (wt %)	SO_2 EF (ton/thousand toe)
Brunei	Natural Gas	0.995	0.04	0.80
Indonesia	Natural Gas	0.955	0.04	0.80
	Diesel Oil	1.176	0.50	8.08
	Fuel Oil	1.000	2.80	53.22
	Coal (Bituminous)	0.508	0.60	22.45
Malaysia	Natural Gas	0.830	0.04	0.92
	Diesel Oil	1.104	0.96	16.52
	Fuel Oil	0.914	3.20	62.34
	Coal (Bituminous)	0.700	0.62	16.83
Myanmar	Natural Gas	0.799	0.04	0.95
	Diesel Oil	1.040	1.44	26.32
	Fuel Oil	0.892	3.20	68.16
	Coal (Bituminous)	0.550	0.86	29.71
Philippines	Natural Gas	0.915	0.04	0.92
	Diesel Oil	17.638	1.00	17.62
	Fuel Oil	67.774	3.20	67.77
	Coal (Bituminous)	25.530	0.65	25.53
Singapore	Diesel Oil	1.084	0.46	8.06
	Fuel Oil	1.032	1.60	29.47
Thailand	Natural Gas	0.854	0.04	0.89
	Diesel Oil	1.116	0.50	8.51
	Fuel Oil	0.897	2.92	61.84
	Coal (Lignite)	0.248	2.80	214.78
Vietnam	Natural Gas	0.817	0.04	0.93
	Diesel Oil	1.020	0.40	7.45
	Fuel Oil	0.999	1.50	28.53
	Coal (Bituminous)	0.700	0.20	5.43

Sources: Akimoto (1992), ADB (1995), Radian (1990), IIASA (1990), and IEA/OECD (1995).

3. FOSSIL-FUEL USE FOR ELECTRICITY GENERATION IN SEA

Since the last two decades, fossil fuels have played an increasingly important role in the SEA countries' economy by providing the energy required, in particular, for electricity generation. ***Table 3.1*** presents fossil-fuel share for electricity generation in SEA countries. As can be seen from the table, fossil fuels provide at least 59% of total energy consumption in 1974 to 63% in 1992 (excluding Vietnam). This dependence on fossil fuels is greatest in relatively more developed economies (based on country's per capita GDP) in SEA such as Brunei, Indonesia, Malaysia, Singapore, and Thailand, where over 80% of all energy needs for power generation in 1992 are provided by fossil fuels, compared with about 45% in less developed economies (for e.g., Myanmar, Philippines, and Vietnam). However, there has also been a significant shift in fossil-fuel

generation-mix from oil to coal and natural gas during the last decade in Indonesia, Malaysia, and Thailand.

Table 3.1 Shares of Fossil Fuels for Electricity Generation in SEA (%)

Country	1974				1985				1992			
	Coal	Oil	Gas	Others**	Coal	Oil	Gas	Others	Coal	Oil	Gas	Others
Brunei*	-	-		-	-	-	100	-	-	-	100	-
Indonesia	-	59	-	41	-	77	1	22	24	52	4	20
Malaysia	-	78		20	-	86	1	13	13	33	41	13
Myanmar	n/a	n/a	n/a	n/a	-	16	37	47	-	10	53	37
Philippines	-	76	-	24	2	57	-	41	6	60	-	34
Singapore	n/a	n/a	n/a	n/a	-	100	-	-	-	100	-	-
Thailand	6	64	-	30	11	36	31	22	23	27	43	7
Vietnam	n/a	n/a	n/a	n/a	52	14	-	34	11	33	0	56

*. Negligible diesel oil consumption for electricity generation. **. Others include non fossil fuels for electricity generation (for e.g., hydro, nuclear, geo-thermal, solar, and wind power genration).

Table 3.2 Total Fossil Fuels Consumption (thousand toe) for Selected Years and Average Annual Growth Rate (AAGR) for Fossil Fuels during 1974 -1992 (%).

Country	Fossil Fuel Consumption			AAGR				
	1974	1982	1992	Natural Gas	Diesel Oil	Fuel Oil	Coal	Average
Brunei	65	236	561	12.7	-	-	-	12.7
Indonesia	581	2740	8646	23.3	11.5	15.5	54.0	16.2
Malaysia	989	2726	6624	30.3	11.8	5.2	92.2	11.1
Myanmar	-	250	537	9.9	1.4	1.8	-	7.9*
Philippines	1851	2603	4679	-	20.6	2.4	17.4	5.3
Singapore	-	1811	3413	-	56.0	6.3	-	6.7**
Thailand	1259	2932	12303	33.9	1.2	6.6	20.6	13.5
Vietnam	-	963	2136	-18.7	21.0	19.6	-3.9	8.0**

*. During 1982-1992. **. During 1981-1992.
Sources: ADB (1995), IEA/OECD (1995).

Dependence of coal, oil, and gas as an energy source of electricity generation varies widely across the countries. As can be seen from ***Table 3.1***, coal share in total energy consumption for electricity generation was 24% and 23% in 1992 in Indonesia and Thailand respectively while it varies from 6 to 13% in Malaysia, Philippines, and Vietnam. Likewise, share of oil was more than half in Indonesia, Philippines, and Singapore while that of natural gas was in Brunei and Myanmar. However, keeping in view the relatively high growth rates of natural gas and coal in Indonesia, Malaysia, and Thailand, the shares of natural gas and coal for electricity generation in these countries are likely to increase substantially in the coming decades see ***Table 3.2***).

The coal, oil, and gas intensities for electricity generation have registered an increasing trend during 1983-1992 for selected countries in SEA. This is evident from the ***Figure 3.1***. The increasing trend of electricity intensity in the SEA countries are in contrast to that of the major industrialized countries, for e.g., France, Japan, United Kingdom, and United States where electricity intensity has shown a declining trend during the same period. In absolute terms,

electricity intensity in Malaysia, Philippines, and Thailand were substantially higher than that of other countries in SEA (see ***Table 3.3***). However, among the type of fossil-fuel intensities, Brunei has the highest average natural gas intensity, while Indonesia has the highest average oil intensity and Thailand has the highest average coal intensity during the period of 1983-92.

Table 3.3 Selected Electricity Indicators for SEA Countries.

Country	Electricity Intensity (kWh/GDP 1992 US$)			Per Capita Electricity Consumption (kWh)			Share of Electricity in Primary EC (%)			Average Electricity Price (cent/kWh)		
	1974	1982	1992	1974	1982	1992	1974	1982	1992	1974	1982	1992
Brunei[#]	0.08	0.17	0.42	1368	2908	5952	1.0	0.1	0.07	n/a	n/a	n/a
Indonesia	0.06	0.14	0.27	19	59	188	8.1	11.8	18.3	4.97	5.96	6.75
Malaysia	0.22	0.32	0.45	340	693	1383	20.5	31.8	29.5	15.33	29.53	18.07
Myanmar	0.02	0.03	0.05	17	32	44	-	29.0	46.9	-	20.51	8.39
Philippines	0.29	0.30	0.40	237	286	337	26.0	37.4	42.3	7.99	9.48	10.03
Singapore	0.24	0.27	0.32	1536	2954	5656	-	13.6	13.0	n/a	n/a	n/a
Thailand	0.22	0.30	0.45	161	308	859	21.5	30.1	36.5	7.08	10.23	6.69
Vietnam	-	0.67[*]	1.02[*]	-	53	100	-	35.1[**]	55.3	n/a	n/a	n/a

[#]. Electricity Intensity is based on 1990 price. [*]. National income was used for the computation [**]. Figure for 1985.

4. EMISSIONS OF AIR POLLUTANTS FROM THERMAL POWER GENERATION

From the view point of emission of air pollutants and the associated environmental impacts, thermal generation is of particular interest. These impacts are evident in the entire cycle beginning with fossil fuel exploration and extraction, production, waste generation, and the disposal of wastes. The combustion of fossil fuels contribute to emissions of various gases such as NO_x, SO_2, trace of heavy metal contaminants, and organic compounds. In addition, fossil fuel combustion also produces CO_2, which absorbs radiant energy, contributing to the greenhouse effect. There is growing recognition that such emissions adversely impact the environment -locally, nationally, and globally. We, however, limit our discussion in this section to the emission of selected air pollutants (i.e., NO_x, SO_2, and CO_2) from thermal power plants.

Table 4.1 shows the estimated emissions levels of NO_x, SO_2, and CO_2 from thermal power generation for selected years in SEA countries under study. It is evident that the electricity sector's contribution of air pollutants is fairly substantial in most countries. In particular, the shares of SO_2 were quite substantial in Malaysia, Philippines, and Singapore, while the shares of NO_x and CO_2 were quite substantial in Brunei (above 35%) and Thailand (above 30%) respectively. Keeping in mind the faster growth in the consumption of electricity and also the growing share of thermal generation in most countries, total emissions are likely to be much higher in future.

Among the fuel types, fuel oil and coal combined together contributed more than 65% of total NO_x, 96% of total SO_2, and 70% of total CO_2 emissions in 1992. The shares of diesel and natural gas, however, contributed relatively less emissions of air pollutants due their better fuel qualities.

The level of NO_x and SO_2 from fossil fuel emissions for power generation per unit of GDP in 1990 in SEA are much higher than that of total NO_x and SO_2 from all sectors combined in North America, OECD Europe, Japan, and OECD standards in late 1980s. This is evident form ***Figure 4.1***. As can be seen from ***Figure 4.2***, the emissions trend of NO_x, SO_2, and CO_2 were increasing more rapidly than that of electricity consumption and GDP in most countries.

Table 4.1 Estimated Emissions of NO_x, SO_2, and CO_2 for Selected Years (thousand tons) and Shares of Electricity Sector in Total Emissions (%) in SEA Countries.

Country	1982**			1986			1992			Share of Electricity Sector*		
	NO_x	SO_2	CO_2	NO_x	SO_2	CO_2	NO_x	SO_2	CO_2	NO_x	SO_2	CO_2
Brunei	2.6	0.9	480	4.1	1.4	753	6.3	2.1	1141	37	49	-
Indonesia	23.2	90.9	8377	35.5	102.4	12120	87.5	215.4	29622	17	7	26
Malaysia	23.0	95.5	8450	28.8	90.4	9075	70.8	110.5	18513	30	16	59
Myanmar	2.4	3.8	459	5.0	3.1	941	5.5	4.8	1032	22	12	15
Philippines	22.3	190.5	8244	20.5	171	7386	41.5	268.5	14976	28	14	53
Singapore	15.2	58.2	5670	19.4	73.8	7244	28.7	106.7	10669	28	25	56
Thailand	31.6	156.8	8435	39.9	257.8	10228	145.0	766.3	36228	33	18	25
Vietnam	11.2	8.5	3922	16.1	13.9	5583	15.9	33.3	7130	17	18	10
OECD	11.5		2884	10.6		2860						
CPE	9.8		2010	11.1		1990		–			–	
DC	2.3		545	3.7		801						
World	23.9		5476	24.9		5950						

*. NO_x is for year 1987, SO_2 for year 1990, and CO_2 is for year 1991. **. Figures for OECD, CPE (centrally planned economies), DC (developing countries), and the world are for 1980. *Source: IEA/OECD (1992).*
Sources: WRI (1994) for CO_2, Akimoto (1994) for NO_x, and Ram et al (1995) for SO_2.

Table 4.2 The Share of Emissions of NO_x, SO_2, and CO_2 by Fuel Types for Selected Years in SEA (%).

Pollutant Type	1982			1986			1992		
	Coal	Oil	Gas	Coal	Oil	Gas	Coal	Oil	Gas
NO_x	13.6	71.2	15.2	29.4	59.0	20.2	28.0	58.1	31.2
SO_2	14.5	85.2	0.2	36.5	63.1	0.3	45.0	54.5	0.5
CO_2	12.2	80.1	7.7	28.4	60.5	11.0	27.8	54.8	17.4

Table 4.3 presents the emission intensity and emission per capita in 1992 for selected pollutants. Emission intensity was found to vary from 0.21 in Myanmar to 2.25 kg/thousand US$ in Vietnam for NO_x, while for SO_2, emission intensity was found to vary from 0.18 in Myanmar to 7.70 kg/thousand US$ in Thailand. Emission intensity for NO_x were particularly high in Brunei, Malaysia, Thailand, and Vietnam. Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam have very high SO_2 emission intensity. As can be seen from the table, emission intensities in most countries are higher than those in industrialized countries. This is partly because, the efficiency of electricity generation from coal-fired power plants was significantly lower in SEA countries (efficiency varies from .... to ....) as compared to 38.8% in Japan and 36.9 in OECD countries as a whole. They also partly reflect the lack of emission controls in SEA countries.

In per capita terms, the emissions varied from 0.13 kg in Myanmar to 23.19 kg in Brunei for NO_x, while it varies from 0.11 in Myanmar to 37.83 kg in Singapore for SO_2. In most of the countries, the figures were less than 24 for NO_x and 38 for SO_2 which were less than the corresponding figures for total SO_2 from all sectors combined in industrialized countries.

Table 4.3 Emission Intensity (kg/thousand US$ 1992 price) and Per Capita Emission (kg) of SEA and Selected Industrialized Countries in 1992.

Country	Emission Intensity*			Emission Per Capita**		
	NO_x	SO_2	CO_2	NO_x	SO_2	CO_2
Brunei	1.59	0.54	290	23.19	7.82	4228
Indonesia	0.73	1.79	246	0.47	1.17	161
Malaysia	1.41	2.20	369	3.80	5.93	995
Myanmar	0.21	0.18	38	0.13	0.11	24
Philippines	0.94	6.11	341	0.65	4.18	233
Singapore	0.73	2.70	270	10.17	37.83	3784
Thailand	1.46	7.70	364	2.50	13.21	625
Vietnam	2.25	4.71	1007	0.23	0.48	103
Canada	3.35	5.79	716	72.34	125.13	14603
France	1.24	1.00	312	26.21	21.15	6557
Germany	2.15	3.78	645	51.14	89.96	12123
Japan	0.44	0.29	370	10.53	7.09	8805
United Kingdom	2.82	3.84	586	48.28	65.84	9985
United States	3.50	3.81	893	77.54	84.27	19520

*. Emission Intensity of six industrialized countries for NO_x (as NO_2 equivalent) and SO_2 are based on 1990 data, and for CO_2 are based on 1991 data. *Sources: WRI (1994), IMF (1995), and ADB (1995).*

5. POSSIBLE ENVIRONMENTAL UPGRADATION THROUGH RENOVATION AND MODERNIZATION OF ELECTRICITY SECTOR IN SEA

6. CONCLUSIONS AND FINAL REMARKS