

# Why Have CO<sub>2</sub> Emissions Increased in the Transport Sector in Asia?

## Underlying Factors and Policy Options

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## Abstract

Rapidly increasing emissions of carbon dioxide from the transport sector, particularly in urban areas, is a major challenge to sustainable development in developing countries. This study analyzes the factors responsible for transport sector CO<sub>2</sub> emissions growth in selected developing Asian countries during 1980–2005. The analysis splits the annual emissions growth into components representing economic development; population growth; shifts in transportation modes; and changes in fuel mix, emission coefficients, and transportation energy intensity. The study also reviews existing government policies to limit CO<sub>2</sub> emissions growth, particularly various fiscal and regulatory policy instruments. The study finds that of the six factors

considered, three—economic development, population growth, and transportation energy intensity—are responsible for driving up transport sector CO<sub>2</sub> emissions in Bangladesh, the Philippines, and Vietnam. In contrast, only economic development and population growth are responsible in the case of China, India, Indonesia, Republic of Korea, Malaysia, Pakistan, Sri Lanka, and Thailand. CO<sub>2</sub> emissions exhibit a downward trend in Mongolia due to decreasing transportation energy intensity. The study also finds that some existing policy instruments help reduce transport sector CO<sub>2</sub> emissions, although they were not necessarily targeted for this purpose when introduced.

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# Why Have CO<sub>2</sub> Emissions Increased in the Transport Sector in Asia? Underlying Factors and Policy Options<sup>†</sup>

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Decomposition analysis.

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## 1. Introduction

Carbon dioxide (CO<sub>2</sub>) emissions released from fossil fuel consumption<sup>2</sup> in Asia increased from 2,136 million tons in 1980 to 7,692 million tons in 2005, with an average annual growth rate of 5.3 percent (IEA, 2007a). The transport sector remains one of the main sources of CO<sub>2</sub> emissions in most countries in Asia despite the fact that its share of total regional CO<sub>2</sub> emissions remained constant at about 10% over the last 25 years. This is because China and India, which are responsible for approximately 80 percent of the region's total CO<sub>2</sub> emissions, feature a relatively low share of emissions from the transport sector in their national CO<sub>2</sub> emissions, thus skewing the regional aggregates. Nevertheless, since rising incomes are associated with higher levels of car ownership and usage (Webster et al, 1986a,b) and greater trip rates and distances (Schäfer, 2000), transport activity and resulting CO<sub>2</sub> emissions could increase significantly in these countries along with economic growth and consumer clout. In most other Asian countries, the transport sector already accounts for a substantial share of total national CO<sub>2</sub> emissions. Therefore, any attempt to address climate change in Asia must pay attention to transport sector emissions. The identification of key factors driving CO<sub>2</sub> emissions is essential for the formulation of effective climate change mitigation policies and strategies. One approach to accomplish this objective is to decompose the growth of emissions into the possible affecting factors.

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<sup>2</sup> This study considers only fossil fuel consumption related CO<sub>2</sub> emissions as our analysis is for the transport sector which emits CO<sub>2</sub> through energy use.

Most existing studies are focused on the decomposition of national CO<sub>2</sub> emissions and emission intensities. Examples include Wu et al (2005) and Wang et al (2005) for China, Kawase et al (2006) for Japan, Rhee and Chung (2006) for Japan and South Korea; Lise (2006) for Turkey, Diakoulaki et al (2006) for Greece, Saikku et al (2008) for 27 EU member States, Lee and Oh (2006) for APEC countries, Luukkanen and Kaivo-oja (2002a) for ASEAN countries; Luukkanen and Kaivo-oja (2002b) for Scandinavian countries, Ebohon and Ikeme (2006) for sub-Saharan African countries, and Han and Chatterjee (1997) for nine developing countries (Brazil, Chile, Colombia, India, Korea, Mexico, Philippines, Thailand and Zambia). Some existing studies are focused on the decomposition of manufacturing and power sector CO<sub>2</sub> emissions or emission intensities (e.g., Liu et al (2007), Yabe (2004), Liaskas et al (2000), Schipper et al (2001), Chang and Lin (1998) and Bhattacharyya and Ussanarassamee (2004), Shrestha and Timilsina (1996), Nag and Kulshrestha (2000) and Shrestha and Marpuang (2006)). Note that power, industry and transport are the three major sectors responsible for fossil fuel related CO<sub>2</sub> emissions in each country in the world. While the factors affecting CO<sub>2</sub> emissions and emission intensities of the industry and power sectors have been analyzed in many countries, transport sector emissions and emission intensities have not been examined to the same extent, especially in developing countries.

Nevertheless, a few studies also examine factors affecting transport sector emissions growth. For example, Lakshmanan and Han (1997) attribute the change in transport sector CO<sub>2</sub> emissions in the US between 1970 and 1991 to growth in people's propensity to travel, population, and GDP. Lu et al (2007) decompose changes in CO<sub>2</sub> emissions from highway vehicles in Germany, Japan, South Korea and Taiwan during

1990-2002 into changes in emission coefficient, vehicle fuel intensity, vehicle ownership, population intensity and economic growth. Scholl et al (1996) calculate how changes in transport activity, modal structure, CO<sub>2</sub> intensity, energy intensity and fuel mix affect CO<sub>2</sub> emissions from passenger transport in nine OECD countries between 1973 and 1992. Similarly, Schipper et al (1997) identify the relative contribution of activity, modal structure, and energy intensity to changes in energy use and carbon emissions from freight transport in ten industrialized countries from 1973 to 1992. Schipper et al (2000) attribute transport sector CO<sub>2</sub> emission growth to transportation activity, modal structure, modal energy intensity and fuel mix. Kveiborg and Fosgerau (2007) decompose the historical growth in national Danish road freight traffic using a Divisia index decomposition method. Finally, Wu et al (2005) consider changes in transport energy intensity, average traveling distance, and number of vehicles (amongst numerous other factors) in their investigation of the underlying forces behind the stagnancy of China's energy-related CO<sub>2</sub> emissions from 1996 to 1999.

Understanding the factors affecting the growth of CO<sub>2</sub> emissions from the transport sector is critical because of its increasing prominence as a source of emissions in most countries and its relevance to the preparation of climate change mitigation strategies. Hence, this study aims to address this gap by executing a Divisia decomposition analysis of CO<sub>2</sub> emissions from the transport sector in 12 Asian countries during the 1980-2005 period. We attribute the growth of transport sector CO<sub>2</sub> emissions over the last 25 years to six factors. These are: (i) fuel switching, (ii) modal shifting, (iii) change in emission coefficients, (iv) sectoral energy intensity change, (v) per capita economic growth and (vi) population growth. Among these, three factors -- change in

transport sector energy intensity, and per capita GDP and population growth -- are found primarily responsible for driving transport sector CO<sub>2</sub> emissions in Asia.

This paper is organized as follows: Section 2 examines CO<sub>2</sub> emission trends and potential factors driving transport sector CO<sub>2</sub> emission growth over the last 25 years. This is followed by a discussion on methodology and data in Section 3. The main results of the study are presented in Section 4, followed by a review of policies addressing transport sector CO<sub>2</sub> emissions in Asia in Section 5. Finally, Section 6 offers key conclusions.

## **2. Potential Factors Driving the Transport Sector CO<sub>2</sub> Emissions Growth**

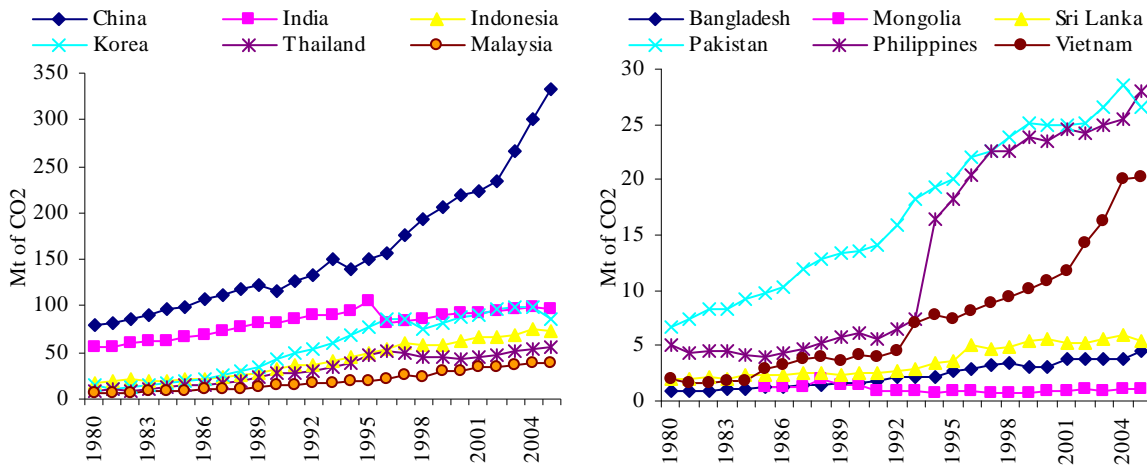
Before discussing potential factors driving transport sector CO<sub>2</sub> emission growth, we first highlight the trend of CO<sub>2</sub> emissions in selected Asian countries. This is followed by a discussion of direct factors, such as fuel switching, modal shifting and changes in transportation energy intensity. Moreover, we analyze some trends, such as population growth and urbanization, and economic growth and motorization, which provide further insights on the causes of transport sector CO<sub>2</sub> emission growth.

### **2.1. CO<sub>2</sub> Emissions**

Figure 1 presents the trend of transport sector CO<sub>2</sub> emissions in the 12 Asian countries that are responsible for more than 95 percent of the total CO<sub>2</sub> emissions from developing countries in the region. Aggregate transport sector CO<sub>2</sub> emissions at the

regional level more than tripled from 210 million tons in 1980 to 745 million tons in 2005 with a robust average annual growth rate of 5.2 percent.

**Figure 1: Trend of Transport Sector CO<sub>2</sub> Emissions in Asia**



Note: These graphs are based on total transport sector CO<sub>2</sub> emissions including those from international aviation, pipeline transport and all non-specified categories, and excluding emissions from electricity, which is assigned to the power sector. Hence, emissions presented in these graphs may differ from the data presented in Tables 2 and 3 where we exclude international aviation and pipeline transport, and include CO<sub>2</sub> emissions from electricity used by the transport sector.

Source: IEA (2007a)

Despite the increase in transport sector emissions in absolute terms, the share of the sector in the national total in China and India are significantly smaller than that in most Asian countries. Table 1 presents total national CO<sub>2</sub> emissions and the sectoral emission mix for the abovementioned 12 Asian countries. Transport sector shares of total national CO<sub>2</sub> emissions have increased in Republic of Korea, the Philippines and Vietnam; decreased in India, Indonesia, Pakistan and Sri Lanka; and remained more or less stable in Bangladesh, China, Malaysia, Mongolia and Thailand. Because the transport, power and industry sectors are the main contributors to national CO<sub>2</sub> emissions, changes in the magnitude of the emissions from the other two sectors, particularly the



power sector, have a considerable impact on the transport sector's share of national CO<sub>2</sub> emissions (see Table 1). For example, the transport sectors in China and India exhibit exceptionally low shares of total national emissions because power generation in these countries is heavily reliant on emission intensive fuels, mainly coal. On the other hand, while the transport sector share of total national emissions in Mongolia has hardly changed, the striking rise in its power sector's share is directly attributable to a drastic drop in industrial output (and industry sector emissions), reflecting the recession that followed the end of Soviet assistance in 1990-91. Low emissions from the power sector typically signify the exploitation of renewable resources such as hydro-power as opposed to fossil fuels. Of the twelve Asian countries considered, only Sri Lanka demonstrates a very low share of emissions from the power sector, and only until 1996, when it started to supplement its almost exclusive reliance on hydro-power with substantial usage of fossil fuels in its generation mix.

**Table 1: CO<sub>2</sub> Emission Mix by Sector**

Country	1980					2005				
	Total	Power	Indus-try	Trans-port	Other	Total	Power	Indus-try	Trans-port	Other
	(Mt of CO <sub>2</sub> )	(%)	(%)	(%)	(%)	(Mt of CO <sub>2</sub> )	(%)	(%)	(%)	(%)
Bangladesh	7	21	41	14	24	36	35	29	12	24
China	1,403	20	51	6	23	5,060	48	37	7	9
India	292	26	39	19	16	1,147	52	30	8	10
Indonesia	69	10	39	26	26	341	28	39	22	11
Korea	122	20	32	12	37	449	35	31	19	15
Malaysia	23	32	34	28	6	138	33	35	28	3
Mongolia <sup>#</sup>	12	48	25	11	16	10	70	8	12	10
Pakistan	26	16	37	25	22	118	30	37	22	11
Philippines	32	27	39	15	18	76	37	19	37	7
Sri Lanka	4	8	22	55	16	12	28	16	45	11
Thailand	34	33	23	28	16	214	30	37	26	7
Vietnam	14	24	36	14	26	80	24	37	25	14

Note: The note for Figure 1 also applies here. <sup>#</sup>: 1985 data are used instead of 1980. Other includes residential, commercial and agricultural sectors.

Source: IEA (2007a)

## 2.2. Modal Mix in the Transport Sector

One potential factor driving transport sector CO<sub>2</sub> emissions growth could be modal shifting, from less emission intensive modes (in terms of CO<sub>2</sub> emissions per passenger/freight kilometer), such as railway and water transportation, to more emission intensive modes, such as commercial airplanes and private road vehicles.

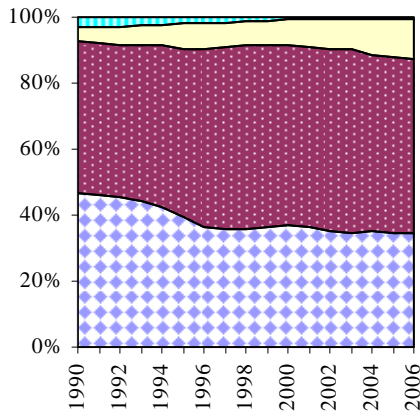
Figures 2(a)-2(d) illustrate the evolution of the modal mix for passenger transport activity in China, Korea, Vietnam and Pakistan, respectively, in terms of passenger kilometers. Road and rail are the main modes of passenger transport in China from 1990 to 2006, but it is clear that there has been a shift from rail towards road (see Figure 2(a)). There has also been a steady increase in the reliance on air transport for passengers, while the use of waterways has declined considerably. It should be noted that international aviation is included in the modal data for China. Road is by far the dominant mode of passenger transport in Korea, although the share of subway in passenger transport has increased over the period 1994-2006 (see Figure 2(b)). On the other hand, the share of aviation in passenger transport has waned only slightly, but the share of rail has declined significantly. Air transport has gained a substantial share of passenger transport in Vietnam from 1990 to 2006, largely at the expense of road transport, which, nonetheless, remains dominant (see Figure 2(c)). The share of rail and navigation has also gone down, especially sharply in 2005-2006, when road regained some of the share it had been losing in previous years. In Pakistan, where there is virtually no water transport, and aviation only accounts for a miniscule and declining share, road is overwhelmingly the main mode

for passenger transport over the period 1990 to 2004 (see Figure 2(d)). Rail's share of passenger transport activity has been steadily declining over the same time frame.

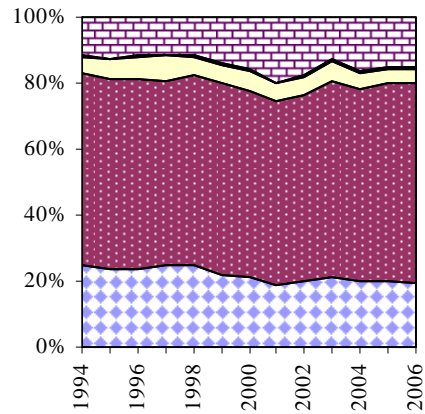
**Figure 2: Modal Mix for Passenger Transport**

Railway
  Roads
  Aviation
  Shipping
  Subway

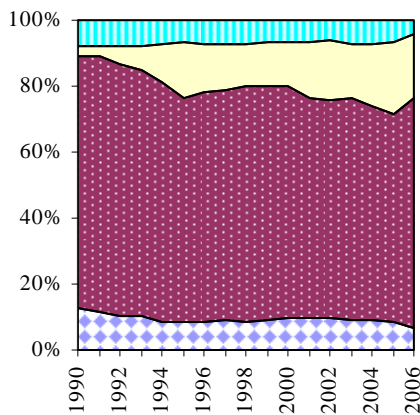
**(a) China (1990-2006)**



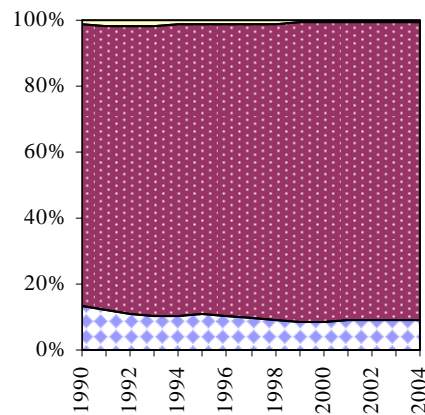
**(b) Korea (1994-2006)**



**(c) Vietnam (1990-2006)**



**(d) Pakistan (1990-2004)**



Source: National Bureau of Statistics of China (2007); Korea National Statistical Office (2008); General Statistical Office of Vietnam (2005); Accountancy (2007); United Nations Statistics Division (2008a)

Whereas road is the chief mode of passenger transport in all four of these countries, the modal mix for freight transport is rather different, except in Pakistan.

Figures 3(a)-3(d) show changes in the modal mix for freight transport activity in China,

Korea, Vietnam and Pakistan, respectively, in terms of ton kilometers. Domestic navigation has supplanted rail as the dominant mode of freight transport in China over the period 1980 to 2006, and although the share of road is higher in 2006 compared to 1980, this share has been relatively stable in recent years (see Figure 3(a)). The use of aviation for freight transport remains negligible in China. In Korea, shipping is the main mode for freight transport from 1994 to 2000 (see Figure 3(b)). Shipping is also by the far the most important mode for freight transport in Vietnam, with a share above 80 percent for much of the 1990-2005 period, followed by road, and then rail (see Figure 3(c)). However, domestic navigation is not utilized for freight transport from 1990 to 2004 in Pakistan, where freight is overwhelmingly transported via road, which gained significant share from rail over this period (see Figure 3(d)).

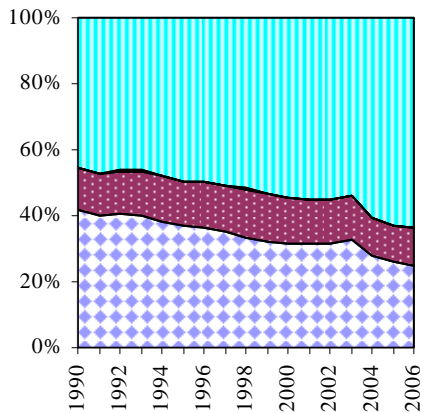
Note that modal mix data in terms of transportation services are available only for four countries (i.e., China, Korea, Vietnam and Pakistan) out of the 12 countries considered in this study. Moreover, since these data are taken from each country's national statistical agency, they are not comparable across countries due to the lack of international reporting standards for transportation data. For example, road transport activity indicated for China does not include public buses and taxis, whereas they are included in road transport activity for Korea. Furthermore, the temporal scope of the data also differs. Modal mix is available for China from 1990 to 2006, while it is only available for varying parts of that time frame for Korea, Vietnam and Pakistan. Hence, such data will not be useful in the decomposition analysis pursued later. Instead, we will

be using energy consumption data as a proxy for transportation services<sup>3</sup> although passenger and freight kilometers (or any equivalent units) would be the desired measurement for transportation services.

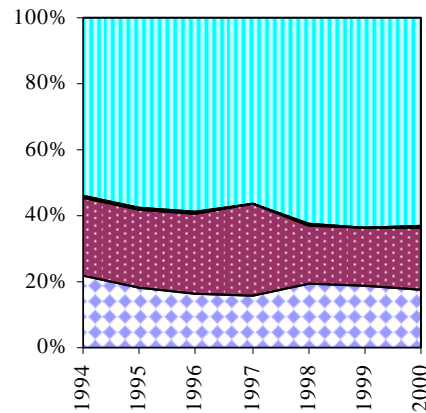
**Figure 3: Modal Mix for Freight Transport**

Railway
  Roads
  Aviation
  Shipping
  Subway

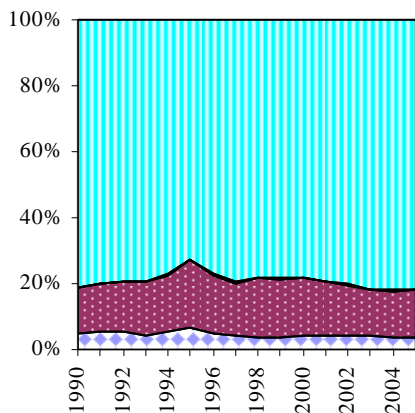
**(a) China (1990-2006)**



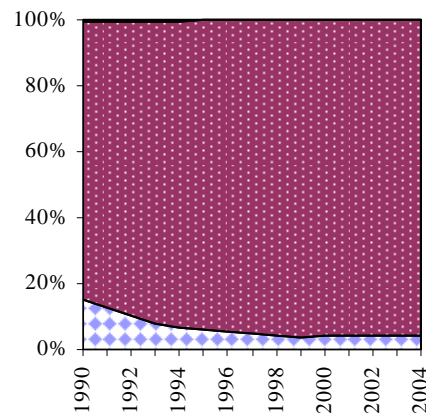
**(b) Korea (1994-2000)**



**(c) Vietnam (1990-2005)**



**(d) Pakistan (1990-2004)**



Source: National Bureau of Statistics of China (2007); Korea National Statistical Office (2008); General Statistical Office of Vietnam (2005); Accountancy (2007); United Nations Statistics Division (2008a).

<sup>3</sup> In energy literature, this is a common practice to measure modal mix in the transportation sector (see e.g., EIA, 2007; IEA, 2004)

Table 2 presents modal mix in terms of energy consumption and CO<sub>2</sub> emissions. Road was the predominant mode of transportation in all countries in 1980, especially in Malaysia and Thailand. The role of road transportation was even more prominent in 2005 as most countries have increased their reliance on road transportation since 1980. Road transport accounted for more than 90% of transport sector CO<sub>2</sub> emissions in 6 out of the 12 countries in 2005, and only China features a modal share of less than 70 percent of CO<sub>2</sub> emissions for road transport. A few countries utilized domestic air transport to a large extent, e.g., more than 10 percent of transport sector fuel consumption and CO<sub>2</sub> emissions in Sri Lanka and Vietnam in 1980 came from domestic air transport, but its share declined in all countries, except for China, by 2005. It should be noted, however, that reliable data for fuel consumption in domestic aviation is not available for half the countries considered (see Table 2).

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**Table 2: Modal Mix for Fuel Consumption in Transport Sector**

Country	1980					2005				
	Modal mix in terms of energy consumption									
	Total Mtoe	Air %	Water %	Rail %	Road %	Total Mtoe	Air %	Water %	Rail %	Road %
Bangladesh	0.3	n.a.	29.5	13.2	57.3	1.5	n.a.	16.6	12.0	71.4
China	24.4	1.2	5.2	43.6	50.0	107.5	7.0	8.6	13.9	70.5
India	16.9	n.a.	2.0	38.6	59.3	33.7	n.a.	1.9	8.3	89.8
Indonesia	6.0	5.9	3.0	0.2	90.8	25.0	2.4	6.9	0.0	90.7
Korea	4.8	4.6	22.3	7.4	65.7	29.1	4.3	3.0	1.7	91.1
Malaysia	2.2	n.a.	0.0	n.a.	100.0	13.3	n.a.	0.0	0.0	100.0
Mongolia	0.44	n.a.	0.0	19.4	80.6	0.39	n.a.	0.0	26.9	73.1
Pakistan	2.2	n.a.	0.0	5.9	94.1	8.1	n.a.	0.0	3.5	96.5
Philippines	1.8	4.2	12.4	0.0	83.4	8.0	3.2	10.3	5.2	81.4
Sri Lanka	0.7	18.7	0.6	5.1	75.5	1.8	9.5	1.2	1.4	87.9
Thailand	3.2	n.a.	0.1	n.a.	99.9	18.6	n.a.	0.4	0.6	99.0
Vietnam	0.6	15.1	0.0	9.7	75.2	6.8	2.5	4.5	0.5	92.4
Country	Modal mix in terms of CO <sub>2</sub> emissions									
	Mt	%	%	%	%	Mt	%	%	%	%
Bangladesh	1.0	n.a.	29.9	13.5	56.6	4.5	n.a.	16.8	12.2	71.0
China	83.6	1.0	4.7	51.5	42.7	338.6	6.7	8.6	18.2	66.5
India	58.1	n.a.	1.9	45.0	53.1	108.6	n.a.	1.9	14.2	83.9
Indonesia	17.9	5.9	3.2	0.3	90.6	74.6	2.4	7.2	0.0	90.4
Korea	14.8	4.4	23.0	8.4	64.2	86.8	4.3	3.2	2.3	90.3
Malaysia	6.5	n.a.	0.0	n.a.	100.0	39.6	n.a.	0.0	0.1	99.9
Mongolia	1.3	n.a.	0.0	18.3	81.7	1.2	n.a.	0.0	29.0	71.0
Pakistan	6.8	n.a.	0.0	6.1	93.9	24.7	n.a.	0.0	3.5	96.5
Philippines	5.2	4.3	13.1	0.0	82.6	24.3	3.1	10.7	5.4	80.8
Sri Lanka	2.1	18.4	0.6	5.2	75.8	5.5	9.3	1.2	1.5	87.9
Thailand	9.6	n.a.	0.1	n.a.	99.9	56.5	n.a.	0.4	0.6	99.0
Vietnam	2.0	14.8	0.0	12.6	72.6	19.2	2.5	4.8	0.8	91.9

Note: Based on the available data and following normal practices in energy accounting systems, we considered four modes of transportation: road, rail, water and air. If data is available, road transportation, which is the primary mode for providing transportation services as well as energy consumption and associated emissions, can be disaggregated further into auto, bus, etc.

Source: IEA (2007b, c)

Rail transport has been an important mode of transportation in a number of the countries since 1980. China and India exhibited particularly high modal shares for rail in 1980, although rail was an important mode of transport in Bangladesh, Mongolia and Vietnam as well. However, by 2005, these two countries had registered massive declines in the modal share for rail, and in fact, only Mongolia and the Philippines show significant gains in the modal share for rail over the study period. The share of CO<sub>2</sub> emissions from rail exceeds its share of fuel consumption appreciably in India, China and Vietnam, again on account of the electricity used being generated largely from coal. Domestic navigation represented a major mode of transportation in Bangladesh, Korea and the Philippines in 1980, but its share declined in all three countries by 2005, and especially drastically in Bangladesh and Korea. Substantial growth in the share of domestic navigation in energy consumption and CO<sub>2</sub> emissions is only seen in China, Indonesia and Vietnam. In the case of Vietnam, fuel consumption in domestic navigation as reported by the IEA (see Table 2) is likely to be a significant underestimate as the data do not capture the overwhelming reliance of freight transport in Vietnam on coastal shipping (see Figure 3(c)). In most countries, there is found to be no or minimal reliance on waterways over the study period.

### **2.3. Transport Sector Fuel Mix**

How fuel substitution occurs within a mode of transportation is another factor that explains transport sector CO<sub>2</sub> emissions growth. However, there exist very limited fuel choices for the transport sector. Motor gasoline and diesel are the main fuels used in the



transport sector (see Table 3). A comparison of the fuel mix between 2005 and 1980 suggests significant substitution of gasoline with diesel in some of the countries – Pakistan, the Philippines, Thailand and Vietnam. According to GTZ<sup>4</sup> (2007), these are the countries where gasoline is taxed while diesel is subsidized. Since the price of diesel has been maintained at an artificially low level by the governments via price controls for socioeconomic reasons, the substitution of gasoline with diesel in these countries is not surprising. Minimal substitution between gasoline and diesel is observed to have occurred in the other countries. Obviously, CO<sub>2</sub> emissions largely originate from the combustion of diesel and motor gasoline, but even though diesel has slightly higher carbon content as compared to gasoline, the substitution of gasoline with diesel does not change CO<sub>2</sub> emissions significantly as diesel provides better fuel economy as compared to gasoline. A comparison of diesel and gasoline shares in Table 6 also demonstrates this fact.

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<sup>4</sup> Deutsche Gesellschaft für Technische Zusammenarbeit

**Table 3: Transport Sector Fuel Mix**

Country	1980											2005												
	Total	Aviation Fuels	Electricity	Diesel	LPG	Bio-fuels	Gasoline	Natural Gas	Heavy Fuel Oil	Coal	Kerosene	Total	Aviation Fuels	Electricity	Diesel	LPG	Bio-fuels	Gasoline	Natural Gas	Heavy Fuel Oil	Coal	Kerosene		
<b>Fuel mix in terms of energy consumption</b>																								
	Mtoe	%	%	%	%	%	%	%	%	%	%	Mtoe	%	%	%	%	%	%	%	%	%	%	%	
Bangladesh	0.3	0.0	0.0	73.3	0.0	0.0	19.2	0.0	7.4	0.0	0.0	1.5	0.0	0.0	79.0	0.0	0.0	21.0	0.0	0.0	0.0	0.0	0.0	
China	24.4	1.2	0.9	13.4	0.0	0.0	43.9	0.0	1.9	38.7	0.0	107.5	7.0	1.6	40.2	0.5	0.0	44.2	0.1	2.6	3.8	0.0	0.0	
India	16.9	0.0	1.2	55.0	0.0	0.0	9.6	0.0	1.9	32.3	0.0	33.7	0.0	2.5	66.4	0.0	0.3	27.5	2.0	1.4	0.0	0.0	0.0	
Indonesia	6.0	5.9	0.0	42.5	0.0	0.0	50.3	0.0	1.1	0.2	0.0	25.0	2.4	0.0	41.3	0.0	0.0	55.5	0.1	0.7	0.0	0.0	0.0	
Korea	4.8	4.6	0.7	60.5	3.5	0.0	17.8	0.0	12.8	0.0	0.0	29.1	4.3	0.8	51.6	14.6	0.0	25.5	1.1	2.0	0.0	0.0	0.0	
Malaysia	2.2	0.0	0.0	39.5	0.0	0.0	60.5	0.0	0.0	0.0	0.0	13.3	0.0	0.0	38.2	0.0	0.0	61.7	0.0	0.0	0.0	0.0	0.0	
Mongolia	0.4	0.0	2.8	20.3	0.0	0.0	76.9	0.0	0.0	0.0	0.0	0.39	0.0	2.3	19.5	0.0	0.0	69.4	0.0	0.0	8.8	0.0	0.0	
Pakistan	2.2	0.0	0.1	71.4	0.0	0.0	26.2	0.0	2.2	0.0	0.0	8.1	0.0	0.0	84.1	0.0	0.0	15.6	0.0	0.2	0.0	0.0	0.0	
Philippines	1.8	4.2	0.0	17.6	0.0	0.0	75.9	0.0	2.1	0.0	0.2	8.0	3.2	0.1	54.4	0.0	0.0	37.5	0.0	4.8	0.0	0.0	0.0	
Sri Lanka	0.7	18.7	0.0	64.4	0.0	0.0	16.9	0.0	0.0	0.0	0.0	1.8	9.5	0.0	63.3	0.0	0.0	27.2	0.0	0.1	0.0	0.0	0.0	
Thailand	3.2	0.0	0.0	52.2	1.2	0.0	46.5	0.0	0.0	0.0	0.1	18.6	0.0	0.0	68.6	1.9	0.0	29.2	0.2	0.0	0.0	0.0	0.0	
Vietnam	0.6	15.1	0.0	15.5	0.0	0.0	59.7	0.0	0.0	9.7	0.0	6.8	2.7	0.5	55.6	0.0	0.0	41.2	0.0	0.0	0.0	0.0	0.0	
<b>Fuel mix in terms of CO<sub>2</sub> emission</b>																								
	Mt	%	%	%	%	%	%	%	%	%	%	Mt	%	%	%	%	%	%	%	%	%	%	%	
Bangladesh	1.0	0.0	0.0	74.0	0.0	0.0	18.1	0.0	7.8	0.0	0.0	4.5	0.0	0.0	80.1	0.0	0.0	19.9	0.0	0.0	0.0	0.0	0.0	0.0
China	83.7	1.2	3.2	12.1	0.0	0.0	37.0	0.0	1.8	44.6	0.0	338.6	6.7	5.1	39.6	0.4	0.0	40.7	0.0	2.6	4.8	0.0	0.0	0.0
India	58.1	0.0	3.0	49.7	0.0	0.0	8.1	0.0	1.8	37.3	0.0	108.6	0.0	8.6	63.8	0.0	0.0	24.7	1.4	1.4	0.0	0.0	0.0	0.0
Indonesia	17.9	5.9	0.0	43.9	0.0	0.0	48.7	0.0	1.2	0.3	0.0	74.6	2.4	0.0	42.9	0.0	0.0	53.8	0.0	0.8	0.0	0.0	0.0	0.0
Korea	14.8	4.4	1.7	60.7	3.0	0.0	16.7	0.0	13.4	0.1	0.0	86.8	4.3	1.3	53.6	12.9	0.0	24.8	0.9	2.2	0.0	0.0	0.0	0.0
Malaysia	6.5	0.0	0.0	41.1	0.0	0.0	58.9	0.0	0.0	0.0	0.0	39.6	0.0	0.1	39.8	0.0	0.0	60.1	0.0	0.0	0.0	0.0	0.0	0.0
Mongolia	1.3	0.0	0.4	21.9	0.0	0.0	77.7	0.0	0.0	0.0	0.0	1.2	0.0	0.3	20.1	0.0	0.0	67.1	0.0	0.0	12.5	0.0	0.0	0.0
Pakistan	6.8	0.0	0.1	72.6	0.0	0.0	24.9	0.0	2.4	0.0	0.0	24.7	0.0	0.0	85.0	0.0	0.0	14.8	0.0	0.2	0.0	0.0	0.0	0.0
Philippines	5.2	4.3	0.0	18.5	0.0	0.0	74.7	0.0	2.3	0.0	0.2	24.3	3.1	0.2	55.7	0.0	0.0	35.9	0.0	5.1	0.0	0.0	0.0	0.0
Sri Lanka	2.1	18.4	0.0	65.5	0.0	0.0	16.1	0.0	0.0	0.0	0.0	5.5	9.3	0.0	64.6	0.0	0.0	26.0	0.0	0.1	0.0	0.0	0.0	0.0
Thailand	9.6	0.0	0.0	53.9	1.1	0.0	44.9	0.0	0.0	0.0	0.1	56.5	0.0	0.1	70.2	1.7	0.0	27.9	0.2	0.0	0.0	0.0	0.0	0.0
Vietnam	2.0	14.8	0.0	15.8	0.0	0.0	56.8	0.0	0.0	12.6	0.0	19.2	2.6	0.8	57.0	0.0	0.0	39.5	0.0	0.0	0.0	0.0	0.0	0.0

Note: CO<sub>2</sub> emission from electricity consumption in transport is computed by multiplying the electricity consumption by country and year specific emission coefficient for electricity (derived using IEA data on electricity output and CO<sub>2</sub> emissions from electricity production).

Source: IEA (2007b, c)

China and India were both highly dependent on coal as fuel for rail transport in 1980 (coal comprised well over 30 percent of fuel consumption for transportation in these two populous nations (see Table 3)). By 2005, coal had already been completely phased out as railway fuel in India, and its share in the fuel mix had declined to under 4 percent in China. Over the same period, considerable growth in the share of diesel in the fuel mix is observed in both countries, especially China. Some of this is the result of the direct substitution of coal with diesel in rail transport. However, since rail transportation itself has been significantly replaced with road transport, the substitution of coal with diesel only accounted for a small part of the gains in diesel consumption in China and India. Most of the increased diesel demand was due to the growth of road transportation.

The combustion of aviation fuels represented another notable source of emissions from transportation in 1980, but only in a few countries such as Sri Lanka and Vietnam. Reliable aviation fuel consumption data is not available for all countries; however, the share of aviation fuel in total transport sector fuel consumption as well as in emissions declined in the countries for which data is available, except for China and the Philippines. Utilization of electricity for transportation in 1980 was negligible in all countries except China, India, Korea and Mongolia. However, the share of electricity has increased slightly in China, India and Korea (along with the Philippines and Vietnam), whereas it has declined in Mongolia. Despite the small share of electricity in the energy mix in China and India, it is nonetheless an important source of CO<sub>2</sub> emissions due to the high CO<sub>2</sub> emission coefficient for electricity generation in these countries.

Liquefied petroleum gas (LPG) was not a major fuel for transportation in any of the countries, except Korea, where its share rose from 3.5 percent of the energy mix in

1980 to over 14 percent in 2005 and is used mainly in taxis, buses and trucks (Liu et al, 1997). China and Thailand, however exhibited far more modest increases in the use of LPG over the study period. Natural gas was not exploited as fuel for transportation in any of the countries in 1980, and only India and Korea had managed to incorporate it noticeably into their fuel mix by 2005. While none of the countries used biofuels for transportation in 1980, biofuels comprised a very small share of the fuel mix in India by 2005. Coal was one of the most important fuels for transportation, primarily for rail, in China and India, and to a lesser extent, Vietnam, in 1980; but these countries managed to either dramatically reduce or eliminate entirely their reliance on coal by 2005. Mongolia, on the other hand, which did not use coal as a fuel for transportation at all in 1980, had incorporated it into its transport fuel mix by 2005. Finally, the use of kerosene as a share of total fuel consumption for transportation was and remains negligible, if not nil, in all countries considered.

#### **2.4. Transportation Energy Intensity**

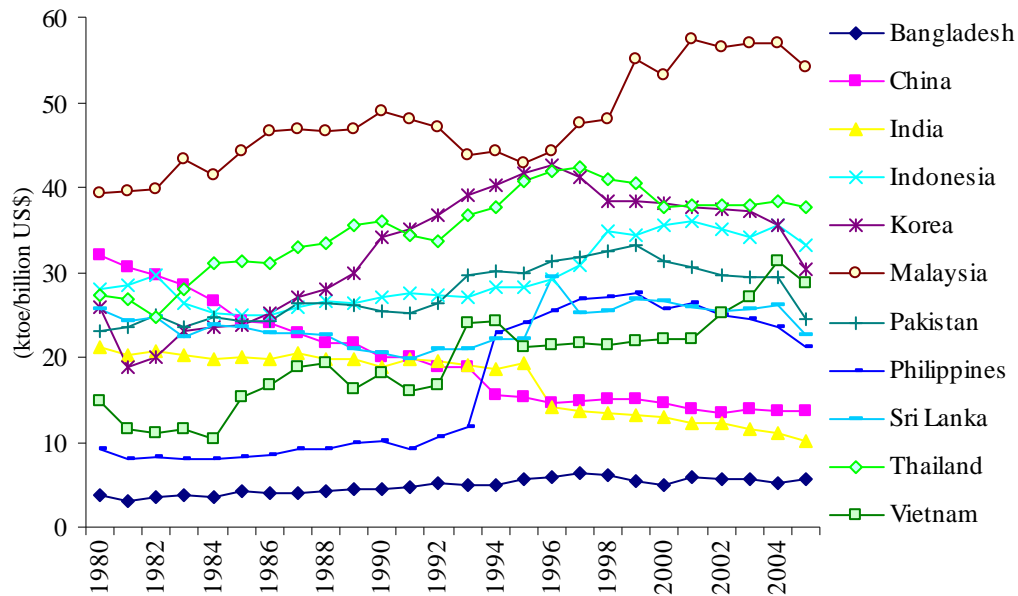
Figure 4 displays transportation energy intensity for all the Asian countries considered (except Mongolia<sup>5</sup>) over the period 1980-2005. It can be seen that transportation energy intensity, which is the ratio of total fuel consumption for transportation in an economy to its gross domestic product, varies significantly across

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<sup>5</sup> Mongolia is by far the most transportation energy intensive country considered in the study, outdistancing the country ranked second, Malaysia, by a very large margin, but transportation energy intensity in Mongolia has been declining, from 172 ktoe per billion US\$ in 1985 to 82 ktoe per billion US\$ in 2005.

countries and over time. Bangladesh registers as the country with the lowest, whereas Malaysia features the highest, transportation energy intensity of these eleven countries throughout the study period. Most of the countries demonstrate an overall upward trend in transportation energy intensity, that is, their fuel consumption for transportation per unit of economic output has increased, yet the two largest economies in the region, China and India (especially China), show steadily improving transportation energy intensity over the study period, which should mitigate some of the increased CO<sub>2</sub> emissions expected from their swift economic growth. Transportation energy intensity in Pakistan and Sri Lanka at the end of the study period are found to be close to the level at the beginning, although they fluctuate in between. Despite the overall deterioration in transportation energy intensity in most of the other countries, a noticeable improvement can be observed in the last year of the study period for every country other than Bangladesh and China.

**Figure 4: Transportation Energy Intensity in Selected Asian Countries (1980-2005)**



Source: IEA (2007b, c, f, g)

## 2.5. Population Growth and Urbanization

The Asian countries included in this study alone currently account for over half of the world's population and are projected to keep growing to comprise 3.6 billion out of the 7.2 billion total world population in 2015 (World Bank, 2008). Aside from population growth, the other notable demographic change in Asia is that it is also going through a period of rapid urbanization. Table 4 lists the population of Asian countries in 1990 and 2006, the percentage of urban dwellers, and the growth rates of total and urban populations. Urban population growth can be seen to be significantly higher than total population growth in all of the countries except Mongolia and Sri Lanka.

**Table 4: Total and Urban Population Size and Growth Rate**

	Population				Avg. Annual Growth (1990-2006)	
	1990		2006		Total (%)	Urban (%)
	Total (millions)	Urban share (%)	Total (millions)	Urban share (%)		
Bangladesh	113	20	156	26	2	3.6
China	1,135.2	27	1,311.8	41	0.9	3.5
India	849.5	26	1,109.8	29	1.7	2.5
Indonesia	178.2	31	223	49	1.4	4.4
Korea, Rep.	42.9	74	48.4	81	0.8	1.3
Malaysia	18.1	50	26.1	68	2.3	4.3
Mongolia	2.1	57	2.6	57	1.3	1.3
Pakistan	108	31	159	35	2.4	3.3
Philippines	61.2	49	86.3	63	2.1	3.8
Sri Lanka	17	17	19.9	15	1	0.2
Thailand	54.3	29	63.4	33	1	1.6
Vietnam	66.2	20	84.1	27	1.5	3.3

Source: World Bank (2008).

While developed and developing countries alike continue to urbanize, the rate of urbanization is especially fast in developing countries where the majority of people have not been city-dwellers traditionally. The year 2007 was historic in that it commemorated the first time that half of the world's population lived in cities, a share that is anticipated

to grow to 58 percent by 2025 because world urban population is projected to expand at almost double the rate of total world population over this period (ESCAP, 2007). Tokyo has been the largest urban area in the world for some time now, but more interestingly, of the twenty mega-cities (defined as a city with a minimum of 10 million inhabitants) around the world, twelve of them are found in Asia. South and Central Asian cities such as Dhaka, which has been growing at an average annual rate of approximately 5 percent since 1975 and is expected to be home to almost 10 percent of Bangladesh by 2015, Karachi and Delhi have been the fastest growing over the past quarter century (ibid.). As Asian countries continue to grow and urbanize, increasing motorization can be expected to generate higher levels of CO<sub>2</sub> emissions and place additional stresses on the transport infrastructure.

## **2.6. Motorization<sup>6</sup> and Economic Growth**

One of the key factors that explain why there occurred a modal shift towards road transportation from other modes of transportation is the rate of motorization. Most Asian countries have experienced significant growth in their road transport fleets, particularly in urban areas, resulting in soaring transportation energy use and CO<sub>2</sub> emissions. Estimates of the stock of passenger cars in Asian countries are presented in Table 5. Rapid growth in the passenger car fleet can be seen in almost every country considered, including approximately 19 percent growth in China, the most populous country in the world, and

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<sup>6</sup> Motorization, as per the commonly utilized UN definition, is measured here as the number of private cars per 1000 people in a country.

around 10 percent or more growth in two of the other most populous countries: India and Indonesia.

**Table 5: Passenger Car Fleet in Selected Asian Countries ('000 cars)**

	1990	1995	2000	2005	Average Annual Growth Rate
Bangladesh	42	51	70	90 <sup>a</sup>	5.6%
India	2,694	3,841	6,143	8,619 <sup>b</sup>	9.4%
Pakistan	559	773	1,066	1,167 <sup>b</sup>	5.8%
Sri Lanka	174	229	335	444 <sup>b</sup>	7.5%
Indonesia	1,313	2,107	3,039	5,494	10.0%
Malaysia	1,715	2,609	4,213	5,500 <sup>b</sup>	9.4%
Philippines	1,471	2,333	2,156	3,982 <sup>b</sup>	8.0%
Thailand	1,222	1,913	2,665	2,993 <sup>a</sup>	6.6%
Vietnam	33	26	44	n.a.	2.9%
China	1,622	4,179	8,537	17,359 <sup>a</sup>	18.5%
Korea	2,075	6,006	8,084	10,621 <sup>a</sup>	12.4%
Mongolia	8	24	44	80 <sup>a</sup>	17.8%

Source: ESCAP (2007b)

Note: <sup>a</sup> data are for 2004; <sup>b</sup> data are for 2003

While all these countries presently have low levels of personal motorization (mostly 2-wheelers in many cases), it is highly probable that these levels will increase dramatically as they achieve economic growth and given the expected increase in urban population (ADB, 2006). The World Energy Outlook 2007 (IEA, 2007h) warns that India is getting closer to the tipping point of US\$3000 GDP per capita (based on purchasing power parity, or PPP), after which vehicle ownership rates accelerate swiftly. It also estimates that per capita GDP (PPP) in India will rise to US\$13,000 by 2030, and greater buying power of that magnitude can be anticipated to assert itself partly in higher demand for 4 wheel vehicles, such as, cars and sports utility vehicles (SUVs) (ESCAP, 2007a). The Asian Development Bank (ADB, 2006) projects the active population of cars and SUVs in China to grow to 15 times its 2005 size to 193 million in 30 years under a business-as-usual (BAU) scenario; the analogous figure for India is 13 times to 80 million in 2035.



Table 6 displays the level of motorization, along with per capita GDP, in the Asian countries considered in this study. The level of motorization in developing Asian countries lags well behind those in developed countries, but since economic growth and energy-demand (and CO<sub>2</sub> emissions) growth are linked, the expected expansion of developing Asian economies at an average rate of more than 5 percent per year through 2030, with China, India, Indonesia and Malaysia leading the way, means that the current levels of motorization are likely only a fraction of what they will be in two or three decades as these populous and rapidly growing economies go through a phase of rapid motorization (ADB, 2006). The demand for passenger cars in Asia is growing much faster than per capita income in every country considered other than Bangladesh; sometimes astonishingly so, as in the case of China, Korea and Mongolia. Recent motorization data for Vietnam is not available.

**Table 6: Motorization (Number of passenger cars per 1,000 persons) and Gross Domestic Product per Capita (US\$)**

	1990		2005		Average Annual Growth Rate	
	Cars per 1,000 people	GDP per capita	Cars per 1,000 people	GDP per capita	Cars per 1,000 people	GDP per capita
Bangladesh	0.4	282	0.6 <sup>a</sup>	422	2.9%	2.9%
India	3.2	381	8.0 <sup>b</sup>	713	7.4%	4.2%
Pakistan	5.0	506	7.7 <sup>b</sup>	820	3.4%	1.7%
Sri Lanka	9.8	479	21.8 <sup>b</sup>	1,253	6.4%	3.7%
Indonesia	7.2	685	24.7	1,244	8.5%	2.9%
Malaysia	96.1	2,432	225.1 <sup>b</sup>	5,098	6.8%	3.8%
Philippines	24.1	724	49.8 <sup>b</sup>	1,163	5.7%	1.4%
Thailand	21.8	1,572	46.7 <sup>a</sup>	2,797	5.6%	3.5%
Vietnam	0.5	98	n.a.	621	n.a.	5.9%
China	1.4	358	13.4 <sup>a</sup>	1,766	17.4%	9.1%
Korea	48.4	6,153	222.9 <sup>a</sup>	16,454	11.5%	4.7%
Mongolia	3.6	567	30.4 <sup>a</sup>	800	16.5%	0.2%

Source: ESCAP (2007b); UN Statistics Division (2008b)

Note: <sup>a</sup> data are for 2004; <sup>b</sup> data are for 2003

### 3. Methodology to Determine Factors Affecting CO<sub>2</sub> Emission Growth

#### 3.1 Methodology

In this section, we derive the methodology to decompose transport sector CO<sub>2</sub> emission growth to the contributing factors. Data needed to implement the methodology are also discussed here.

Total CO<sub>2</sub> emission from the transport sector in a country in year t (CO<sub>2</sub><sub>t</sub>) is the summation of CO<sub>2</sub> emissions from all fuels used in all transport modes in that year, i.e.,

$$CO2_t = \sum_{ij} CO2_{ijt} \quad (1)$$

where, subscripts i, j and t refer to fuel type (e.g., gasoline, diesel, electricity), transportation mode (e.g., road, rail, air and water) and year, respectively. In order to decompose the emission to the potential factors affecting it, Equation (1) can be expressed as:

$$CO2_t = \sum_{ij} \frac{CO2_{ijt}}{FC_{ijt}} \times \frac{FC_{ijt}}{FC_{jt}} \times \frac{FC_{jt}}{TS_{jt}} \times \frac{TS_{jt}}{TS_t} \times \frac{TS_t}{GDP_t} \times \frac{GDP_t}{POP_t} \times POP_t \quad (2)$$

where, FC refers to fuel consumption, TS represents transport services (e.g., passenger kilometers, tons kilometers or any equivalent measurement representing transport services<sup>7</sup>) and GDP is used to measure economic output.

Unfortunately, data for transportation services are not available for the countries and for the time horizon considered in the study. We use an alternative approach as shown in Equation (3) to decompose the emission to the potential factors affecting it.

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<sup>7</sup> Includes transport services provided to all sectors (e.g., households, industry, government).

$$CO2_t = \sum_{ij} \frac{CO2_{ijt}}{FC_{ijt}} \times \frac{FC_{ijt}}{FC_{jt}} \times \frac{FC_{jt}}{FC_t} \times \frac{FC_t}{GDP_t} \times \frac{GDP_t}{POP_t} \times POP_{tt} \quad (3)$$

As implied in Equation (3), we represent modal mix by energy consumption by mode instead of transportation services provided by the mode. Equation (3) can also be rewritten as:

$$CO2_t = \sum_{ij} EC_{ijt} \times FM_{ijt} \times MM_{jt} \times EI_t \times PC_t \times POP_t \quad (4)$$

where, EC is emission coefficient or CO<sub>2</sub> intensity of a fuel (i.e., CO<sub>2</sub>/FC), FM refers to fuel mix (i.e., share of a fuel in a transportation mode), MM represents modal mix (i.e., share of fuel consumption by a mode in total transport sector energy consumption); EI is the transportation energy intensity (i.e., FC/GDP), PC is economic activity as captured by per capita GDP, and POP is population.

The growth of emissions is often decomposed into the potential driving factors using different methods, such as the Laspeyres or Divisia methods. While studies such as Lin et al (2008), Diakoulaki and Mandaraka (2007), Diakoulaki et al (2006), and Ebohon and Ikeme (2006) use the refined Laspeyres techniques, studies such as Liu et al (2007), Hatzigeorgiou et al (2007) and Wang et al (2005) use the Arithmetic Mean Divisia Index (AMDI) and the Logarithmic Mean Divisia Index (LMDI) techniques. In this study we follow the LMDI approach, which, unlike the AMDI approach, provides a residual-free decomposition and can accommodate the occurrence of zero values in the data set<sup>8</sup> (Ang, 2004). Although the refined Laspeyres methods also have these virtues, their formulae become increasingly complex when the number of factors exceeds three, and the linkages between the additive and multiplicative forms can not be established easily.

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<sup>8</sup> In this approach zero values are replaced with a small positive constant.

Using LMDI (Ang, 2005), the additive decomposition of the change in transport sector CO<sub>2</sub> emissions from year t-1 to t is expressed as:

$$\begin{aligned}
CO2_t - CO2_{t-1} &= \sum_{ij} \tilde{w}_{ij} \ln \frac{EC_{ijt}}{EC_{ijt-1}} + \sum_{ij} \tilde{w}_{ij} \ln \frac{FM_{ijt}}{FM_{ijt-1}} + \sum_{ij} \tilde{w}_{ij} \ln \frac{MM_{ijt}}{MM_{ijt-1}} \\
&+ \sum_{ij} \tilde{w}_{ij} \ln \frac{EI_t}{EI_{t-1}} + \sum_{ij} \tilde{w}_{ij} \ln \frac{PC_t}{PC_{t-1}} + \sum_{ij} \tilde{w}_{ij} \ln \frac{POP_t}{POP_{t-1}}
\end{aligned} \tag{5}$$

where

$$\begin{aligned}
\tilde{w}_{ijt} &= \frac{CO2_{ijt} - CO2_{ijt-1}}{\ln CO2_{ijt} - \ln CO2_{ijt-1}} && \text{for } CO2_{ijt} \neq CO2_{ijt-1} \\
&= CO2_{ijt} && \text{for } CO2_{ijt} = CO2_{ijt-1}
\end{aligned} \tag{6}$$

Similarly, the multiplicative decomposition of the change in the transport sector CO<sub>2</sub> emissions from year t-1 to t (again, following Ang (2005)) is given as:

$$\begin{aligned}
\frac{CO2_t}{CO2_{t-1}} &= \exp \left[ \sum_{ij} \tilde{v}_{ij} \ln \frac{EC_{ijt}}{EC_{ijt-1}} \right] \times \exp \left[ \sum_{ij} \tilde{v}_{ij} \ln \frac{FM_{ijt}}{FM_{ijt-1}} \right] \\
&\times \exp \left[ \sum_{ij} \tilde{v}_{ij} \ln \frac{MM_{ijt}}{MM_{ijt-1}} \right] \times \exp \left[ \sum_{ij} \tilde{v}_{ij} \ln \frac{EI_t}{EI_{t-1}} \right] \\
&\times \exp \left[ \sum_{ij} \tilde{v}_{ij} \ln \frac{PC_t}{PC_{t-1}} \right] \times \exp \left[ \sum_{ij} \tilde{v}_{ij} \ln \frac{POP_t}{POP_{t-1}} \right]
\end{aligned} \tag{7}$$

where

$$\tilde{v}_{ijt} = L(CO2_{ijt}, CO2_{ijt-1}) / L(CO2_t, CO2_{t-1}) \tag{8}$$

with

$$\begin{aligned}
L(a, b) &= \frac{a - b}{\ln a - \ln b} && \text{for } a \neq b \\
&= a && \text{for } a = b
\end{aligned} \tag{9}$$

The first term on the right hand side of Equations (5) and (7) represents the emission coefficient (EC) effect. Note that only the coefficient of electricity is changing

due to variations in electricity generation mix over time. Emission coefficients (i.e., carbon contents) for other fuels are assumed to be constant over time. The second and third terms represent the fuel mix (FM) or fuel switching and the modal mix (MM) or modal shift effects, respectively. The fourth term represents the transportation energy intensity (EI) effect. And finally, the fifth and sixth terms represent the economic activity or per capita GDP (PC) effect and population (POP) effect, respectively.

We have carried out the decomposition analysis on an annual basis over the twenty five year period between 1980 and 2005.

### **3.2 Data**

The study required a large set of data on energy consumption and emissions by fuel and by mode for the study period of 25 years. We explored every potential source of data, such as national energy statistics, UN energy statistics, and US Department of Energy databases. While national statistical agencies collect data at the level of detail needed in a few countries (e.g., Korea), they do not provide such data in most of the countries. Moreover, mixing data from different sources with different conventions and assumptions used for collection and aggregation would cause an artificial change in the trends. Therefore, we use transport sector energy consumption data by fuel type and mode from the International Energy Agency (IEA, 2007b, 2007c). No source other than the IEA provides data at the required details and time series needed for the study.

Fuels included are biofuel (i.e., ethanol), natural gas, liquefied petroleum gases (LPG), motor gasoline, aviation fuels (i.e., aviation gasoline, kerosene and jet fuel),

diesel oil, heavy fuel oil, coal, kerosene and electricity. The modes of transportation considered are domestic aviation, road, rail and domestic navigation<sup>9</sup>. We have excluded energy consumption in oil and gas pipeline transport.

Emission coefficients are based on the carbon contents of fuels and are obtained from Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) for all fuels except electricity. Emission coefficients for electricity are derived using IEA data on electricity output and CO<sub>2</sub> emissions from electricity production (IEA, 2007a, 2007d, 2007e). While CO<sub>2</sub> emission factors for other transportation fuels (e.g., gasoline, diesel, etc.) remain the same throughout the study period, CO<sub>2</sub> emission factors for electricity vary with time. This is because, the carbon content of a fossil fuel is not expected to change over time, but CO<sub>2</sub> emission coefficients of an electricity grid change over time as the electricity generation mix and thereby the input fuel mix for electricity generation changes every year. Moreover, the CO<sub>2</sub> emission coefficient of a particular fossil fuel is the same for all countries, whereas the coefficient for electricity varies across the countries depending on their electricity generation mix. CO<sub>2</sub> emissions are estimated by type of fuel and mode, using the corresponding fuel consumption and associated emission factors. Data on gross domestic product (GDP), expressed in 2000 constant dollar measured at purchasing power parity, and population are also taken from the IEA (IEA, 2007f, 2007g).

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<sup>9</sup> In energy statistics, energy consumption by international aviation and maritime transportation are not considered part of national energy consumption. These are treated separately under their international conventions (i.e., International Civil Aviation Organization and International Maritime Organization).

Data for China does not include Hong Kong or Macau. Korea refers to the Republic of Korea. Data for Mongolia was only available for the period 1985-2005.

#### **4. Results and Discussion**

All countries, with the exception of Mongolia, experienced significant growth in transportation sector CO<sub>2</sub> emissions during the 1980-2005 period. However, there remain significant differences in the magnitude of emissions growth and the factors driving it. Table 7 summarizes the results of the additive decomposition of transport sector CO<sub>2</sub> emissions growth into fuel switching, modal shifting and changes in emission coefficients<sup>10</sup>, transportation energy intensity, per capita GDP and population. Detailed year-by-year additive decomposition results for each country can be found in the Appendix. Figure 5 displays indexed time-series charts of the multiplicative decomposition of CO<sub>2</sub> emissions and its driving factors in each of the 12 countries considered.

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<sup>10</sup> Only the emission coefficients of electricity changes due to different electricity generation mix over time; emission coefficients of other fuels remain constant throughout the study period.

**Table 7: Annual Average CO<sub>2</sub> Emission Change and Responsible Factors (1980-2005)**

Country	Average CO <sub>2</sub> Emission Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors <sup>¥</sup>
		Fuel Mix (FM)	Modal Mix (MM)	Emission Coefficient (EC)	Energy Intensity (EI)	Per Capita GDP <sup>†</sup> (PC)	Population (POP)	
China	10,199	173	-664	-27	-4,553	13,591	1,679	FM, PC, POP
Bangladesh	140	0	0	0	31	61	48	EI, PC, POP
India	2,022	80	-291	30	-2,896	3,508	1,592	FM, EC, PC, POP
Indonesia	2,271	-14	1	0	392	1,256	637	MM, EI, PC, POP
Korea	2,882	32	-88	-10	-254	2,758	445	FM, PC, POP
Malaysia	1,322	2	0	0	215	647	458	FM, EI, PC, POP
Mongolia*	-4	14	-7	0	-45	17	16	MM, EI
Pakistan	719	4	0	0	-75	360	430	FM, PC, POP
Philippines	761	37	6	0	236	192	290	FM, MM, EI, PC, POP
Sri Lanka	137	-1	0	0	-19	120	37	PC, POP
Thailand	1,874	27	-18	0	251	1,272	343	FM, EI, PC, POP
Vietnam	746	5	-4	0	236	398	112	FM, EI, PC, POP

Note: The modal mix effect, as defined in this study, considers only four modes: road, rail, water and air. If necessary data is available to further disaggregate road transportation into auto, bus, etc., modal mix might be found to influence CO<sub>2</sub> emission growth.

<sup>†</sup> In 2000 US\$ PPP.

<sup>¥</sup> Factors in the same direction as average emission change.

\* Analysis for Mongolia is from 1985 to 2005.

As can be seen from Table 7, economic growth (i.e., per capita GDP growth) and population growth are the critical factors in the growth of transportation sector CO<sub>2</sub> emissions in all countries except Mongolia. Deterioration in transportation energy intensity is also found to contribute to emissions growth in Bangladesh, Indonesia, Malaysia, the Philippines, Thailand and Vietnam. Change in transportation energy intensity is not selected as an influencing factor in China, India, Korea, Pakistan and Sri Lanka because it is not directly contributing to emission growth in these countries, but improvements in transportation intensity, nonetheless, have had a tremendous impact by reducing emissions from where they would have been otherwise. This is particularly clear in the case of China and India, where average emission growth would have been 45% higher (14,753 kilotons of CO<sub>2</sub> rather than 10,199 kilotons) and 143% higher (4,918



kilotons of CO<sub>2</sub> rather than 2,022 kilotons), respectively, if there were no reduction in transportation energy intensity. The same applies for modal mix effects in China and India, where average emission growth would have been 6.5% and 14.3 % higher, respectively, otherwise. This may appear to be a counter-intuitive result given the shift in China and India away from rail to road (see Table 2), but the reliance of rail in these countries on coal, and coal based electricity renders road a less carbon intensive mode of transport than rail<sup>11</sup>.

Fuel switching contributes directly to emission growth in most of the countries considered (i.e., China, India, Korea, Malaysia, Pakistan, the Philippines, Thailand and Vietnam), but its impact is relatively small (see Table 7). For example, in India and the Philippines, where the fuel switching effect is most influential, it still only accounts for 4% and 4.9%, respectively, of the average growth in emissions. In Indonesia and Sri Lanka, where fuel switching serves as a brake on emission growth, its effect is negligible in magnitude. Although fuel switching is a common phenomenon in many Asian countries during the 1980-2005 period (see Table 3), interestingly, the fuel switching effect is not found to play a major role in driving transport sector CO<sub>2</sub> emissions in these countries. This is because fuel substitution mostly occurred between diesel and gasoline, and their CO<sub>2</sub> emission coefficients are not significantly different. Moreover, the effects of fuel mix and modal mix are much smaller relative to the impacts of economic and population growth.

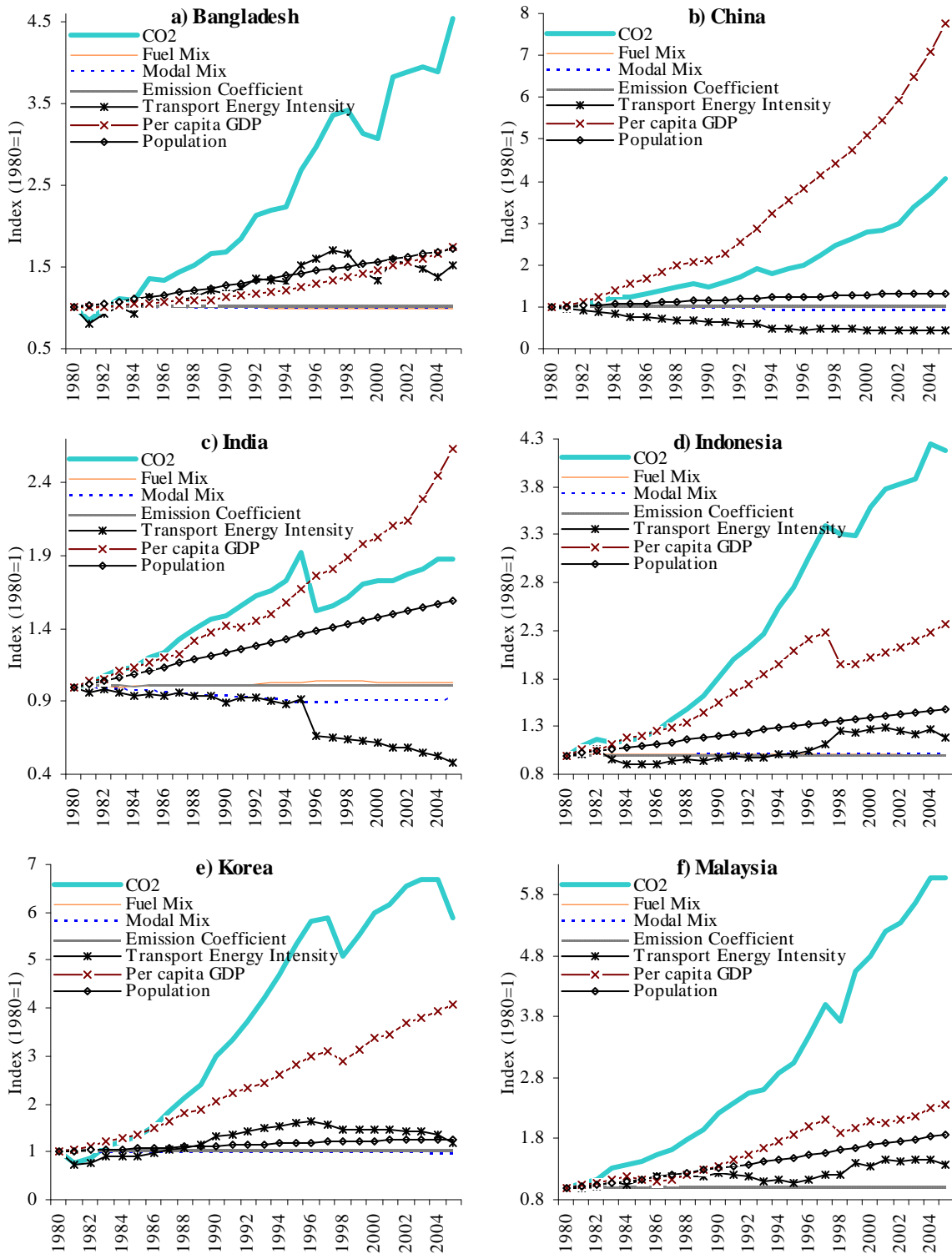
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<sup>11</sup> Note however that the carbon intensity of rail would, in fact, be lower than road on a passenger-km or ton-km basis.

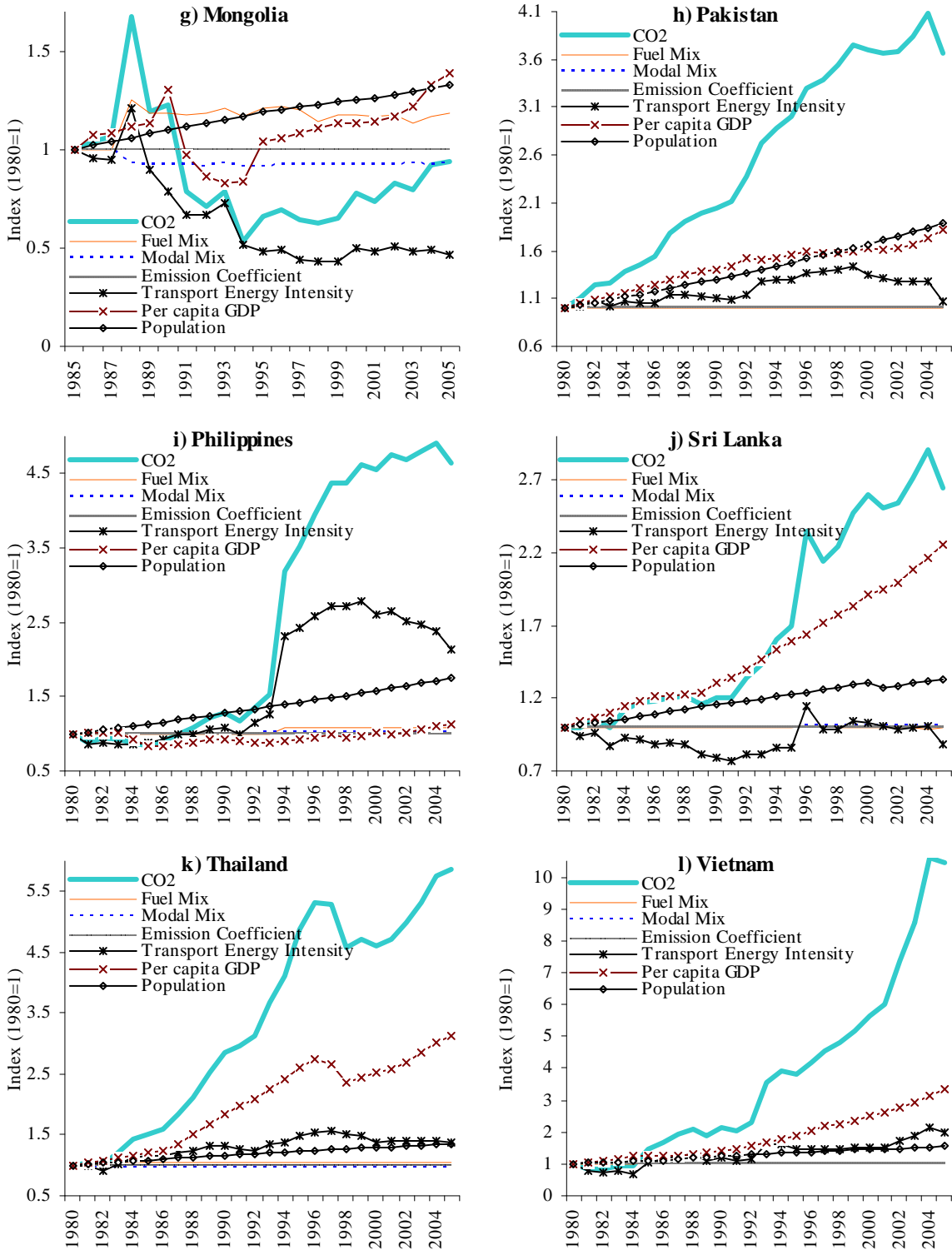
The emission coefficient effect has no impact on emission growth in all of the countries considered, with the exception of China, India and Korea. Considering that only the emission coefficient of electricity changes over time and that electricity use for transportation remained minimal in most of the countries, this is not surprising. The emission coefficient effect exacerbated emission growth in India, while it moderated it in China and Korea, but the effect is seen to be nominal in all cases. In all countries considered aside from Mongolia, the effects of fuel switching, modal shifting and changes in emission coefficients were eclipsed by the effects of the overwhelming growth in economic activity and population. In Mongolia, the only country considered where transport sector CO<sub>2</sub> emissions display a declining trend (an average reduction of 4 kilotons of CO<sub>2</sub> per year over the study period), the amelioration of emissions is largely due to improvements in transportation energy intensity and, to a lesser extent, modal mix.

A sharp decline in per capita GDP, reflecting the financial crisis in the region in 1997, can be observed for Indonesia, Korea, Malaysia and Thailand in 1997-1998, followed by renewed growth (see Figure 5d, 5e, 5f and 5k). CO<sub>2</sub> emission growth also follows this pattern in these countries. Deteriorating transportation energy intensity is found to have exacerbated CO<sub>2</sub> emission growth from economic activity in Indonesia, Malaysia, and Thailand. On the other hand, improvement of transportation energy intensity has restrained emission growth in Korea as well as China (see Figure 5b).

**Figure 5: Transport Sector CO<sub>2</sub> Emissions Growth and Driving Factors in Selected Asian Countries**



**Figure 5: Transport Sector CO<sub>2</sub> Emissions Growth and Driving Factors in Selected Asian Countries (continued)**



As mentioned above, improvement of transportation energy intensity has also had a tremendous impact on emission growth in India. However, the drastic improvement in transportation energy intensity between 1995 and 1996 (see Figure 5c) is the product of a statistical adjustment in the reporting of diesel consumption rather than the result of any real change (Zhou, 2007). It is thus likely that both CO<sub>2</sub> emission growth and transportation energy intensity for India ought to be revised downwards from 1980 to 1995. Similarly, an abrupt change in diesel consumption is reported for the Philippines between 1993 and 1994 (see Figure 5i). While no documentation could be found, it is highly likely that this is another instance of a statistical adjustment to the energy consumption data, and CO<sub>2</sub> emission growth and transportation energy intensity for the Philippines ought to be revised upwards from 1980 to 1993.

Figure 5g presents an indexed time-series chart of the decomposition results for Mongolia, the only country where transport sector CO<sub>2</sub> emission changes were primarily driven by changes in transportation energy intensity. Transportation energy intensity in Mongolia declined drastically after 1988, but especially from 1990-91 onwards, without Soviet assistance after the demise of the Soviet Union. Although Mongolia suffered a devastating recession after the collapse of the Soviet Union, its primary trading partner, its economy recovered and started growing again after 1994. However, its transportation energy intensity remained low as the country continued to suffer from chronic energy shortages. This explains the net reduction in CO<sub>2</sub> emissions from the transport sector as

compared to 1985. Further studies are needed to precisely determine the causes of decreases in the transportation energy intensities in Mongolia.<sup>12</sup>

## **5. Policy Initiatives to Address CO<sub>2</sub> Emissions Growth**

The results of our decomposition analysis show that economic activity, population growth and transport sector energy intensity are the main factors driving transport sector emissions growth in Asia. Developing Asian countries are not expected to slow down their economic growth to control their CO<sub>2</sub> emissions because these countries have neither mandatory nor voluntary commitments to reduce CO<sub>2</sub> emissions under the Kyoto Protocol. Thus, the main strategy to limit the growth of CO<sub>2</sub> emissions in the transport sector in these countries in the future would be the decoupling (or weakening) of the growth of CO<sub>2</sub> emissions from economic growth, which has not been the case historically. Rapid switching to clean fuels and shifting over to public transportation, including rail and water transportation, could help achieve this objective. Fiscal instruments, such as subsidies for public transportation, clean fuels and clean vehicles, would be helpful in triggering fuel switching and modal shifting activities. Moreover, regulatory instruments, such as vehicle efficiency standards, vehicle occupancy standards, congestion charges, investments in road maintenance and congestion reduction, would also be required to reduce transportation energy intensity and thereby reduce transport sector CO<sub>2</sub> emissions.

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<sup>12</sup> In order to determine the reasons for transportation energy intensity change, this indicator itself can be decomposed into its driving factors, such as fuel efficiency of transportation by mode and transport service intensity of the economy.

In the following sub-sections, we summarize policy initiatives undertaken by Asian countries that help address energy consumption and associated emissions from the transport sector.

### **5.1. Fiscal Instruments to Reduce Fuel Consumption**

Many countries in Asia have traditionally subsidized fuels used for transportation<sup>13</sup>. Historically, some Asian countries, such as Indonesia and Malaysia, have featured the some of lowest fuel prices in the region due to high subsidization, but both raised retail prices sharply between November 2004 and November 2006 (GTZ, 2007). The Philippines has also introduced drastic price increases, whereas Vietnam has pursued a policy of continuous reductions in subsidies. In both cases, gasoline has recently begun to be taxed although diesel remains subsidized. Thailand raised diesel prices by 76 percent to the point where it is almost subsidy-free, like gasoline in the country. Korea, which has long featured some of the highest fuel prices in the world, continues to raise taxes on diesel and gasoline. China has also raised its fuel prices by more than 40 percent between November 2004 and November 2006 so that they are no longer subsidized and hover near U.S. levels. India and Pakistan both maintain high non-

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<sup>13</sup> GTZ (2007) has been conducting worldwide surveys of diesel and gasoline prices since 1991 and uses U.S. retail prices (minus the U.S. highway tax) as benchmark values for non-subsidized fuels. U.S. prices are taken as benchmark values because the high degree of competition in the U.S. fuel market implies pricing that reflect commercially calculated full-cost prices. Most Asian countries tend to price diesel below this benchmark, indicating significant national subsidies for diesel, and some do so for gasoline as well.

subsidized prices for gasoline, but India has relaxed price controls on diesel since the early part of this decade. Even though Bangladesh has increased the price of state-subsidized diesel by over 30 percent, smuggling from Bangladesh to India (and, similarly, from Iran to Pakistan) continues to subvert state fuel policy in these countries.

Increasing diesel prices, or removing subsidies from diesel, could have environmental and ethical ramifications. First, diesel is mainly used in vehicles for public transportation which emit less CO<sub>2</sub> emissions than automobiles in terms of passenger kilometer traveled. Rising diesel price could encourage switching over to private transportation from public transportation and hence increase CO<sub>2</sub> emissions. Second, since public transportation is the main mode of road transportation for low income households, removing subsidies from diesel or increasing taxes on diesel would put extra burden on those households.

Fuel pricing is not the only means by which governments in Asia have attempted to curtail fuel consumption and CO<sub>2</sub> emissions growth. Other policies, such as providing incentives to low emission vehicles, are also practiced in some Asian countries. For example, the Chinese government updated excise tax rates, cutting rates by 5 to 3 percent on small-engine (1.0-1.5 liter) vehicles while raising rates by 8 to 20 percent on vehicles with larger-engines (more than 4 liters), to further encourage the manufacture of smaller-engine vehicles (ICCT, 2007). This was supplemented by the elimination of the preferential 5 percent tax rate on SUVs. Similarly, in 2007, Thai authorities approved a range of incentives for the production of eco-cars<sup>14</sup>: Eco-car manufacturers were granted

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<sup>14</sup> Cars with engine displacement of under 1,300cc if running on petrol or less than 1,400cc if running on diesel, and fuel consumption that is better than 20 kilometers per liter.



a maximum eight-year exemption from corporate income tax payments and machinery import duties, and excise rates for eco-cars were set at 17%, compared with a rate of 30 – 50% for other types of cars in Thailand (Economist Intelligence Unit, 2008).

Due to the relative price inelasticity of demand for automotive fuel in Asia, pricing instruments alone may not be effective in curtailing transport sector fuel consumption and associated emissions substantially (ADB, 2006). Other policy instruments, particularly regulatory policy instruments, would also be needed.

## **5.2. Regulatory Instruments to Improve Fuel Economy**

Regulatory instruments, such as vehicle fuel economy standards, have been applied in many developed countries, where they are regarded as successful tools to reduce fuel demand and CO<sub>2</sub> emissions from the transportation sector (Pew, 2004). In developing Asia, fuel economy standards have already been implemented in China and South Korea, and India is expected to join them in the near future.

China first began regulating fuel economy standards for its passenger vehicle fleet in 2005 and followed that with even more stringent standards in 2008 in order to decrease its dependence on foreign oil and to encourage foreign automakers to introduce more efficient vehicle technologies to the local market (ICCT, 2007). The standards, which are structured to be more stringent for the heavier vehicle classes to provide incentives for manufacturers to produce lighter vehicles, specify maximum allowable fuel consumption by 16 weight categories and cover passenger cars, SUVs and multi-purpose vans (MPVs) but not commercial vehicles and pickup trucks (Pew, 2004). As the Chinese standards are

not based on fleet average, every single vehicle model sold in China is required to conform to the standard for its weight class in terms of maximum liters consumed per 100-km (Pew, 2004). A recent study by the China Automotive Technology and Research Center finds that the standards implemented in 2005 improved overall passenger vehicle fuel efficiency from 26 mpg in 2002 to 28.4 mpg in 2006, or by about 9 percent, in spite of increases in gross weight and engine displacement (ICCT, 2007).

South Korea announced, in 2004, that it will implement mandatory fuel economy regulations – the Average Fuel Economy (AFE) standard – to replace the existing system of voluntary standards in 2006 for domestic cars and in 2009 for imports. The standards are set at 34.4 CAFE-normalized<sup>15</sup> mpg for vehicles with engine displacement less than 1,500 cubic centimeters (cc) and 26.6 mpg for those over 1,500 cc (ICCT, 2007).

However, despite being mandatory, there are no fiscal or criminal penalties for violating the AFE standard, with only a public shaming to serve as deterrent (Pew, 2004). The new AFE standard is partly a reaction to declining average fuel economy resulting largely from the growing popularity of SUVs, but since fuel economy standards remain static from 2006 onwards while the market share of larger, more powerful vehicles continues to rise gradually, South Korea is the only country with mandatory fuel economy standards where fleet average fuel economy is expected to deteriorate through 2012 (ICCT, 2007).

In India, the “Mashelkar Committee” proposed voluntary fuel economy standards for the automotive industry in 2002 (Mashelkar, 2002). Manufacturers, however, failed to commit to the voluntary scheme within the four year grace period granted by the

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<sup>15</sup> U.S. Corporate Average Fuel Economy (CAFE) test method. Other methods include New European Drive Cycle (NEDC), and Japan 10-15 Cycle.

government. In 2007, it was reported that the Indian government had resolved to create mandatory fuel efficiency standards for vehicles of every class and type, including cars, scooters, bikes, trucks, buses and three-wheelers; and that manufacturers may be penalized for neglecting to meet these standards (Times of India, 5 Oct 2007). Government projections estimated that the country could save up to \$36 billion if fuel efficiency is improved by 50% by 2030 in all sectors (CSE, 2008).

### **5.3. Policy Instruments to Promote Fuel Switching**

Aside from fuel economy regulations and pricing instruments to control fuel consumption, policy instruments to promote switching to alternative fuels have also been implemented in some countries and municipalities. The International Association of Natural Gas Vehicles (2008) reports extraordinary average growth of approximately 50 percent a year in the CNG vehicle population in Asia since 2000. Consequently, almost 2.5 million of the total 7 million compressed natural gas (CNG) vehicles estimated to be in service around the world in 2007 are found in developing countries in Asia (IANGV, 2008). This is, to some extent, by design. For example, in 2002, the Supreme Court in India directed the Union government to give priority to the transport sector over other sectors in India with regard to the allocation of CNG (ADB, 2006). In Thailand, the government, aiming to displace at least 10 percent of gasoline and diesel consumed with natural gas to help reduce the country's dependence on oil, scrapped import duties and lowered excise taxes on CNG-compatible cars in 2006 (Economist Intelligence Unit, 2008). CNG, which is sold by the state monopoly, PTT, is also priced to be more

attractive than other fuels and costs only about 30 percent as much as unleaded regular gasoline. In addition, ceiling prices have been set to ensure that the price of CNG does not exceed 55 percent of the price of unleaded regular gasoline in 2007, 60% in 2008, and 65% in 2009 (IANGV, 2007).

At the municipal level, more than 10,000 CNG buses are already running in Delhi (IANGV, 2008), where India's Supreme Court mandated CNG as the fuel for public transport in 1998 to improve urban air quality (ADB, 2006). Another four cities in India – Ahmedabad, Lucknow, Kanpur, and Hyderabad – have implemented CNG programs for urban transport and 22 more cities will be enabled to do so if the national gas grid is implemented (ADB, 2006). Elsewhere in the region, Dhaka requires its 3-wheelers to run on CNG (as does Delhi), while Shanghai requires a fraction of its new buses to be constructed to run on CNG. CNG has also started to be used in buses and taxis in cities such as Xi'an and Beijing (Schipper and Ng, 2004).

Most of the approximately 10 million LPG vehicles in use worldwide in 2004 were concentrated in a few countries, and four countries of them – Korea, Japan, Poland, Turkey, and Australia – account for more than half the world on-road transport consumption of LPG (ADB, 2006). In Asia, Korea and Japan actively promote the use of LPG. More than 10 percent of all registered vehicles in Korea, the world's largest automotive LPG consumer, are LPG-fueled due to the rapid market growth brought about by a large excise tax advantage over gasoline and diesel (which has since been reduced) (DOE, 2002). The world's second largest automotive LPG market is Japan, where the government offers grants for conversion or purchase of LPG vehicles and installation of filling stations. LPG is primarily utilized for taxis, buses and trucks in Korea, and mainly

for taxis in Japan, where more than 90 percent of taxis run on LPG, because the capital costs of conversion are more easily recovered by high mileage commercial vehicles (Liu et al, 1997).

Introduction of biofuels would be another option to replace gasoline and diesel in the transport sector. Current biofuels production capacity in Asia is very small. Of the 2.2 billion liters of biodiesel produced globally in 2004 (accounting for around 0.33% of worldwide diesel production), only a small fraction of that was made in Asia, specifically in the Philippines and in Malaysia (ADB, 2006). 33 billion liters of ethanol were produced worldwide, of which 0.2 billion liters came from Thailand, a major producer of sugar cane and cassava, two important feedstocks for the manufacture of ethanol. However, investment in new biodiesel production capacity, with coconut oil, palm oil, and jatropha as feedstock, is growing. Production of coconut biodiesel has already been started at the commercial scale in the Philippines, and Malaysia is expanding its palm oil biodiesel production capacity.

Thailand, where a National Biofuels Committee, supported by the ministries of finance, agriculture, industry and energy, is responsible for policy direction, strategy planning and implementation (Gonsalves, 2006), has taken aggressive steps towards displacing substantial quantities of fossil fuels with biofuels in its transport sector. The Thai government, which mandated that all government vehicles use gasohol by 2006, more recently passed a tax incentive package to encourage motorists and truckers to switch to ethanol or compressed natural gas from gasoline or diesel since it is negatively affected by rising oil prices as a net crude oil importer (Reuters UK, 2008). Following three years of strong sales growth of E10, propelled by lower government duties and

surcharges compared to gasoline, Thailand announced the launch of E85 (an 85:15 mix of ethanol and gasoline) in October 2008. Retail prices for E85 will be 30-40 percent cheaper than premium gasoline, and the excise tax on E85 vehicles will be lower than that on E20 vehicles (currently 25 percent) and regular vehicles (30-50 percent) (USDA, 2008).

Biodiesel production also enjoys tax incentives in Thailand: the government does not assess taxes on it and subsidizes it via an oil fund financed by surcharges from domestic retail prices of diesel and gasoline (Reuters UK, 2007). From February 1, 2008 onward, the Thai government began to enforce compulsory production of B2 (2 percent biodiesel in diesel) throughout the country and guarantee the sale quantity and prices to manufacturers (USDA, 2008). The mandate is expected to escalate to B5 in the near future. In support of this program, it also grants B2 manufacturers a subsidy of 0.30 Baht/liter from the State Oil Fund.

#### **5.4. Investments in Public Transport Infrastructure**

Even though public transportation is more sustainable than private cars in economic, social and environmental terms, many Asian cities have not been able to deliver the urban transport services needed to meet growing demand. Most Asian cities offer some inexpensive public transport options, but these are often overcrowded and dirty, and consequently, unable to draw commuters who can afford private transport. Despite the availability of formal bus services, more passenger trips are carried out on informal buses and paratransit vehicles (ADB, 2006). Both these public buses and

paratransit vehicles are typically responsible for significant amounts of local and pollutants and GHG emissions.

A number of cities in the region have constructed rail-based public transport systems, which provide high capacity along with high quality service, in recent years. Some, such as Manila and Shanghai, have put in place light rail systems, while others, such as Beijing, Delhi, Nanjing and Shanghai, have opted for subway systems, and Bangkok has invested in both light rail and subway systems (ESCAP, 2007). Rail-based mass transit systems have long been operational in the Korean cities of Seoul, Busan, Daegu and Incheon, the Chinese cities of Beijing and Tianjin, and the Indian city of Kolkata. Furthermore, they are under construction in Bangalore and Mumbai; and have been proposed for Karachi and Dhaka. Despite their high public profile, rail-based public transport systems are responsible for a relatively small share of overall trips (usually less than 10%), yet they have always required large subsidies for construction and operation (ADB, 2006). Even with the subsidies, they are only viable with high passenger flows, and, thus, are best suited for large, densely populated cities.

Another option that is gaining popularity in Asian cities is the bus rapid transit (BRT) system, characterized by “high-capacity (usually articulated) buses operating in exclusive segregated bus lanes, with rapid loading and unloading of passengers at stations that provide electronic fare pre-payment and obstacle-free waiting areas and level access to the buses” (ADB, 2006). Whereas rail-based public transport systems have larger passenger capacity, higher speeds and emit less air pollutants than bus systems (Litman, 2008), their construction and operation costs are often prohibitive. These modern bus corridors have proven that carrying capacities close to that of rail-based systems can be

delivered without subsidizing operations as they are often the product of public-private partnerships where the public sector funds only the infrastructure costs. As the infrastructure costs of BRT systems are far lower than those for rail-based mass transit, e.g., US\$1-15 million per km compared to US\$50 million to over US\$200 million per km (Wright and Fulton, 2005 (citing Wright, 2004)), this makes them especially attractive as an alternative to rail-based systems in developing countries.

Twenty BRT systems were already operational in Asia as of July 2008, with another fifty planned or under construction (CAI-Asia, 2009). The ADB (2006) reports that more cities in Asia are planning to implement BRT systems than rail-based mass transit systems. While existing BRT systems are most common in Japan, they are already operational in cities in China, India, Indonesia and South Korea as well. Most of the BRT systems that are planned, under construction or under consideration are in Chinese cities, but they are also anticipated in Thailand, Philippines, Sri Lanka, Bangladesh and Pakistan (CAI-Asia, 2009). The potential of BRT to reduce GHG emissions is recognized, as evidenced by the approval of the baseline and monitoring methodologies of the BRT in Bogotá, Columbia for the Clean Development Mechanism in July 2006.

## **6. Conclusions**

This study examines the growth of the transport sector CO<sub>2</sub> emissions and determines the underlying factors in twelve Asian countries over 25 years between 1980 and 2005. To identify the driving factors, we decompose the emission growth into fuel switching, modal shifting, per capita economic growth, population growth and changes in



emission coefficients and transportation energy intensity using the logarithmic mean Divisia index (LMDI) approach. We find that population growth, per capita economic growth and change in transportation energy intensity are generally found to be principal drivers of transport sector CO<sub>2</sub> emission growth in Asian countries, whereas fuel switching, modal shifting and change in emission coefficients are not found to have a sizeable influence on the growth of transport sector CO<sub>2</sub> emissions.

The per capita economic growth effect and the population growth effect are found to be primarily responsible for driving transport sector CO<sub>2</sub> emissions growth over the study horizon in all countries except Mongolia. The transportation energy intensity effect is found to be the main driver of the reduction of CO<sub>2</sub> emissions in Mongolia. However, improvement in transportation energy intensity is also found to restrain the growth of transport sector CO<sub>2</sub> emissions in some countries, significantly in China and India, while deterioration of transportation energy intensity exacerbates emission growth in other countries.

Some Asian countries, such Korea, China and India, have already implemented or are planning to implement, regulatory instruments, such as stringent fuel economy standards. This policy would reduce transportation energy intensity and thereby help reduce CO<sub>2</sub> emissions. Transportation energy intensity can also be reduced by improving vehicle occupancy rates through carpooling, which has not been promoted widely in Asia, or through the use of high occupancy public transit systems. China and Thailand are using fiscal instruments (e.g., favorable tax treatment to the production of vehicles with smaller engine). Korea maintains one of the highest tax rates on gasoline and diesel in the world. Several Asian countries have eliminated or reduced subsidies on fuels used by

private vehicles. However, automotive fuel demand is relatively price inelastic and hence pricing policies need to be supplemented with other policy instruments, such as the incentives offered in China and Thailand to promote the proliferation of smaller vehicles. Congestion pricing, a fiscal instrument to lessen traffic congestion, has not been attempted in any of the countries considered although it has been applied with great success in Singapore.

The fuel switching and modal shifting effects are not found to have a sizeable influence on the growth of transport sector CO<sub>2</sub> emissions in any of the Asian countries studied. However, policy instruments to encourage these underutilized approaches could significantly reduce emissions. Some countries are giving preferential treatment to less carbon intensive fuels, such as compressed natural gas, liquefied petroleum gas and biofuels, through favorable taxation and vehicular and blending mandates (e.g., mandating CNG buses in Delhi and Shanghai and 3-wheelers in Dhaka and Delhi). If these policies are successful in inducing large scale switching from gasoline and diesel to less carbon intensive fuels, such as natural gas and electricity, then the fuel mix effect can be expected to have a significant impact on transport sector CO<sub>2</sub> emissions. Some countries, such as Thailand, have used subsidies, exemption of import duties, and lower excise taxes to promote switching to cleaner fuels. Moreover, Korea and China have already introduced fuel economy standards, which others Asian countries could follow.

The study does not detect modal shifting to be a main factor in the growth of transport sector CO<sub>2</sub> emissions, but the analysis is limited by the unavailability of data specific to the various types of transport within road transport, such as cars, minibuses, buses and BRT systems. As road is overwhelmingly the most popular mode of transport

in Asia, disaggregated data on intra-modal shifting in road transport would enable a more accurate depiction of the impact of modal switching on transport sector CO<sub>2</sub> emissions. Moreover, several Asian cities have recently constructed light rail (e.g., in China, India, Korea, Philippines, Malaysia and Thailand) and Bus Rapid Transit systems (e.g., in Jakarta, Seoul and Beijing) to provide convenient and price competitive alternatives to private road vehicles.

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**Appendix**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Bangladesh**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	-162	-1	0	0	-195	12	22	FM, EI
1982	151	2	0	0	128	-1	22	FM, EI, POP
1983	120	3	0	0	77	15	26	FM, EI, PC, POP
1984	-27	-3	0	0	-79	28	27	FM, EI
1985	273	3	0	0	233	9	29	FM, EI, PC, POP
1986	-27	-3	0	0	-79	23	32	FM, EI
1987	96	1	0	0	45	18	32	FM, EI, PC, POP
1988	86	-1	0	0	56	-3	34	EI, POP
1989	139	-3	0	0	101	4	36	EI, PC, POP
1990	25	1	-1	0	-70	57	38	FM, PC, POP
1991	166	0	1	0	108	18	40	MM, EI, PC, POP
1992	278	1	0	0	180	52	45	FM, EI, PC, POP
1993	56	-3	0	0	-37	48	48	PC, POP
1994	43	-2	0	0	-42	40	48	PC, POP
1995	458	0	0	0	342	65	52	EI, PC, POP
1996	270	-1	0	0	144	69	58	EI, PC, POP
1997	384	-7	-1	0	228	102	62	EI, PC, POP
1998	75	2	0	0	-99	105	66	FM, PC, POP
1999	-298	8	1	0	-462	91	63	EI
2000	-61	-13	-2	0	-223	118	59	FM, MM, EI
2001	748	12	2	0	559	108	66	FM, MM, EI, PC, POP
2002	62	2	0	0	-106	91	74	FM, PC, POP
2003	66	-7	-1	0	-125	125	74	PC, POP
2004	-68	4	1	0	-309	163	73	EI
2005	653	5	1	0	406	166	75	FM, MM, EI, PC, POP

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**China**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	1,145	148	760	-85	-3,943	3,188	1,078	FM, MM, PC, POP
1982	4,438	-50	-97	-76	-2,911	6,292	1,280	PC, POP
1983	5,644	233	-603	-74	-3,425	8,185	1,329	FM, PC, POP
1984	6,927	198	-383	55	-6,843	12,612	1,289	FM, EC, PC, POP
1985	1,914	-463	-380	-366	-9,871	11,597	1,397	PC, POP
1986	7,081	-172	-583	-40	-1,157	7,440	1,593	PC, POP
1987	5,983	97	-777	26	-5,839	10,653	1,823	FM, EC, PC, POP
1988	7,152	229	-626	83	-5,408	10,938	1,936	FM, EC, PC, POP
1989	4,987	172	-276	68	-53	3,140	1,937	FM, EC, PC, POP
1990	-5,634	423	-533	83	-10,306	2,849	1,849	MM, EI,
1991	10,416	220	-1,758	59	611	9,535	1,749	FM, EC, EI, PC, POP
1992	8,359	452	-1,552	-74	-8,747	16,593	1,687	FM, PC, POP
1993	17,473	-181	-1,611	24	-471	17,982	1,729	EC, PC, POP
1994	-9,671	797	-247	-267	-28,974	17,273	1,747	MM, EC, EI,
1995	11,346	-326	-1,021	223	-3,590	14,372	1,686	EC, PC, POP
1996	6,827	510	-1,633	117	-7,838	13,948	1,723	FM, EC, PC, POP
1997	19,491	-320	1,326	-405	3,133	13,943	1,814	MM, EI, PC, POP
1998	18,378	-1,534	988	285	3,919	12,839	1,881	MM, EC, EI, PC, POP
1999	13,385	550	-893	-172	-1,649	13,542	2,007	FM, PC, POP
2000	12,410	-133	-457	-377	-4,786	16,568	1,595	PC, POP
2001	5,497	426	-307	-381	-12,927	16,985	1,701	FM, PC, POP
2002	13,906	417	-336	198	-7,625	19,617	1,635	FM, EC, PC, POP
2003	31,884	-909	414	201	6,773	23,745	1,660	MM, EC, EI, PC, POP
2004	26,606	4,102	-5,629	539	-745	26,569	1,769	FM, EC, PC, POP
2005	29,042	-555	-382	-309	-1,145	29,358	2,076	PC, POP

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**India**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	847	50	-260	47	-2,595	2,302	1,303	FM, EC, PC, POP
1982	3,350	9	-423	61	1,529	844	1,330	FM, EC, EI, PC, POP
1983	2,513	-20	-299	83	-1,592	2,975	1,367	EC, PC, POP
1984	692	183	-739	-171	-1,209	1,260	1,369	FM, PC, POP
1985	4,270	8	-207	138	630	2,320	1,380	FM, EC, EI, PC, POP
1986	1,994	63	-792	61	-675	1,808	1,529	FM, EC, PC, POP
1987	4,991	127	-500	186	2,078	1,524	1,576	FM, EC, EI, PC, POP
1988	4,303	201	-585	-176	-2,540	5,754	1,650	FM, PC, POP
1989	4,315	-58	-647	-35	-133	3,479	1,709	PC, POP
1990	736	34	-293	-25	-3,819	3,108	1,730	FM, PC, POP
1991	4,543	251	-299	59	3,736	-953	1,751	FM, EC, EI, POP
1992	3,988	484	-616	140	-775	3,031	1,724	FM, EC, PC, POP
1993	1,530	744	-1,446	119	-2,407	2,759	1,761	FM, EC, PC, POP
1994	4,089	621	-1,199	-204	-2,176	5,282	1,766	FM, PC, POP
1995	11,688	312	-726	303	3,999	5,911	1,888	FM, EC, EI, PC, POP
1996	-23,543	849	110	287	-31,885	5,341	1,753	EI
1997	1,827	144	-67	-189	-1,971	2,356	1,555	FM, PC, POP
1998	3,450	-808	810	-151	-1,739	3,759	1,579	MM, PC, POP
1999	5,126	419	-200	-17	-1,698	4,988	1,635	FM, PC, POP
2000	1,832	-528	65	158	-1,808	2,274	1,672	MM, EC, PC, POP
2001	-614	-571	374	-36	-5,471	3,470	1,620	FM, EC, EI
2002	3,187	-111	140	-127	-429	2,137	1,578	MM, PC, POP
2003	1,622	133	-108	-143	-6,637	6,827	1,551	FM, PC, POP
2004	4,456	121	-217	363	-4,366	7,026	1,529	FM, EC, PC, POP
2005	-634	-656	841	14	-10,447	8,127	1,488	FM, EI

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Indonesia**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	1,786	11	-6	0	314	1,091	376	FM, EI, PC, POP
1982	1,172	44	-3	0	909	-167	389	FM, EI, POP
1983	-680	10	-1	0	-2,348	1,278	382	MM, EI
1984	355	-4	-5	0	-1,043	1,033	374	PC, POP
1985	633	6	16	0	-99	330	381	FM, MM, PC, POP
1986	1,248	-18	-15	0	24	864	393	EI, PC, POP
1987	2,092	1	-1	0	884	793	415	FM, EI, PC, POP
1988	2,049	10	-2	0	471	1,121	448	FM, EI, PC, POP
1989	2,318	-35	45	0	-83	1,904	486	MM, PC, POP
1990	3,371	17	9	0	720	2,078	546	FM, MM, EI, PC, POP
1991	3,653	12	8	0	731	2,318	583	FM, MM, EI, PC, POP
1992	2,063	-9	-5	0	-494	1,965	605	PC, POP
1993	2,575	17	9	0	-195	2,130	614	FM, MM, PC, POP
1994	4,865	1	1	0	1,746	2,478	639	FM, MM, EI, PC, POP
1995	3,903	-4	6	0	89	3,142	669	MM, EI, PC, POP
1996	5,341	22	5	0	1,493	3,096	724	FM, MM, EI, PC, POP
1997	6,055	-6	3	0	3,414	1,854	790	MM, EI, PC, POP
1998	-1,451	-51	14	0	7,010	-9,237	813	FM, PC
1999	-371	-4	-11	0	-821	-323	788	FM, MM, EI, PC
2000	5,122	10	-8	0	2,174	2,138	808	FM, EI, PC, POP
2001	3,436	19	11	0	939	1,600	866	FM, MM, EI, PC, POP
2002	892	-61	-5	0	-1,947	1,999	906	PC, POP
2003	1,064	-111	-15	0	-1,980	2,251	919	PC, POP
2004	6,448	-129	-26	0	3,032	2,591	979	EI, PC, POP
2005	-1,161	-108	-3	0	-5,144	3,074	1,019	FM, MM, EI



**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Korea**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	-3,354	7	-27	-2	-4,106	571	202	MM, EC, EI
1982	1,472	14	-47	-12	662	666	189	FM, EI, PC, POP
1983	3,535	33	-85	-14	2,114	1,273	213	FM, EI, PC, POP
1984	1,738	4	-13	55	347	1,130	215	FM, EC, EI, PC, POP
1985	1,519	38	-15	-39	291	1,057	186	FM, EI, PC, POP
1986	3,202	37	-30	-49	1,101	1,936	207	FM, EI, PC, POP
1987	4,424	-10	57	-90	1,837	2,383	247	MM, EI, PC, POP
1988	3,951	-11	-46	43	1,011	2,668	286	EC, EI, PC, POP
1989	4,279	-8	-55	-36	2,202	1,844	331	EI, PC, POP
1990	8,726	1,245	-1,046	39	5,134	2,976	377	FM, EC, EI, PC, POP
1991	5,351	43	-9	40	1,069	3,740	468	FM, EC, EI, PC, POP
1992	5,576	-6	25	26	2,548	2,443	540	MM, EC, EI, PC, POP
1993	6,973	-19	8	-37	3,534	2,888	600	MM, EI, PC, POP
1994	7,395	3	-62	-14	2,081	4,736	651	FM, EI, PC, POP
1995	9,060	57	-43	-14	2,569	5,749	742	FM, EI, PC, POP
1996	7,085	-24	22	-8	1,548	4,751	796	MM, EI, PC, POP
1997	1,057	-16	79	44	-2,963	3,123	790	MM, EC, PC, POP
1998	-11,666	-340	213	-92	-5,718	-6,323	595	FM, EC, EI, PC
1999	6,961	-83	-17	-21	-30	6,554	557	PC, POP
2000	6,479	27	-128	32	-388	6,227	709	FM, EC, PC, POP
2001	2,495	-4	-110	38	-807	2,712	666	EC, PC, POP
2002	5,538	34	-77	-147	-584	5,799	513	FM, PC, POP
2003	2,253	67	-12	49	-830	2,488	491	FM, EC, PC, POP
2004	-151	0	-117	24	-4,619	4,191	371	MM, EI
2005	-11,833	-295	-656	-68	-14,360	3,357	190	FM, MM, EC, EI

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Malaysia**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	483	-2	0	0	33	283	169	EI, PC, POP
1982	439	-3	0	0	26	234	182	EI, PC, POP
1983	1,172	4	0	0	683	278	207	FM, EI, PC, POP
1984	272	-21	0	0	-359	421	232	PC, POP
1985	471	-12	0	0	586	-356	253	EI, POP
1986	635	7	0	0	517	-163	273	FM, EI, POP
1987	602	3	0	0	59	238	301	FM, EI, PC, POP
1988	994	9	0	0	-64	727	322	FM, PC, POP
1989	1,133	32	0	0	53	699	348	FM, EI, PC, POP
1990	1,737	4	0	0	564	790	380	FM, EI, PC, POP
1991	1,090	-2	0	0	-274	958	408	PC, POP
1992	1,059	7	0	0	-315	949	418	FM, PC, POP
1993	313	-41	0	0	-1,225	1,155	424	PC, POP
1994	1,742	-23	0	0	202	1,116	447	EI, PC, POP
1995	1,121	-19	0	0	-660	1,319	482	PC, POP
1996	2,803	-7	0	0	795	1,468	547	EI, PC, POP
1997	3,485	77	2	0	1,693	1,102	612	FM, MM, EI, PC, POP
1998	-1,873	-150	0	1	188	-2,529	616	FM, PC
1999	5,406	68	8	0	3,734	952	643	FM, MM, EI, PC, POP
2000	1,690	150	-1	-1	-1,036	1,891	686	FM, PC, POP
2001	2,620	18	-4	1	2,502	-603	706	FM, EC, EI, POP
2002	810	8	3	2	-597	709	686	FM, MM, EC, PC, POP
2003	2,246	7	2	-3	260	1,294	687	FM, MM, EI, PC, POP
2004	2,662	11	0	0	-22	1,968	705	FM, PC, POP
2005	-51	-73	-1	2	-1,970	1,275	716	FM, MM, EI

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Mongolia**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1986	54	-2	0	0	-59	88	27	PC, POP
1987	28	-4	0	-1	-13	18	27	PC, POP
1988	766	392	-119	0	423	42	28	FM, EI, PC, POP
1989	-604	-107	-27	-1	-541	38	34	FM, MM, EC, EI
1990	47	4	1	1	-191	202	29	FM, MM, EC, PC, POP
1991	-556	-8	0	-1	-205	-360	18	FM, EC, EI, PC
1992	-101	4	-2	-1	-9	-111	17	MM, EC, EI, PC
1993	97	23	16	2	85	-41	13	FM, MM, EC, EI, POP
1994	-317	-31	-17	-1	-287	7	11	FM, MM, EC, EI
1995	157	25	2	0	-46	164	13	FM, MM, PC, POP
1996	46	6	3	0	18	12	7	FM, MM, EI, PC, POP
1997	-67	-10	0	0	-91	22	11	FM, EC, EI
1998	-21	-40	4	0	-12	17	10	FM, EI
1999	36	24	-1	0	-12	18	7	FM, PC, POP
2000	153	2	-1	0	142	2	8	FM, EI, PC, POP
2001	-44	-9	0	0	-46	2	8	FM, EI
2002	112	9	1	0	63	26	12	FM, MM, EI, PC, POP
2003	-43	-39	5	0	-62	42	12	FM, EI
2004	162	34	-4	0	23	91	17	FM, EI, PC, POP
2005	17	12	4	0	-70	57	14	FM, MM, PC, POP

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Pakistan**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	714	2	1	1	167	341	201	FM, MM, EC, EI, PC, POP
1982	963	-4	2	0	462	288	215	MM, EI, PC, POP
1983	47	17	4	1	-529	327	228	FM, MM, EC, PC, POP
1984	863	-16	-3	-1	442	200	240	EI, PC, POP
1985	531	3	0	1	-176	445	258	FM, EC, PC, POP
1986	523	-1	-5	-1	-14	273	270	PC, POP
1987	1,652	17	5	3	927	405	295	FM, MM, EC, EI, PC, POP
1988	883	-2	-6	0	-27	588	329	PC, POP
1989	531	-3	-1	2	-106	302	337	EC, PC, POP
1990	335	40	2	0	-301	248	346	FM, MM, PC, POP
1991	508	3	-1	0	-188	338	356	FM, PC, POP
1992	1,812	5	-5	-1	685	747	381	FM, EI, PC, POP
1993	2,303	7	-3	0	1,998	-131	432	FM, EI, POP
1994	1,053	10	0	0	348	220	476	FM, EI, PC, POP
1995	766	10	-1	0	-205	472	489	FM, PC, POP
1996	2,082	-28	-1	1	1,104	486	520	EC, EI, PC, POP
1997	545	-1	0	0	318	-315	543	EI, POP
1998	1,075	22	0	-1	464	28	562	FM, EI, PC, POP
1999	1,373	7	0	1	480	292	594	FM, EC, EI, PC, POP
2000	-320	26	1	0	-1,396	443	607	EI
2001	-211	-1	0	0	-668	-141	600	FM, EI, PC
2002	89	-2	0	0	-695	188	598	PC, POP
2003	1,062	-20	0	-1	-144	614	613	PC, POP
2004	1,633	-1	0	0	-23	1,011	644	MM, PC, POP
2005	-2,829	3	0	0	-4,790	1,329	630	EI

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**The Philippines**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	-588	3	4	0	-760	42	124	EI
1982	321	4	6	0	142	52	118	FM, MM, EI, PC, POP
1983	-86	0	0	0	-178	-27	118	EI, PC
1984	-304	-2	-2	0	59	-473	114	FM, MM, PC
1985	-196	-2	-2	0	148	-447	108	FM, MM, PC
1986	290	-1	-2	0	140	43	109	EI, PC, POP
1987	541	0	1	0	331	89	119	MM, EI, PC, POP
1988	446	0	0	0	91	225	130	EI, PC, POP
1989	721	1	1	0	358	218	143	FM, MM, EI, PC, POP
1990	340	2	2	0	140	41	155	FM, MM, EI, PC, POP
1991	-591	7	8	0	-569	-186	149	EI, PC
1992	950	4	5	0	919	-129	152	FM, MM, EI, POP
1993	969	4	3	0	803	-14	172	FM, MM, EI, POP
1994	8,646	960	121	0	7,106	219	240	FM, MM, EI, PC, POP
1995	1,681	0	9	0	871	416	385	MM, EI, PC, POP
1996	2,265	-7	3	0	1,162	688	419	MM, EI, PC, POP
1997	2,246	-1	9	2	1,137	638	460	MM, EC, EI, PC, POP
1998	-53	-12	4	1	86	-609	477	FM, PC
1999	1,282	-13	-14	-3	529	294	489	EI, PC, POP
2000	-276	30	-15	0	-1,679	886	502	MM, EI
2001	979	17	-13	3	549	-88	511	FM, EC, EI, POP
2002	-348	-31	-12	0	-1,356	541	509	FM, MM, EI
2003	691	1	7	-1	-510	675	519	FM, MM, PC, POP
2004	557	-43	54	0	-970	993	524	MM, PC, POP
2005	-1,447	7	-17	3	-2,649	703	506	MM, EI

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Sri Lanka**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	-3	-1	-1	0	-118	79	36	FM, MM, EI
1982	118	1	1	0	30	60	27	FM, MM, EI, PC, POP
1983	-112	0	2	0	-214	70	31	EI
1984	249	1	-2	0	140	84	26	FM, EI, PC, POP
1985	102	1	0	0	-15	80	36	FM, PC, POP
1986	12	-1	0	0	-91	60	44	PC, POP
1987	60	-1	0	0	19	6	37	EI, PC, POP
1988	24	-3	1	0	-36	26	35	MM, PC, POP
1989	-129	-3	2	0	-184	22	34	FM, EI
1990	93	1	-1	0	-59	124	27	FM, PC, POP
1991	18	4	-1	0	-98	76	36	FM, PC, POP
1992	285	2	0	0	168	90	24	FM, EI, PC, POP
1993	195	1	1	0	0	157	36	FM, MM, PC, POP
1994	342	1	-1	0	171	129	43	FM, EI, PC, POP
1995	192	1	-1	0	8	136	48	FM, EI, PC, POP
1996	1,349	17	10	0	1,168	109	45	FM, MM, EI, PC, POP
1997	-418	-4	-2	0	-701	231	58	FM, MM, EI
1998	215	-41	41	0	7	160	49	MM, EI, PC, POP
1999	484	2	-1	0	276	137	70	FM, EI, PC, POP
2000	251	0	-1	0	-56	220	88	PC, POP
2001	-193	-8	4	0	-107	93	-175	FM, EI, POP
2002	78	-6	2	0	-123	126	78	MM, PC, POP
2003	364	-7	-1	0	52	251	69	EI, PC, POP
2004	386	-20	0	0	102	242	63	EI, PC, POP
2005	-524	39	-53	0	-807	235	62	MM, EI

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Thailand**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	472	30	0	0	-123	388	177	FM, PC, POP
1982	-339	385	-434	0	-793	336	166	MM, EI
1983	1,919	25	1	0	1,312	406	175	FM, MM, EI, PC, POP
1984	2,027	30	2	0	1,287	509	199	FM, MM, EI, PC, POP
1985	757	-6	8	0	116	430	209	MM, EI, PC, POP
1986	803	13	8	0	-18	588	212	FM, MM, PC, POP
1987	2,398	38	-11	0	880	1,268	224	FM, EI, PC, POP
1988	2,786	68	-1	0	365	2,107	248	FM, EI, PC, POP
1989	3,860	33	0	0	1,263	2,280	284	FM, EI, PC, POP
1990	3,096	11	-2	0	353	2,418	316	FM, EI, PC, POP
1991	1,014	-35	-1	0	-1,241	1,954	337	PC, POP
1992	1,667	-24	-7	0	-572	1,927	344	PC, POP
1993	5,310	53	0	0	2,667	2,215	374	FM, EI, PC, POP
1994	4,190	-4	-1	0	973	2,799	424	EI, PC, POP
1995	7,290	78	-4	0	3,407	3,327	482	FM, EI, PC, POP
1996	4,305	11	0	0	1,488	2,248	558	FM, EI, PC, POP
1997	-306	-80	-1	0	480	-1,271	567	FM, MM, PC
1998	-6,893	-126	0	0	-1,513	-5,774	520	FM, EI, PC
1999	1,344	55	-2	0	-652	1,487	455	FM, PC, POP
2000	-1,094	-14	0	0	-3,156	1,647	430	FM, EI
2001	1,179	-34	0	0	253	578	382	EI, PC, POP
2002	2,541	1	2	-1	122	2,045	372	FM, MM, EI, PC, POP
2003	3,293	44	-3	0	-118	3,009	360	FM, PC, POP
2004	4,047	69	-3	0	793	2,812	376	FM, EI, PC, POP
2005	1,194	42	0	0	-1,288	2,057	383	FM, PC, POP

**Appendix (Cont'd)**  
**CO<sub>2</sub> Emissions Change and Contributing Factors**  
**Vietnam**

Year	CO <sub>2</sub> Emissions Change ('000 tCO <sub>2</sub> )	Factors Influencing the CO <sub>2</sub> Emissions Change						Influencing Factors
		Fuel Mix	Modal Mix	Emission Coefficient	Transport Energy Intensity	Per Capita GDP	Population	
1981	-357	4	-2	0	-460	67	34	MM, EI
1982	77	-2	12	0	-64	101	29	MM, PC, POP
1983	196	1	8	0	64	92	31	FM, MM, EI, PC, POP
1984	-50	1	2	0	-204	117	34	EI
1985	1,090	77	-34	0	964	38	45	FM, EI, PC, POP
1986	339	4	-14	0	264	13	72	FM, EI, PC, POP
1987	526	0	7	0	395	37	87	MM, EI, PC, POP
1988	287	16	-20	0	95	101	95	FM, EI, PC, POP
1989	-352	29	-34	-18	-606	185	92	MM, EC, EI
1990	547	-5	-11	-8	371	111	87	EI, PC, POP
1991	-223	2	14	-9	-472	153	88	EC, EI
1992	489	-10	-4	-5	153	269	87	EI, PC, POP
1993	2,518	34	5	-4	2,044	329	110	FM, MM, EI, PC, POP
1994	726	-11	-3	3	108	489	139	EC, EI, PC, POP
1995	-263	11	2	0	-974	559	137	EI
1996	735	13	-2	3	17	563	141	FM, EC, EI, PC, POP
1997	751	14	-2	11	51	543	134	FM, EC, EI, PC, POP
1998	536	-18	10	8	16	390	129	MM, EC, EI, PC, POP
1999	704	-11	9	-12	257	333	128	MM, EI, PC, POP
2000	880	-13	12	5	174	685	17	MM, EC, EI, PC, POP
2001	791	-12	8	-7	34	613	155	MM, EI, PC, POP
2002	2,608	-25	-13	9	1,735	729	173	EC, EI, PC, POP
2003	2,406	36	163	-37	1,135	881	228	FM, MM, EI, PC, POP
2004	3,985	4	-25	55	2,555	1,135	262	FM, EC, EI, PC, POP
2005	-284	-2	-198	-2	-1,757	1,404	271	FM, MM, EC, EI