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# Why Have $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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. $CO_2$ 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 $CO_2$ emissions, although they were not necessarily targeted for this purpose when introduced.

This paper—a product of the Environment and Energy Team, Development Research Group—is part of a larger effort in the department to study climate change and clean energy issues. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at gtimilsina@worldbank.org.

# Why Have $CO_2$ Emissions Increased in the Transport Sector in Asia? Underlying Factors and Policy Options[†]

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**Key Words**: Transport sector $CO_2$ emissions, Driving factors for emission growth, Decomposition analysis.

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## 1. Introduction

Carbon dioxide ($CO_2$) emissions released from fossil fuel consumption[2] 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 $CO_2$ emissions in most countries in Asia despite the fact that its share of total regional $CO_2$ 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 $CO_2$ emissions, feature a relatively low share of emissions from the transport sector in their national $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions. Therefore, any attempt to address climate change in Asia must pay attention to transport sector emissions. The identification of key factors driving $CO_2$ 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.

[2] This study considers only fossil fuel consumption related $CO_2$ emissions as our analysis is for the transport sector which emits $CO_2$ through energy use.

Most existing studies are focused on the decomposition of national $CO_2$ 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 CO2 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 $CO_2$ emissions in each country in the world. While the factors affecting $CO_2$ 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 $CO_2$ 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 $CO_2$ 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, $CO_2$ intensity, energy intensity and fuel mix affect $CO_2$ 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 CO2 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 CO2 emissions from 1996 to 1999.

Understanding the factors affecting the growth of $CO_2$ 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 $CO_2$ emissions from the transport sector in 12 Asian countries during the 1980-2005 period. We attribute the growth of transport sector $CO_2$ 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 $CO_2$ emissions in Asia.

This paper is organized as follows: Section 2 examines $CO_2$ emission trends and potential factors driving transport sector $CO_2$ 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 $CO_2$ emissions in Asia in Section 5. Finally, Section 6 offers key conclusions.

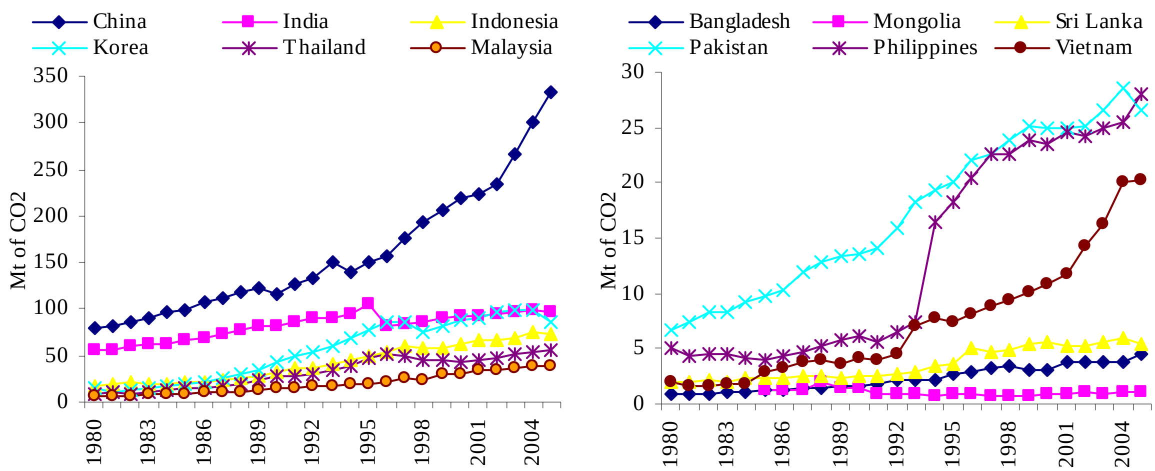
## 2. Potential Factors Driving the Transport Sector $CO_2$ Emissions Growth

Before discussing potential factors driving transport sector $CO_2$ emission growth, we first highlight the trend of $CO_2$ 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 $CO_2$ emission growth.

### 2.1. $CO_2$ Emissions

Figure 1 presents the trend of transport sector $CO_2$ emissions in the 12 Asian countries that are responsible for more than 95 percent of the total $CO_2$ emissions from developing countries in the region. Aggregate transport sector $CO_2$ 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 $CO_2$ Emissions in Asia**




Note: These graphs are based on total transport sector $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions and the sectoral emission mix for the abovementioned 12 Asian countries. Transport sector shares of total national $CO_2$ 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 $CO_2$ 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 $CO_2$ 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: $CO_2$ Emission Mix by Sector**

| Country | 1980 | | | | | 2005 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Power | Industry | Transport | Other | Total | Power | Industry | Transport | Other |
| | (Mt of $CO_2$) | (%) | (%) | (%) | (%) | (Mt of $CO_2$) | (%) | (%) | (%) | (%) |
| 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[#] | 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 |

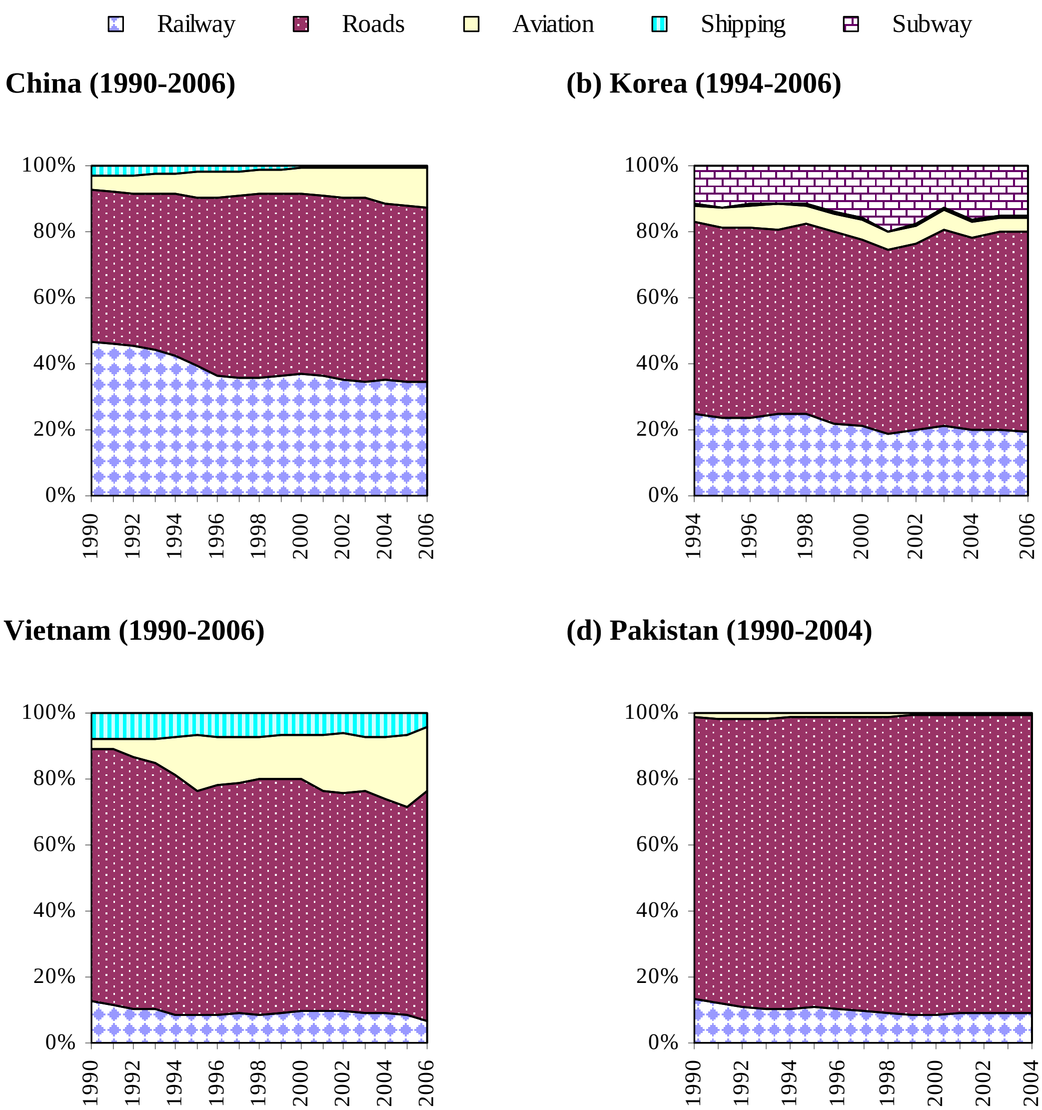
Note: The note for Figure 1 also applies here. [#:] 1985 data are used instead of 1980. Other includes residential, commercial and agricultural sectors.
Source: IEA (2007a)

### 2.2. Modal Mix in the Transport Sector

One potential factor driving transport sector $CO_2$ emissions growth could be modal shifting, from less emission intensive modes (in terms of $CO_2$ 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 or 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**

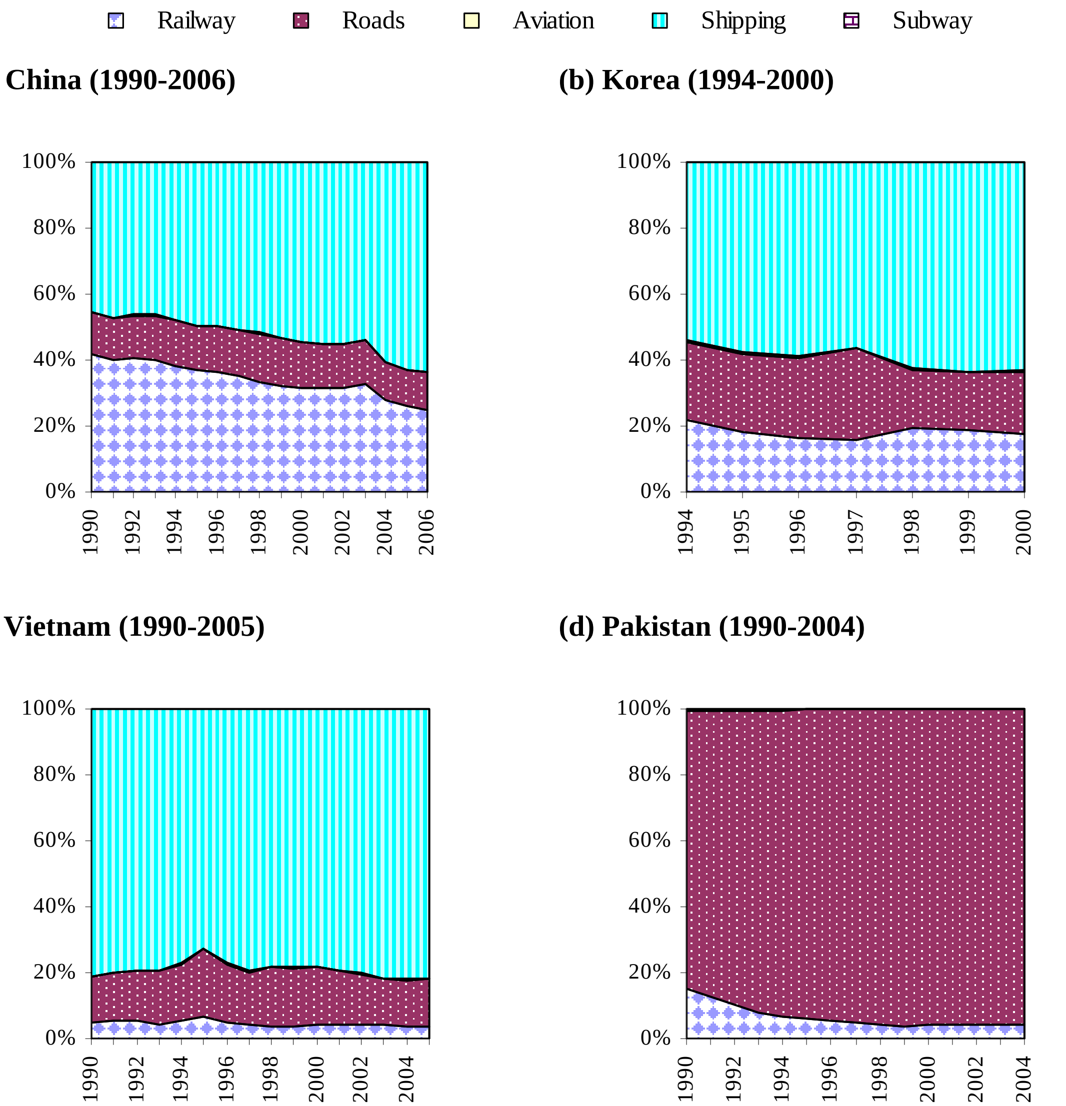



Source: National Bureau of Statistics of China (2007); Korea National Statistical Office (2008); General Statistical Office of Vietnam (2005); Accountancy (2007); United Nations Statistics Division (2008a)

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[3] although passenger and freight kilometers (or any equivalent units) would be the desired measurement for transportation services.

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




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).

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[3] 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 $CO_2$ 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 $CO_2$ emissions in 6 out of the 12 countries in 2005, and only China features a modal share of less than 70 percent of $CO_2$ 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 $CO_2$ 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).

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

| | 1980 | | | | | 2005 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Modal mix in terms of energy consumption** | | | | | | | | | |
| | Total | Air | Water | Rail | Road | Total | Air | Water | Rail | Road |
| Country | Mtoe | % | % | % | % | Mtoe | % | % | % | % |
| 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 |
| | **Modal mix in terms of $CO_2$ emissions** | | | | | | | | | |
| Country | 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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[4] (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, $CO_2$ 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 $CO_2$ 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.

[4] Deutsche Gesellschaft fur Technische Zusammenarbeit

**Table 3: Transport Sector Fuel Mix**

| | 1980 | | | | | | | | | | | 2005 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | 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 |
| **Fuel mix in terms of energy consumption** | | | | | | | | | | | | | | | | | | | | | | |
| | 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| **Fuel mix in terms of $CO_2$ emission** | | | | | | | | | | | | | | | | | | | | | | |
| | 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |

Note: $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions due to the high $CO_2$ 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.

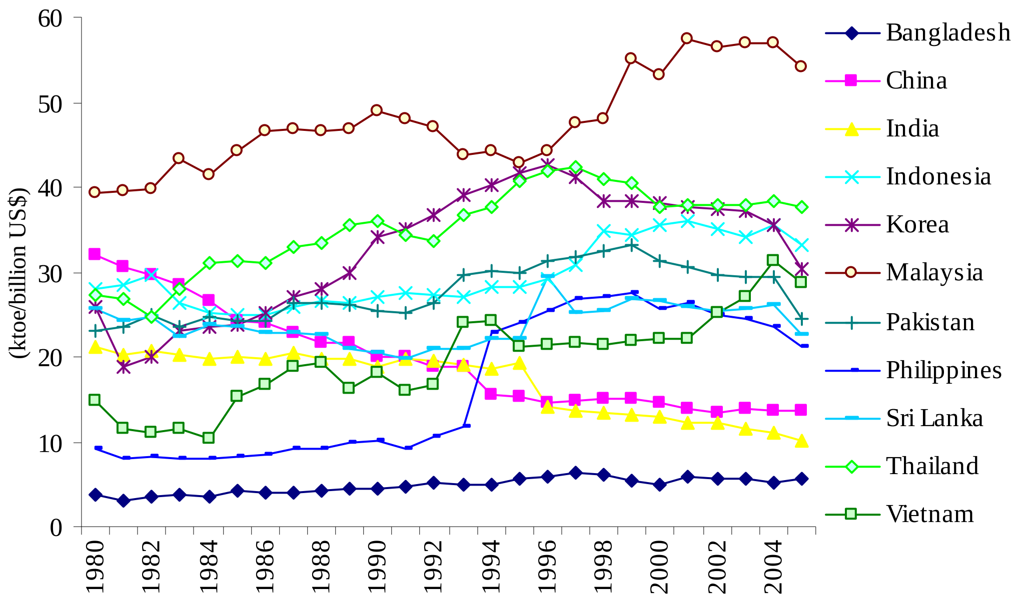
### 2.4. Transportation Energy Intensity

Figure 4 displays transportation energy intensity for all the Asian countries considered (except Mongolia[5]) 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

[5] 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 $CO_2$ 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 (millions) | Urban share (%) | Total (millions) | Urban share (%) | Total (%) | Urban (%) |
| 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 $CO_2$ emissions and place additional stresses on the transport infrastructure.

### 2.6. Motorization[6] 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 $CO_2$ 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

[6] 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[a] | 5.6% |
| India | 2,694 | 3,841 | 6,143 | 8,619[b] | 9.4% |
| Pakistan | 559 | 773 | 1,066 | 1,167[b] | 5.8% |
| Sri Lanka | 174 | 229 | 335 | 444[b] | 7.5% |
| Indonesia | 1,313 | 2,107 | 3,039 | 5,494 | 10.0% |
| Malaysia | 1,715 | 2,609 | 4,213 | 5,500[b] | 9.4% |
| Philippines | 1,471 | 2,333 | 2,156 | 3,982[b] | 8.0% |
| Thailand | 1,222 | 1,913 | 2,665 | 2,993[a] | 6.6% |
| Vietnam | 33 | 26 | 44 | n.a. | 2.9% |
| China | 1,622 | 4,179 | 8,537 | 17,359[a] | 18.5% |
| Korea | 2,075 | 6,006 | 8,084 | 10,621[a] | 12.4% |
| Mongolia | 8 | 24 | 44 | 80[a] | 17.8% |

Source: ESCAP (2007b)
Note: [a] data are for 2004; [b] 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 $CO_2$ 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[a] | 422 | 2.9% | 2.9% |
| India | 3.2 | 381 | 8.0[b] | 713 | 7.4% | 4.2% |
| Pakistan | 5.0 | 506 | 7.7[b] | 820 | 3.4% | 1.7% |
| Sri Lanka | 9.8 | 479 | 21.8[b] | 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[b] | 5,098 | 6.8% | 3.8% |
| Philippines | 24.1 | 724 | 49.8[b] | 1,163 | 5.7% | 1.4% |
| Thailand | 21.8 | 1,572 | 46.7[a] | 2,797 | 5.6% | 3.5% |
| Vietnam | 0.5 | 98 | n.a. | 621 | n.a. | 5.9% |
| China | 1.4 | 358 | 13.4[a] | 1,766 | 17.4% | 9.1% |
| Korea | 48.4 | 6,153 | 222.9[a] | 16,454 | 11.5% | 4.7% |
| Mongolia | 3.6 | 567 | 30.4[a] | 800 | 16.5% | 0.2% |

Source: ESCAP (2007b); UN Statistics Division (2008b)
Note: [a] data are for 2004; [b] data are for 2003

## 3. Methodology to Determine Factors Affecting $CO_2$ Emission Growth

### 3.1 Methodology

In this section, we derive the methodology to decompose transport sector $CO_2$ emission growth to the contributing factors. Data needed to implement the methodology are also discussed here.

Total $CO_2$ emission from the transport sector in a country in year t ($CO2_t$) is the summation of $CO_2$ emissions from all fuels used in all transport modes in that year, i.e.,

$$\mathrm{CO2}_t = \sum_{ij} \mathrm{CO2}_{ijt} \qquad (1)$$

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:

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

where, FC refers to fuel consumption, TS represents transport services (e.g., passenger kilometers, tons kilometers or any equivalent measurement representing transport services[7]) 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.

[7] 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 $CO_2$ intensity of a fuel (i.e., $CO_2$/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[8] (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.

[8] 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 $CO_2$ emissions from year t-1 to t is expressed as:

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

where

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

Similarly, the multiplicative decomposition of the change in the transport sector $CO_2$ emissions from year t-1 to t (again, following Ang (2005)) is given as:

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

where

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

with

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

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 uses 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[9]. 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 $CO_2$ emissions from electricity production (IEA, 2007a, 2007d, 2007e). While $CO_2$ emission factors for other transportation fuels (e.g., gasoline, diesel, etc.) remain the same throughout the study period, $CO_2$ 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 $CO_2$ 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 $CO_2$ 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. $CO_2$ 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).

[9] 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 $CO_2$ 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 $CO_2$ emissions growth into fuel switching, modal shifting and changes in emission coefficients[10], 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 $CO_2$ emissions and its driving factors in each of the 12 countries considered.

[10] 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 $CO_2$ Emission Change and Responsible Factors (1980-2005)**

| Country | Average $CO_2$ Emission Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ Emissions Change | | | | | | Influencing Factors[¥] |
|---|---|---|---|---|---|---|---|---|
| | | Fuel Mix (FM) | Modal Mix (MM) | Emission Coefficient (EC) | Energy Intensity (EI) | Per Capita GDP† (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 $CO_2$ emission growth.

† In 2000 US$ PPP.

¥ 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 $CO_2$ 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 $CO_2$ rather than 10,199 kilotons) and 143% higher (4,918 kilotons of $CO_2$ 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[11].

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 $CO_2$ emissions in these countries. This is because fuel substitution mostly occurred between diesel and gasoline, and their $CO_2$ 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.

[11] 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 $CO_2$ emissions display a declining trend (an average reduction of 4 kilotons of $CO_2$ 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). $CO_2$ emission growth also follows this pattern in these countries. Deteriorating transportation energy intensity is found to have exacerbated $CO_2$ 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 $CO_2$ Emissions Growth and Driving Factors in Selected Asian Countries**

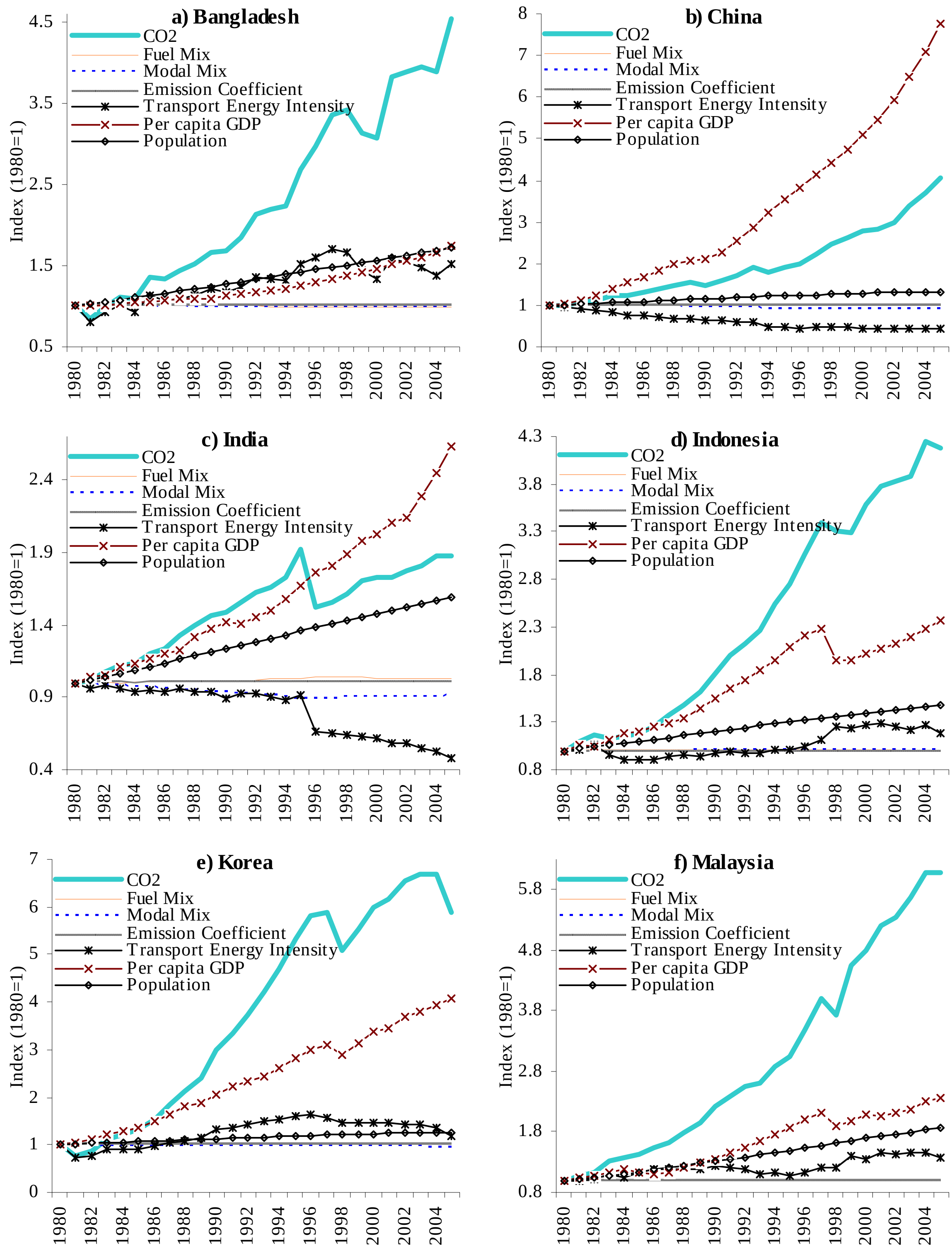
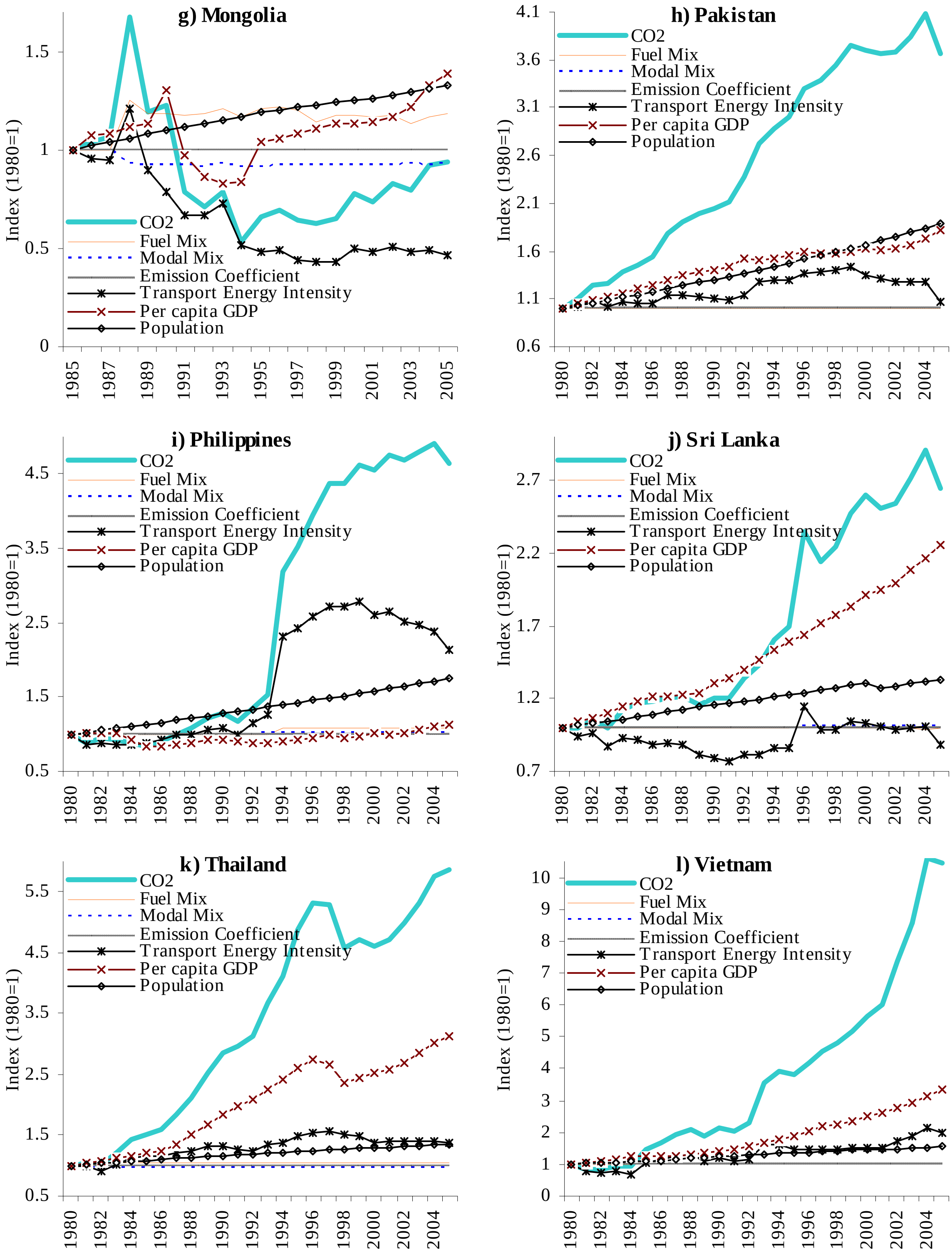


**Figure 5: Transport Sector $CO_2$ Emissions Growth and Driving Factors in Selected Asian Countries (continued)**



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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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.[12]

### 5. Policy Initiatives to Address $CO_2$ 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 $CO_2$ emissions because these countries have neither mandatory nor voluntary commitments to reduce $CO_2$ emissions under the Kyoto Protocol. Thus, the main strategy to limit the growth of $CO_2$ emissions in the transport sector in these countries in the future would be the decoupling (or weakening) of the growth of $CO_2$ 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 $CO_2$ emissions.

[12] 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[13]. 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-

[13] 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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[14]: Eco-car manufacturers were granted

[14] 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 $CO_2$ 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[15] 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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[15] 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 cites 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions.

The per capita economic growth effect and the population growth effect are found to be primarily responsible for driving transport sector $CO_2$ 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 $CO_2$ emissions in Mongolia. However, improvement in transportation energy intensity is also found to restrain the growth of transport sector $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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

### $CO_2$ Emissions Change and Contributing Factors

### Bangladesh

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)

### $CO_2$ Emissions Change and Contributing Factors

### China

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)

### $CO_2$ Emissions Change and Contributing Factors

### India

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)

### $CO_2$ Emissions Change and Contributing Factors

### Indonesia

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)

### $CO_2$ Emissions Change and Contributing Factors

### Korea

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)

### $CO_2$ Emissions Change and Contributing Factors

### Malaysia

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)**

**$CO_2$ Emissions Change and Contributing Factors**

**Mongolia**

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)

### $CO_2$ Emissions Change and Contributing Factors

### Pakistan

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)

## $CO_2$ Emissions Change and Contributing Factors

## The Philippines

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)**

**$CO_2$ Emissions Change and Contributing Factors**

**Sri Lanka**

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)**

**$CO_2$ Emissions Change and Contributing Factors**

**Thailand**

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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)

### $CO_2$ Emissions Change and Contributing Factors

### Vietnam

| Year | $CO_2$ Emissions Change ('000 $tCO_2$) | Factors Influencing the $CO_2$ 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 |