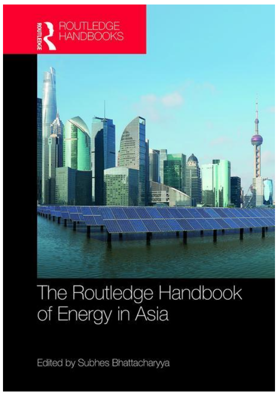

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Govinda R. Timilsina, Ashish Shrestha
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6

TRANSPORTATION ENERGY DEMAND IN ASIA

Status, trends, and drivers

Govinda R. Timilsina and Ashish Shrestha

Introduction

Total final consumption of energy in Asia increased from 1,136 million tons of oil equivalent (Mtoe) in 1980 to 3,606 Mtoe in 2013, with a robust average annual growth rate of 3.6% (IEA, 2016a). The transport sector remains one of the most important energy consumption sectors in Asia, and its share of total regional energy demand has grown from about 11% to 16.5% over these 33 years, as shown in Figure 6.1.

This has happened despite the fact that China[1] and India, who account for almost 70% of the region's energy demand, feature a relatively low share of energy consumption from the transport sector (13.3 and 14.2%, respectively, in 2013) in their national energy demand, 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 energy demand could increase significantly in these countries along with economic growth and consumers' purchasing power. In most other Asian countries, the transport sector already accounts for a substantial share of total national energy demand (about 23% for Asia, other than China and India). Therefore, any attempt to address climate change in Asia must pay attention to transport sector energy demand. The identification of key factors driving transport energy demand and 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 energy demand into the possible affecting factors.

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 CO_2 emissions or emission intensities (Liu et al. (2007),

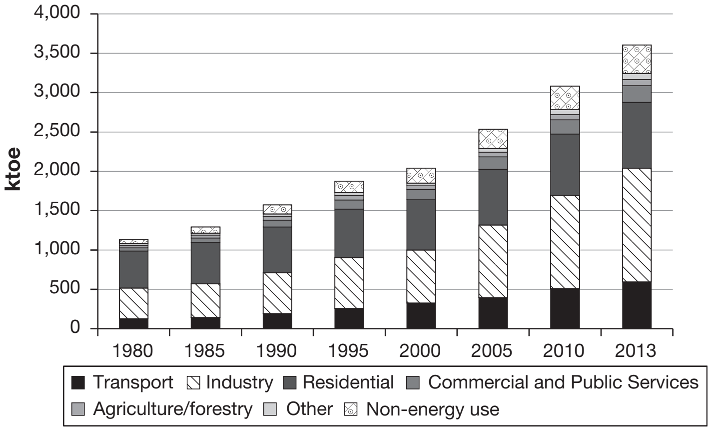

Figure 6.1 Total final consumption and energy sector demand growth in Asia

Data source: IEA (2016a).

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)). While the factors affecting CO_2 emissions and emission intensities of the industry and power sectors have been analysed in many countries, the transport sector has 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 gross domestic product (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 CO_2 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. Wu et al. (2005) consider changes in transport energy intensity, average traveling distance, and number of vehicles (amongst numerous other factors) in their investigation of the underlying forces behind the stagnancy of China's energy-related CO_2 emissions from 1996 to 1999. Finally, Timilsina and Shrestha (2009) decompose CO_2 emissions growth in 20 Latin American and Caribbean countries into components associated with changes in fuel mix, modal mix, emission coefficients and transportation energy intensity, along with economic growth.

Understanding the factors affecting energy demand growth in 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 chapter aims to address this gap by executing a Divisia decomposition analysis of CO_2 emissions from the transport sector in 14 Asian countries during the 1980–2013 period. We attribute the growth of transport sector CO_2 emissions over these 33 years to five factors. These are: (i) fuel switching, (ii) modal shifting, (iii) sectoral energy intensity change, (iv) per capita economic growth and (v) 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 chapter is organized as follows: the second section presents trends of transportation energy demand and that of potential factors driving the demand over the last 33 years. The roles of different factors are then quantified using an identity approach in the third section. The fourth section draws key conclusions.

Potential factors driving the transport sector energy demand growth

Before discussing potential factors driving transport sector energy consumption growth, we first highlight the trend of energy consumption 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 analyse some trends, such as population growth and urbanization, and economic growth and motorization, which provide further insights on the causes of transport sector energy consumption growth.

Energy demand

Figure 6.2 presents the trend of transport sector energy demand in the 14 Asian countries that are responsible for more than 95% of the total energy demand in the region, and for which data is available over the entire study period. Aggregate transport sector energy demand at the regional level rose almost five-fold from 126 Mtoe in 1980 to 593 Mtoe in 2013, with a robust average annual growth rate of 4.8%, higher than the average growth in total final consumption over the same period.

Despite the increase in transport sector energy demand in absolute terms, the share of the sector in the national total in China and India are significantly smaller than in most other Asian countries. Figure 6.3 presents total national energy demand and the sectoral demand mix for the 14 Asian countries. The transport sector share of total national energy demand has historically been relatively high in Japan, Korea,[2] Malaysia and Thailand, and only modest growth is observed over the study period in those countries, along with Myanmar. The transport sector share of total national energy demand increased most substantially in Indonesia and the Philippines, exceeding even the sectoral shares in Japan, Korea and Thailand (but not Malaysia, which still features the highest transport share of energy demand in the region) by 2013. Although significant growth in transport energy demand is also found in all of the remaining countries, the transport sector in a number of countries, particularly Nepal and Myanmar (and also India and China), still does not account for a large share of the total final consumption relative to regional norms.

Because the transport, industry and residential sectors are the main contributors to national energy demand in almost all of the countries considered, changes in the magnitude of the demand from the other two sectors have a considerable impact on the transport sector's share of national energy demand. With a few exceptions, what has typically occurred is that the share of total final consumption from the residential sector has decreased while the share of the transport sector has increased, without much change in the low level of the other final consumption sectors. However, the commercial and public services sector in Japan, Korea, Malaysia and the

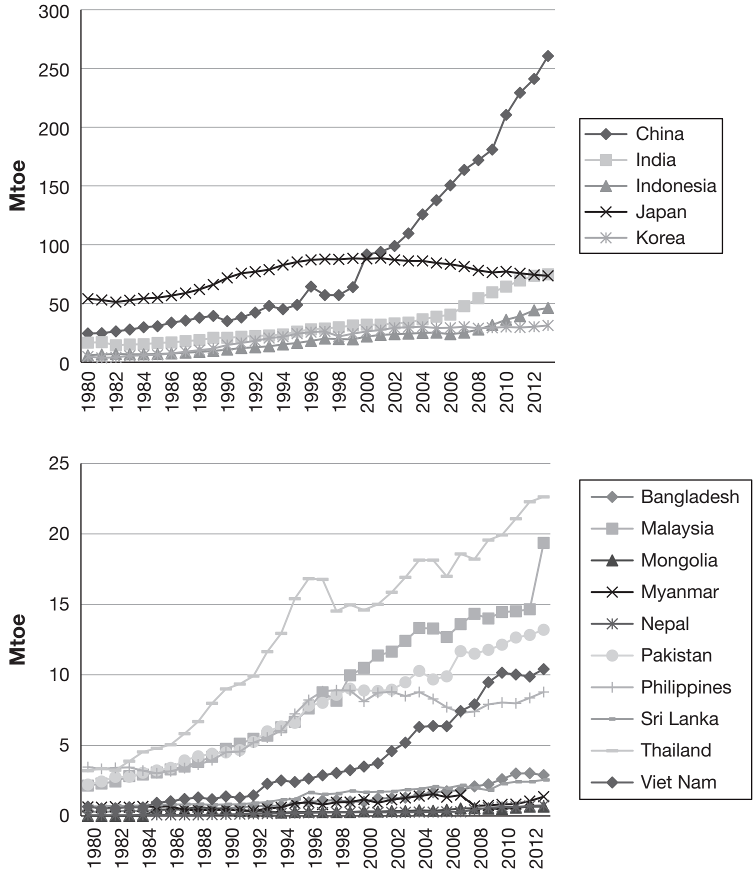

Figure 6.2 Transport sector energy demand growth by country

Data source: IEA (2016a).

Philippines has grown to become a key consumer of energy. Similarly, non-energy use, where fuels are used as raw materials, such as in the manufacture of bitumen, lubricants, paints, solvents, plastics, adhesives, and fertilizer, instead of being consumed as a source of energy, is an important final consumption sector in a few countries with strong manufacturing bases: Japan, Korea, Malaysia and Thailand.

Modal mix in the transport sector

One potential factor driving transport sector energy demand growth could be modal shifting, from less energy intensive modes (in terms of ktoe per passenger/freight kilometre), such as railway and water transportation, to more energy intensive modes, such as commercial airplanes and private road vehicles. However, since modal mix data in terms of transportation services are available only for a few countries out of the 14 considered in this chapter, and the available data are not comparable across countries due to the lack of standardized reporting practices, we instead use energy consumption data as a proxy for transportation services[3] although passenger and freight kilometres (or any equivalent units) would be the desired measurement if available. Table 6.1 presents modal mix in terms of energy consumption.

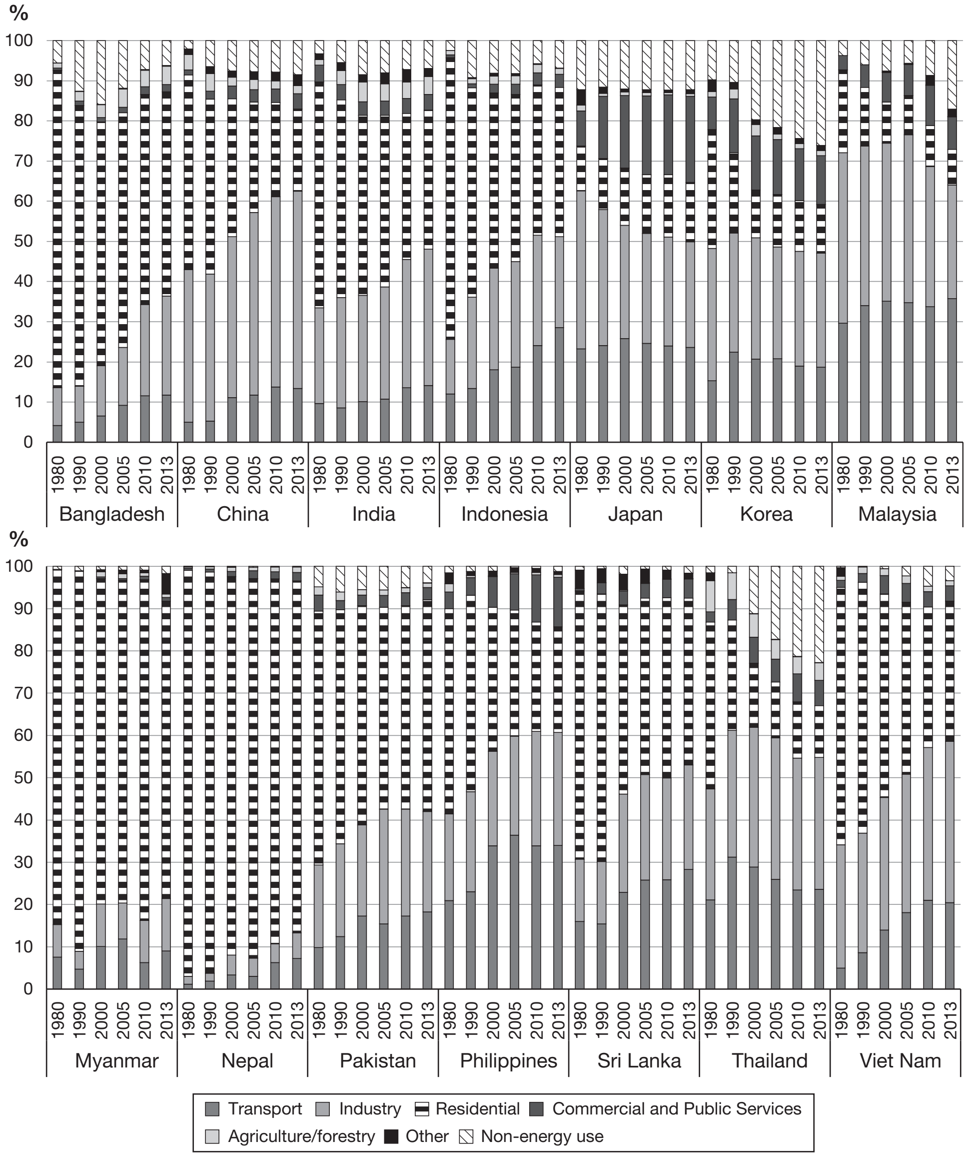

Figure 6.3 Sectoral energy demand mix

Data source: IEA (2016a).

Road was the predominant mode of transportation in all of the countries considered in 1980, especially in Malaysia, Thailand and Nepal, and the role of road transportation was even more prominent in 2013 as most countries have increased their reliance on road transportation since 1980, with only Bangladesh and Myanmar featuring modal shares of road transport under 70% in 2013. However, reliable data for fuel consumption in domestic aviation is not available for half the countries considered, likely resulting in a slight overstatement of the shares of the other modes of transport in those countries.

Table 6.1 Modal mix in 1980 vs. 2013

Country	*1980*					*2013*				
	Total (Mtoe)	*Air (%)*	*Water (%)*	*Rail (%)*	*Road (%)*	*Total (Mtoe)*	*Air (%)*	*Water (%)*	*Rail (%)*	*Road (%)*
Bangladesh	0.32	n.a.	29.5	13.2	57.3	2.89	n.a.	12.1	8.8	79.1
China	24.60	0.1	5.0	39.5	55.4	260.28	5.4	8.6	4.7	81.3
India	16.69	2.2	2.1	35.6	60.1	74.76	2.4	0.9	5.4	91.3
Indonesia	5.95	5.9	3.0	0.2	90.8	46.19	5.8	5.5	0.0	88.7
Japan	53.91	4.6	10.4	4.8	80.2	73.44	4.8	4.5	2.4	88.4
Korea	4.78	4.6	22.3	7.4	65.7	31.38	2.1	0.7	1.1	96.1
Malaysia	2.14	n.a.	0.0	0.0	100.0	19.36	n.a.	0.3	0.1	99.6
Myanmar	0.63	5.0	0.0	0.0	95.0	1.37	5.8	5.6	13.5	75.2
Nepal	0.05	n.a.	0.0	0.2	99.8	0.74	n.a.	0.0	0.1	99.9
Pakistan	2.21	n.a.	0.0	5.9	94.1	13.19	5.1	0.0	1.9	92.9
Philippines	3.46	0.2	5.2	0.0	94.6	8.78	4.9	7.3	0.1	87.7
Sri Lanka	0.68	18.7	0.6	5.1	75.5	2.55	0.1	1.4	1.4	97.1
Thailand	3.21	n.a.	0.1	0.0	99.9	22.63	2.5	0.7	0.4	96.4
Vietnam	0.65	15.1	0.0	9.7	75.2	10.41	1.7	0.4	0.0	97.9

Data source: IEA (2016b).

Only Sri Lanka and Vietnam utilized domestic air transport to a large extent in 1980, i.e., more than 10% of transport sector fuel consumption came from domestic air transport, but the modal share of domestic aviation had declined precipitously in both countries by 2013. Aside from Korea, the share of domestic aviation increased or remained steady in the other countries in 2013 compared with 1980, although domestic aviation generally accounts for a modest modal share (the highest share is 5.8% in Indonesia and Myanmar). Similarly, domestic navigation accounted for a very significant modal share in three countries, namely Bangladesh, Korea and Japan, in 1980, but this had declined significantly by 2013 in all three countries, most notably in Korea where the modal share declined from 22.3% to 0.7%. In 2013, only Bangladesh featured modal share of domestic navigation above 10%.

Rail transport was a critical mode of transportation in China and India, the two most populous countries in the world, in 1980, with modal shares in excess of 35%, and to a lesser extent in Bangladesh and Vietnam as well. All four countries experienced significant decline in the share of rail transport by 2013, especially China and India, where the modal share of rail had fallen to 4.7% and 5.4% respectively. This is reflective of the general drop in the modal share of rail transport across the region, with Myanmar the only country where rail gained a substantial share (going from nil to 13.5%) over this period.

Domestic navigation, which was a major transport mode in Bangladesh, Japan and Korea in 1980, was significantly less popular in 2013, particularly in Korea, where the modal share had fallen from 22.3% to 0.7%. Nevertheless, despite a considerable decline in modal share, domestic navigation remained an important transport mode in Bangladesh, which was the only country where its share was found to be above 10% in 2013. Most of the other countries witnessed a small increase in the modal share of domestic navigation over this period.

Overall, domestic aviation and domestic navigation tend to be less popular modes of transport as compared to rail and especially road, with modal shares for these two modes well under 10% in most countries and completely negligible in a few. The general trend is for modest growth in modal shares of domestic aviation and navigation, while the share of rail transport underwent significant decline in many countries, resulting in road transport entrenching its dominant position in terms of transport mode with significant growth in its modal share in many countries and a substantial reduction in only Myanmar and the Philippines.

Transport sector fuel mix

Fuel substitution within a mode of transportation is another factor that explains transport sector energy demand growth, but fuel choices for transport remain limited, and gasoline and diesel are by far the most utilized fuel for transport across all of the countries considered. However, a few other fuels have gained market share in the transport sectors of several countries in recent years, leading to reductions in the share of diesel and gasoline in the fuel mix. A comparison of the fuel mix between 1980 and 2013 suggests significant substitution of gasoline with diesel in only one country – Vietnam, which provides sizable subsidies for diesel while taxing gasoline – whereas gasoline and diesel have been substituted as transport fuel in significant quantities by natural gas, liquefied petroleum gas (LPG) and biofuels in a number of countries (see Table 6.2).

Natural gas, which was scarcely utilized as a transport fuel in 1980, has emerged as vital fuel for transport in Bangladesh, Myanmar, Pakistan and Thailand, where compressed natural gas (CNG) is often used in lieu of gasoline by light duty vehicles, accounting for more than 10% of the fuel mix in all of these countries in 2013, and it is also gaining market share in China with 4.7% in 2013. It should be noted that the share of gasoline in Bangladesh is exceptionally low – only 10.3% – because the penetration of natural gas is so high. While the country has had significant natural gas production for quite some time, it only started to use natural gas as transport fuel in 2003, and since then the share of natural gas in the transport sector fuel mix has grown to 31.6% in 2013. The experience in Pakistan was similar, with natural gas adopted for transport fuel on a large scale in the late 1990s, and in 2013, it accounted for 16% of the transport fuel mix. Natural gas is considerably cheaper compared to gasoline and diesel in Pakistan, rendering it a popular choice for vehicle owners, as reflected in the fact that Pakistan leads the world in the number of natural gas vehicles (Khan and Yasmin, 2014).

LPG had also become a significant transport fuel by 2013, but only in two countries, namely Korea and Thailand. In Korea, where natural gas is used mainly in taxis, buses and trucks (Liu et al., 1997), the share of LPG in the transport fuel mix rose from 3.5% in 1980 to over 13% in 2013. Other than Korea, only Japan and Thailand used LPG as a transport fuel in 1980, it still accounts for a miniscule share in most countries as on 2013. Similarly, none of the countries used biofuels for transportation in 1980, but biofuels had become a notable transport fuel in Thailand and the Philippines in 2013, although its share was still relatively modest at 5.3% and 3.6% respectively.

China and India were both highly dependent on coal as fuel for rail transport in 1980 (coal comprised 38.6% and 29.2% of fuel consumption for transportation, respectively). By 2013, the share of coal in the transport fuel mix in China had declined to 1.1, while India completely phased out coal as fuel of rail transport in 1998. Between 1980 and 2013, considerable growth in the share of diesel in the fuel mix was observed in both countries, especially China, and 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, whereas most of the growth in diesel demand can be attributed to the increase in road transportation. Vietnam, which had also relied on coal as fuel for rail transport in 1980, eliminated coal from its transport fuel mix by 1996. As in India and China, marginalization of rail transport is the main reason for the reduction in demand for coal as a transport fuel rather than substitution by diesel.

Table 6.2 Transport sector fuel mix (1980 vs. 2013)

		Bangladesh	*China*	*India*	*Indonesia*	*Japan*	*Korea*	*Malaysia*	*Myanmar*	*Nepal*	*Pakistan*	*Philippines*	*Sri Lanka*	*Thailand*	*Vietnam*
1980															
Total	Mtoe	0.32	24.6	16.7	5.95	53.9	4.78	2.14	0.63	0.05	2.21	3.46	0.68	3.21	0.65
Aviation Fuels	%	0.0	0.1	2.2	5.9	4.6	4.6	0.0	5.0	0.0	0.0	0.2	18.7	0.0	15.1
Electricity	%	0.0	0.9	1.2	0.0	2.4	0.7	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0
Diesel	%	73.3	15.8	55.7	42.5	32.1	60.5	39.5	53.2	82.5	71.4	59.9	64.4	52.1	15.5
LPG	%	0.0	0.0	0.0	0.0	3.1	3.5	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0
Biofuels	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gasoline	%	19.2	44.3	9.8	50.3	50.3	17.8	60.5	41.7	17.4	26.2	38.6	16.9	46.6	59.7
Natural Gas	%	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Oil	%	7.4	0.0	2.0	1.1	7.5	12.8	0.0	0.0	0.0	2.2	1.1	0.0	0.0	0.0
Coal	%	0.0	38.6	29.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7
Kerosene	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
2013															
Total	Mtoe	2.89	260	74.8	46.2	73.4	31.4	19.4	1.37	0.74	13.2	8.78	2.55	22.6	10.4
Aviation Fuels	%	0.0	5.4	2.4	5.8	4.8	2.1	0.0	5.8	0.0	5.1	4.9	0.1	2.5	1.7
Electricity	%	0.0	1.9	1.8	0.0	2.1	0.6	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0
Diesel	%	58.1	47.0	68.5	36.5	29.1	49.2	33.6	22.3	73.7	50.4	52.9	65.0	48.3	50.6
LPG	%	0.0	0.5	0.3	0.0	1.7	13.7	0.0	0.0	1.3	0.0	0.6	0.0	9.2	0.0
Biofuels	%	0.0	0.7	0.2	1.8	0.0	1.1	1.0	0.0	0.0	0.0	3.6	0.0	5.3	0.0
Gasoline	%	10.3	36.4	24.5	55.8	59.1	29.2	63.5	55.6	24.9	28.4	35.4	33.7	23.6	47.3
Natural Gas	%	31.6	4.7	2.0	0.1	0.1	3.8	1.5	14.0	0.0	16.0	0.0	0.0	11.0	0.0
Fuel Oil	%	0.0	2.3	0.4	0.0	3.1	0.3	0.3	2.3	0.0	0.0	2.4	1.2	0.0	0.4
Coal	%	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Data source: IEA (2016b).

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.

The consumption of aviation fuels represented another notable source of energy demand 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 increased in the countries for which data is available, except for Korea, Sri Lanka and Vietnam. Utilization of electricity for transportation in 1980 was negligible in all countries except China, India, Japan and Korea, and while the share of electricity in the fuel mix has increased slightly in China and India, it remains a very minor source of energy for transport in all of the countries.

Transportation energy intensity

Transportation energy intensity, which is the ratio of total fuel consumption for transportation in an economy to its gross domestic product, is displayed for all of the Asian countries considered over the period 1980–2013 in Figure 6.4. While transportation energy intensity varies significantly across countries and over time, some trends can be observed in Figure 6.4. Bangladesh and Nepal feature the lowest intensity by far over the study period, although it has increased rather significantly in Nepal since 2007, placing it at a similar level to India in recent year. Transportation energy intensity has grown over time in Malaysia, Thailand and Vietnam over the study period, with these three countries exhibiting the highest intensities in 2013. China and Myanmar, which had the highest transportation energy intensity in 1980, had both achieved drastic reductions by 2013, while India realized a more modest but steady decline. On the other

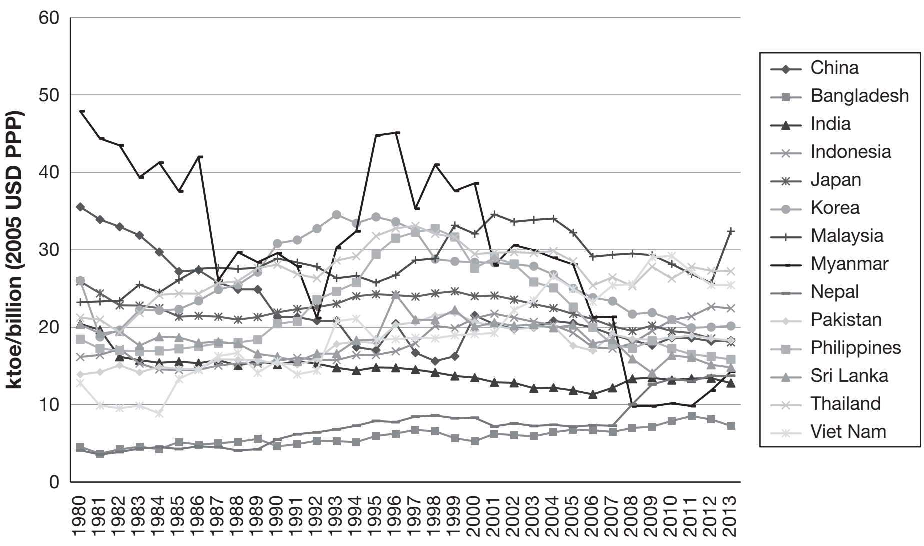

Figure 6.4 Transport energy intensity 1980–2013

Data source: IEA (2016a, 2016c).

Table 6.3 Total and urban population size and growth rate

Country	*1980*		*1995*		*2015*		*Average Annual Growth (1980–2015)*	
	Population (millions)	*Urban Share (%)*	*Population (millions)*	*Urban Share (%)*	*Population (millions)*	*Urban Share (%)*	*Total (%)*	*Urban (%)*
Bangladesh	81.4	14.9	118.4	21.7	161.0	34.3	2.0	4.4
China	981.2	19.4	1,204.9	31.0	1,371.2	55.6	1.0	4.1
India	697.2	23.1	960.9	26.6	1,311.1	32.7	1.8	2.8
Indonesia	147.5	22.1	197.0	36.1	257.6	53.7	1.6	4.2
Japan	116.8	76.2	125.4	78.0	127.0	93.5	0.2	0.8
Korea	38.1	56.7	45.1	78.2	50.6	82.5	0.8	1.9
Malaysia	13.8	42.0	20.7	55.7	30.3	74.7	2.3	4.0
Myanmar	34.5	24.0	44.7	25.5	53.9	34.1	1.3	2.3
Nepal	14.9	6.1	21.4	10.9	28.5	18.6	1.9	5.2
Pakistan	78.1	28.1	122.6	31.8	188.9	38.8	2.6	3.5
Philippines	47.4	37.5	69.8	48.3	100.7	44.4	2.2	2.7
Sri Lanka	14.7	18.8	18.1	18.5	21.0	18.4	1.0	0.9
Thailand	47.4	26.8	59.3	30.3	68.0	50.4	1.0	2.9
Vietnam	53.7	19.2	72.0	22.2	91.7	33.6	1.5	3.2

Data source: World Bank (2016).

Note: China does not include Hong Kong.

hand, transportation energy intensity in Korea and the Philippines deteriorated at first but improved from the mid to late 1990s so that it wasn't too much different in 2013 as compared to 1980. Therefore, a common trend cannot be found in terms of transportation energy intensity among the Asian countries considered.

Population growth and urbanization

The Asian countries included in this chapter alone accounted for over half of the world's population in 2015, and these countries are also undergoing a period of rapid urbanization. Table 6.3 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 Sri Lanka.

While developed and developing countries alike continue to urbanize, the rate of urbanization is especially swift 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 (ESCAP, 2007a), and this is only expected to increase given the higher growth rate of urban populations compared to total population. As Asian countries continue to grow and urbanize, increasing motorization can be expected to generate higher levels of energy consumption for transportation and place additional stresses on the transport infrastructure.

Motorization[4] and economic growth

Growth in the rate of motorization is one of the key factors that explains the modal shift towards road transportation from other modes of transportation observed in Asia. Most Asian countries have experienced significant growth in their road transport fleets, particularly in urban areas, resulting in soaring transportation energy demand (ESCAP, 2007b). Table 6.4 presents the motorization rate (i.e., the number of passenger cars per 1000 persons) in 2000 and in 2011 for the 14 Asian countries considered, along with the average annual growth rate in motorization. Rapid growth in motorization can be seen in almost every country, including 20.7% growth in China, the most populous country in the world, and robust growth in two of the other most populous countries, India and Indonesia, albeit not at the tremendous pace as in China. It is only in the Philippines that a slight decline in motorization can be observed.

Table 6.4 also presents the per capita GDP and per capita GDP growth, along with motorization rate, and a positive relationship between higher levels of per capita GDP and increased motorization becomes apparent. The relatively more affluent economies of Japan, Korea and Malaysia feature much higher levels of motorization than the other Asian countries. The level of motorization in developing Asian countries lags well behind those in developed countries, but the expected expansion of developing Asian economies in the coming years means that the current levels of motorization are likely only a fraction of what they will be in a couple of decades. Excluding the mature economy of Japan, some of the remaining 13 countries have achieved impressive growth in per capita GDP from 2000 to 2011, for example, China with 9.8% growth, Myanmar with 9.1%, Vietnam with 5.7% and India with 5.6%. The demand for passenger cars in Asia is growing much faster than per capita income in every country considered, other than Myanmar and the Philippines, sometimes astonishingly so, as in the case

Table 6.4 Motorization and GDP per capita (2005 USD using PPP)

	2000		*2011*		*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	0.5	1,434	2.1[a]	2,191[a]	16.1	4.3
China	6.8	3,220	53.6	8,967	20.7	9.8
India	5.8	2,274	11.0[b]	3,720[b]	7.3	5.6
Indonesia	14.2	4,942	39.4	7,506	9.7	3.9
Japan	404.0	28,898	455.0	30,798	1.1	0.6
Korea	172.0	19,682	284.0	29,706	4.7	3.8
Malaysia	179.9	13,974	340.6	18,782	6.0	2.7
Myanmar	3.8	619	5.4	1,615	3.2	9.1
Nepal	2.0	1,404	4.0	1,820	6.5	2.4
Pakistan	7.7	2,993	16.0	3,798	6.9	2.2
Philippines	9.9	3,777	8.7[a]	4,998[a]	−1.4	2.8
Sri Lanka	12.2	4,404	19.9[a]	6,743[a]	5.0	4.4
Thailand	34.7	7,959	73.5	11,394	7.1	3.3
Vietnam	0.6	2,359	14.0[c]	3,479[c]	56.8	5.7

Data source: ESCAP (2016) and IEA (2016c).

Notes: Road motor vehicles designed for the conveyance of passengers and seating not more than nine persons, including the driver. Taxis, jeep-type vehicles and station wagons are included. Special-purpose vehicles, such as two- or three-wheeled cycles or motorcycles, trams, trolley-buses, ambulances, hearses and military vehicles operated by police or other governmental security organizations, are excluded. China does not include Hong Kong.

a Data for 2010;

b data for 2009;

c data for 2007.

of China and Bangladesh. India still had a modest motorization rate of 11 passenger cars per 1,000 people in 2009, but its per capita GDP had only passed the $3,000 threshold a few years earlier, which has been called the tipping point past which vehicle ownership accelerates quickly (IEA, 2007).

Quantification of factors driving transportation energy demand

Methodology

In this section, we derive the methodology to decompose total transport sector energy consumption to its driving factors. Data needed to implement the methodology are also discussed here.

The total transport sector energy consumption in a country in year t (TE_t) is the summation of energy consumption from all fuels used in all transport modes in that year, i.e.,

$$TE_t = \sum_{ij} TE_{ijt} \tag{6.1}$$

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 (6.1) can be expressed as

$$TE_t = \sum_{ij} \frac{FC_{ijt}}{FC_{jt}} \times \frac{FC_{jt}}{TS_{jt}} \times \frac{TS_{jt}}{TS_t} \times \frac{TS_t}{GDP_t} \times \frac{GDP_t}{POP_t} \times POP_t \tag{6.2}$$

where FC refers to fuel consumption, TS represents transport services (e.g., passenger kilometres, tons kilometres or any equivalent measurement representing transport services[5]) 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 (6.3) to decompose the emission to the potential factors affecting it:

$$TE_t = \sum_{ij} \frac{FC_{ijt}}{FC_{jt}} \times \frac{FC_{jt}}{FC_t} \times \frac{FC_t}{GDP_t} \times \frac{GDP_t}{POP_t} \times POP_{tt} \tag{6.3}$$

As implied in Equation (6.3), we represent modal mix by energy consumption by mode instead of transportation services provided by the mode. Equation (3) can also be rewritten as

$$TE_t = \sum_{ij} FM_{ijt} \times MM_{jt} \times EI_t \times PC_t \times POP_t \tag{6.4}$$

where 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. (2008) and Wang et al. (2005) use the Arithmetic Mean Divisia Index (AMDI) and the Logarithmic Mean

Divisia Index (LMDI) techniques. Like Timilsina and Shrestha (2009), this chapter follows 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[6] (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 cannot be established easily.

Using LMDI (Ang, 2005), the additive decomposition of the change in transport sector energy demand from year $t-1$ to t is expressed as

$$TE_t - TE_{t-1} = \sum_{ij}\sum_{ij} \tilde{w}_{ij} \ln \frac{FM_{ijt}}{FM_{ijt-1}} + \sum_{ij} \tilde{w}_{ij} \ln \frac{MM_{ijt}}{MM_{ijt-1}} + \sum_{ij} \tilde{w}_{ij} \ln \frac{EI_t}{EI_{t-1}} + \sum_{ij} \tilde{w}_{ij} \ln \frac{PC_t}{PC_{t-1}} + \sum_{ij} \tilde{w}_{ij} \ln \frac{POP_t}{POP_{t-1}} \quad (6.5)$$

where

$$\tilde{w}_{ijt} = \frac{TE_{ijt} - TE_{ijt-1}}{\ln TE_{ijt} - \ln TE_{ijt-1}} \quad \text{for} \quad TE_{ijt} \neq TE_{ijt-1}$$
$$= TE_{ijt} \quad \text{for} \quad TE_{ijt} = TE_{ijt-1} \quad (6.6)$$

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

$$\frac{TE_t}{TE_{t-1}} = \exp\left[\sum_{ij} \tilde{v}_{ij} \ln \frac{FM_{ijt}}{FM_{ijt-1}}\right] \times \exp\left[\sum_{ij} \tilde{v}_{ij} \ln \frac{MM_{ijt}}{MM_{ijt-1}}\right] \times \exp\left[\sum_{ij} \tilde{v}_{ij} \ln \frac{EI_t}{EI_{t-1}}\right] \times \exp\left[\sum_{ij} \tilde{v}_{ij} \ln \frac{PC_t}{PC_{t-1}}\right] \times \exp\left[\sum_{ij} \tilde{v}_{ij} \ln \frac{POP_t}{POP_{t-1}}\right] \quad (6.7)$$

where

$$\tilde{v}_{ijt} = L(TE_{ijt}, TE_{ijt-1}) / L(TE_t, TE_{t-1}) \quad (6.8)$$

with

$$L(a, b) = \frac{a-b}{\ln a - \ln b} \quad \text{for} \quad a \neq b$$
$$= a \quad \text{for} \quad a = b \quad (6.9)$$

The first and second terms on the right-hand side of Equations (6.5) and (6.7) represent the fuel mix (FM) or fuel switching and the modal mix (MM) or modal shift effects, respectively. The third term represents the transportation energy intensity (EI) effect. And finally, the fourth and fifth 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 33-year period between 1980 and 2013.

Data

The study required a large set of data on energy consumption by fuel and by mode for the study period of 33 years. 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. No source other than the IEA provides data at the required details and time series needed for the study. Therefore, we use transport sector energy consumption data by fuel type and mode from the International Energy Agency (IEA, 2016a, 2016b).

Fuels included are biofuel (i.e., ethanol and biodiesel), natural gas, liquefied petroleum gases (LPG), motor gasoline, aviation fuels (i.e., aviation gasoline, kerosene type jet fuel and gasoline type jet fuel), diesel oil, fuel oil, coal, kerosene and electricity. The modes of transportation considered are domestic aviation, road, rail and domestic navigation.[7] We have excluded energy consumption in oil and gas pipeline transport.

Data on gross domestic product (GDP), expressed in 2005 constant dollar measured at purchasing power parity, and population are also taken from the IEA (2016c). Data for China includes Hong Kong. Korea refers to the Republic of Korea.

Results and discussion

All of the countries considered experienced significant growth in transportation sector energy demand during the 1980–2013 period. However, there remain meaningful differences in the magnitude of transport energy demand growth and the factors driving it. Table 6.5 summarizes the results of the additive decomposition of transport sector energy demand growth into fuel switching, modal shifting, transportation energy intensity, per capita GDP and population.

When a main influencing factor is considered as one that accounts for more than 25% of the change in energy demand (and since all of the countries experienced growth in transport energy demand, this can be taken to mean that the factor contributed at least 25% to the growth in transport energy demand), economic activity (i.e., per capita GDP growth) is a main influencing factor in all countries, as can be seen from Table 6.5. Population growth is a main influencing factor in India, Malaysia, Pakistan and the Philippines, and deterioration in transportation energy intensity is a main influencing factor in Nepal alone.

However, if we consider all the factors that have contributed to transport energy demand growth, regardless of the magnitude, then population growth must also be noted as an influencing factor in all of the countries. Similarly, deterioration in transportation energy intensity is found to contribute to emissions growth in Bangladesh, Indonesia, Malaysia, Pakistan, Thailand and Vietnam. Although fuel switching is not a main influencing factor in any of the countries considered, with the exception of India, Japan, Myanmar and Sri Lanka, it contributes directly to transport energy demand growth in all of the countries considered, but its impact is very modest (see Table 6.5). For example, in the Philippines and Korea, where the fuel switching effect makes the largest contribution, it still only accounts for 2.9% and 1.5%, respectively, of the average growth in transport energy demand.

While fuel switching appears to be a notable phenomenon in a few of the Asian countries during the 1980–2013 period (see Table 6.2), e.g., the penetration of natural gas as an important transport fuel in Myanmar, Pakistan, Thailand, and especially Bangladesh; the increased utilization of LPG in Korea and Thailand; and the increased reliance on biofuels in Thailand, the fuel switching effect is not found to play a major role in driving transport sector energy demand

Table 6.5 Average annual transport energy demand change and responsible factors (1980–2013)

Country	*Average energy demand change (ktoe)*	*Factors influencing the energy demand change*					*Influencing factors*[a]	*Main influencing factors*[b]
		Fuel mix (FM)	*Modal mix (MM)*	*Transport energy intensity (EI)*	*Per capita GDP (PC)*	*Population (POP)*		
Bangladesh	77.8	0.1	0.1	13.7	45.5	18.4	FM, MM, EI, PC, POP	PC,
China	7,188.8	37.3	11.0	–747.9	7,252.9	635.5	FM, MM, PC, POP	PC,
India	1,759.5	–0.5	1.0	–284.0	1,528.1	515.0	MM, PC, POP	PC, POP
Indonesia	1,219.2	0.4	0.2	277.4	659.2	282.0	FM, MM, EI, PC, POP	PC,
Japan	591.8	–0.1	0.6	–744.1	1,167.3	168.1	MM, PC, POP	PC,
Korea	893.6	31.7	–11.0	–223.0	954.2	141.6	FM, PC, POP	PC,
Malaysia	521.6	0.3	0.1	77.6	266.7	176.9	FM, MM, EI, PC, POP	PC, POP
Myanmar	22.3	–4.1	–0.5	–33.9	51.2	9.6	PC, POP	PC,
Nepal	20.8	0.0	0.0	10.4	6.3	4.1	FM, MM, EI, PC, POP	EI, PC,
Pakistan	332.5	0.8	0.5	27.9	140.0	163.3	FM, MM, EI, PC, POP	PC, POP
Philippines	161.3	4.7	–4.2	–79.9	106.8	133.9	FM, PC, POP	PC, POP
Sri Lanka	56.4	0.0	0.2	–18.2	62.6	11.7	MM, PC, POP	PC,
Thailand	588.5	5.4	–4.4	24.7	458.2	104.6	FM, EI, PC, POP	PC,
Vietnam	295.8	0.5	0.2	54.8	191.7	48.6	FM, MM, EI, PC, POP	PC,

Data source: Authors.

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.

a Factors in the same direction as average emission change.

b Factors that account for more than 25% of the energy demand change.

growth in these countries. Similarly, despite the significant decline in the modal share of domestic navigation in Bangladesh, Korea and Japan; of domestic aviation in Sri Lanka; rail transport in China, India and Vietnam; and the increase in modal share of rail transport in Myanmar, and of road transport in many countries, modal shift is not found to be a main influencing factor in the growth of transport energy demand in those countries. This is because the effects of fuel switching and modal shifting were eclipsed by the effects of the overwhelming growth in economic activity and population.

Nevertheless, despite the fact that fuel mix, modal mix, and transport energy intensity are not found to be main influencing factors in any of the countries (except for transport energy intensity in Nepal), they have been crucial in *restraining* the growth of transport energy demand in a few countries. For example, were it not for the ameliorating impact of fuel mix effect, the average transport energy demand would have been more than 18% higher in Myanmar and about 3% higher in the Philippines. The modal mix factor does not have such a large impact, but is seen to have reduced average transport energy demand growth in Myanmar and the Philippines by 2.3% and 2.6% respectively. When examining countervailing factors that have enabled countries to reduce their transport energy demand from what it would otherwise be, then the impact of improvements in transport energy intensity becomes clear. For example, if not for the reduction in transport energy intensity (i.e., decoupling of energy consumption from economic growth), the average transport energy demand would have been 152% higher in Myanmar and 126% higher in Japan over the study period. While not as effective as in Myanmar and Japan, improvement in transport energy intensity also significantly depressed transport energy demand in China, India, Korea, the Philippines and Sri Lanka.

Figure 6.5 displays indexed time-series charts of the multiplicative decomposition of transport energy and its driving factors in each of the 14 countries considered. 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 6.5d, f, g and m). This has a visible impact on transport energy demand, which follows the same trajectory.

Since Figure 6.5 offers a visual representation of this decomposition analysis, it reiterates much of the preceding discussion on the relative impacts of the various factors on transport energy demand. Most countries have experienced secular growth in economic activity and population, while the impact of fuel switching and modal shift has been negligible. This means that the year on year volatility of transport energy demand is largely explained by changes in transport energy intensity. One can see this effect most clearly in the case of Japan, where transport energy intensity rises over the early part of the study period and then declines from the late 1990s forward (see Figure 6.5e). On the other hand, in Nepal, deterioration in transport energy intensity clearly accounts for the drastic rise in energy demand from 2007. Finally, Myanmar is particularly notable for how it has managed to moderate transport energy demand growth through both significant improvements in transport energy intensity and fuel switching.

It could be surprising to note why the fuel-mix and modal-mix effects do not play a major role in driving the transport energy demand in most countries in the region. Fuel-mix is not expected to play a role because there are only two major fuels (i.e., gasoline and diesel) used for transportation[8] and energy contents of these two fuels are not much different. Modal-mix did not show much impact by the design of the decomposition technique in this study due to lack of data. In fact, the modes of transportation should have been measured in terms of passenger or tons kilometres; however, such data is not available mainly for road transportation, which is the main mode for transportation.

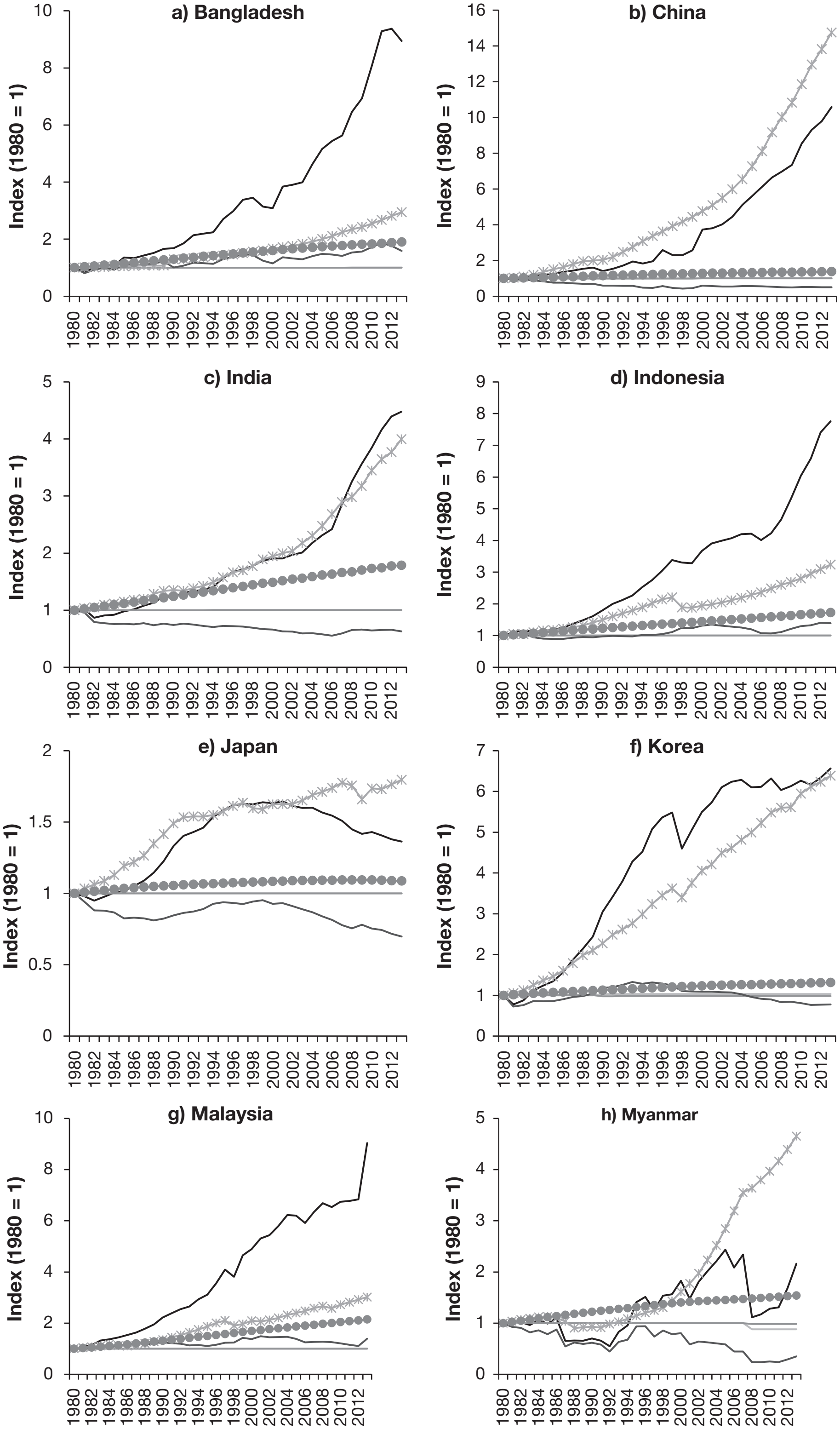

Figure 6.5 Transport sector energy demand growth and driving factors in selected Asian countries

Data source: Authors.

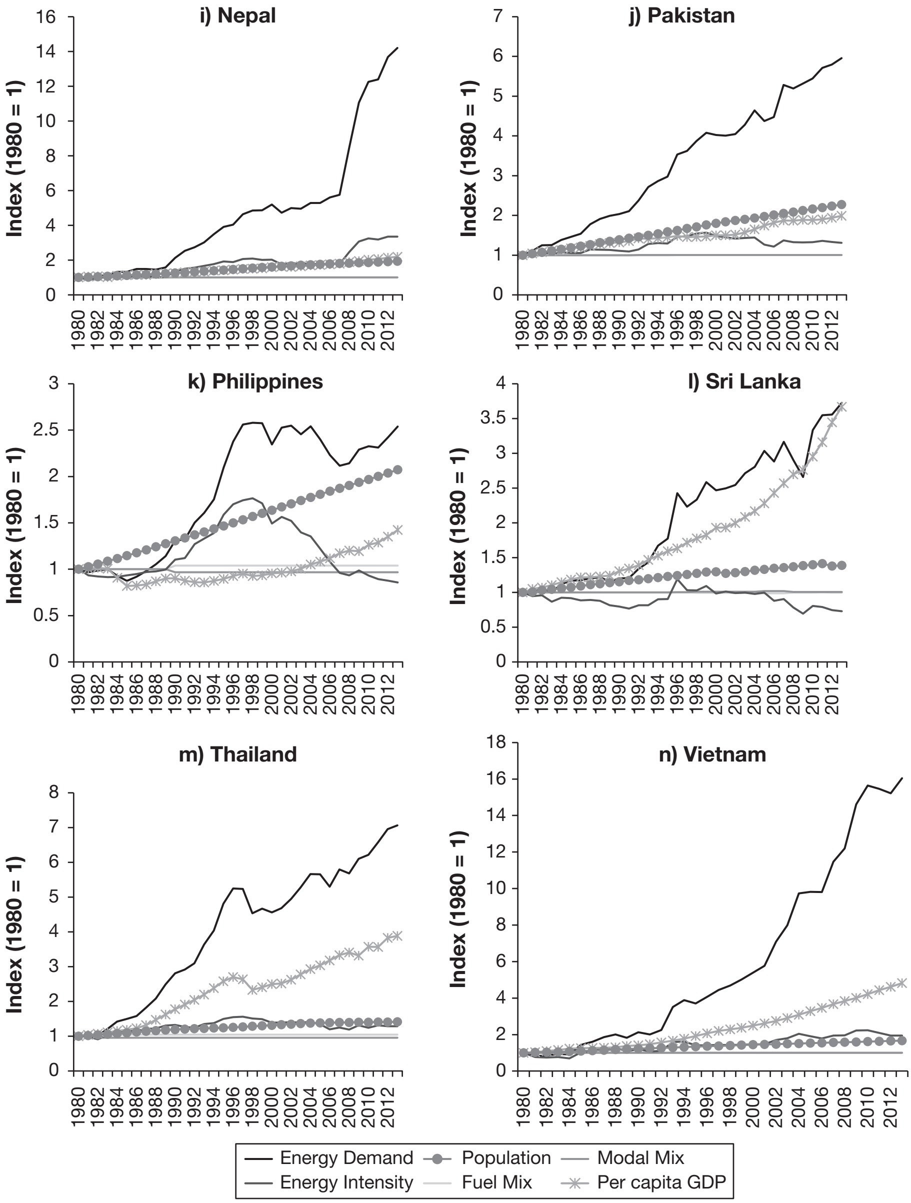

Figure 6.5 (Continued)

Conclusions

This chapter examines the growth of the transport sector energy demand and determines the underlying factors in 14 Asian countries over 33 years between 1980 and 2013. To identify the driving factors, we decompose the growth of transportation energy demand into income growth, population growth, changes in transportation energy intensity, change in fuel–mix and shifts in transportation modes. We used the LMDI approach for the decomposition analysis. The income (i.e., per capita GDP) growth effect and the population growth effect are found to be the principal drivers of transport energy demand growth in Asian countries over the study horizon, whereas fuel switching and modal shifting have not had a sizeable influence other than in Myanmar and the Philippines. While worsening of transport energy intensity was a major factor in the growth of energy demand in Nepal, in many countries, this one the main reason transport energy demand did not grow as much as it would have otherwise. 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, but this chapter could not explore those details due to lack of data.

The fuel switching and modal shifting effects are not found to have a sizeable influence on the growth of transport sector energy demand in any of the Asian countries studied. However, given the increased availability of transport fuels other than gasoline and diesel in many countries, along with rapid urbanization, which makes high-capacity public transport more viable, policy instruments to encourage these underutilized approaches could make a significant dent in transport energy demand growth if successfully implemented.

While this chapter does not detect modal shifting to be a main factor in the growth of transport sector energy demand, a major limitation of the analysis is that data specific to the various types of transport within road transport, such as cars, minibuses, buses and Bus Rapid Transit (BRT) systems, is not available. As road is by far 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 energy demand. Furthermore, several large Asian cities have already constructed light rail (e.g. in China, India, Korea, Philippines, Malaysia and Thailand) and BRT systems (e.g. in Jakarta, Seoul and Beijing) to provide convenient and price competitive alternatives to private road vehicles, and more may elect to do so in response to urbanization in the region. While increases in economic activity and population may be beyond the mandate of transport planners, and transport energy demand growth associated with these factors may be difficult to control, improvements in transport energy intensity and modal mix could all be promoted to reduce transport sector energy demand.

Acknowledgement and Disclaimer

The views expressed in this paper are those of the authors and do not necessarily represent the World Bank and its affiliated organizations.

Notes

1 China refers to the People's Republic of China and Hong Kong unless otherwise specified.
2 Korea refers to the Republic of Korea.
3 In energy literature, this is a common practice to measure modal mix in the transportation sector (see e.g., EIA, 2007; IEA, 2004)
4 Motorization, as per the commonly utilized UN definition, is measured here as the number of private cars per 1000 people in a country.
5 Includes transport services provided to all sectors (e.g., households, industry, government).
6 In this approach zero values are replaced with a small positive constant.
7 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).
8 In air and water modes, single fuel in each of these modes (jet fuel for air transportation and diesel for water transportation) are used.

References

Ang, B.W., 2004. Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Policy*, Volume 32 (9), 1131–1139.

Ang, B.W., 2005. The LMDI approach to decomposition analysis: a practical guide. *Energy Policy*, Volume 33 (7), 867–871.

Bhattacharyya, S.C. & Ussanarassamee, A., 2004. Decomposition of energy and CO_2 intensities of Thai industry between 1981 and 2000. *Energy Economics*, Volume 26 (5), 765–781.

Chang, Y.F. & Lin, S.J., 1998. Structural decomposition of industrial CO_2 emission in Taiwan: an input-output approach. *Energy Policy*, Volume 26 (1), 5–12.

Diakoulaki, D. & Mandaraka, M., 2007. Decomposition analysis for assessing the progress in decoupling industrial growth from CO_2 emissions in the EU manufacturing sector. *Energy Economics*, Volume 29 (4), 636–664 (Modeling of Industrial Energy Consumption).

Diakoulaki, D., Mavrotas, G., Orkopoulos, D. & Papayannakis, L., 2006. A bottom-up decomposition analysis of energy-related CO_2 emissions in Greece. *Energy*, Volume 31 (14), 2638–2651.

Ebohon, O.J. & Ikeme, A.J., 2006. Decomposition analysis of CO_2 emission intensity between oil-producing and non-oil-producing sub-Saharan African countries. *Energy Policy*, Volume 34 (18), 3599–3611.

EIA, 2007. International Energy Outlook 2007. Washington, DC: Energy Information Administration. US Department of Energy.

ESCAP, 2007a. Review of Developments in Transport in Asia and the Pacific 2007: Data and Trends. Thailand: United Nations Economic and Social Commission for Asia and the Pacific (ESCAP).

ESCAP, 2007b. Statistical Abstract of Transport in Asia and the Pacific. Thailand: United Nations Economic and Social Commission for Asia and the Pacific (ESCAP).

ESCAP, 2016. Statistical Yearbook for Asia and the Pacific 2015. Thailand: United Nations Economic and Social Commission for Asia and the Pacific (ESCAP).

Han, X. & Chatterjee, L., 1997. Impacts of growth and structural change on CO_2 emissions of developing countries. *World Development*, Volume 25 (3), 395–407.

Hatzigeorgiou, E., Polatidis, H. & Haralambopoulos, D., 2008. CO_2 emissions in Greece for 1990–2002: A decomposition analysis and comparison of results using the Arithmetic Mean Divisia Index and Logarithmic Mean Divisia Index techniques. *Energy*, Volume 33 (3), 492–499.

IEA, 2004. 30 Years of Energy Use in IEA Countries. Paris: International Energy Agency (IEA). p. 123.

IEA, 2007. World Energy Outlook 2007. Paris: International Energy Agency (IEA).

IEA, 2016a. "World energy balances", *IEA World Energy Statistics and Balances* (database). DOI: http://dx.doi.org.libproxy-wb.imf.org/10.1787/data-00512-en (Accessed on 18 July 2016).

IEA, 2016b. "Extended world energy balances", *IEA World Energy Statistics and Balances* (database). DOI: http://dx.doi.org.libproxy-wb.imf.org/10.1787/data-00513-en (Accessed on 15 August 2016).

IEA, 2016c. "World Indicators", *IEA World Energy Statistics and Balances* (database). DOI: http://dx.doi.org.libproxy-wb.imf.org/10.1787/data-00514-en (Accessed on 26 July 2016).

Kawase, R., Matsuoka, Y. & Fujino, J., 2006. Decomposition analysis of CO_2 emission in long-term climate stabilization scenarios. *Energy Policy*, Volume 34 (15), 2113–2122.

Khan, M.I. & Yasmin, T., 2014. Development of natural gas as a vehicular fuel in Pakistan: Issues and prospects. *Journal of Natural Gas Science and Engineering*, Volume 17, 99–109.

Kveiborg, O. & Fosgerau, M., 2007. Decomposing the decoupling of Danish road freight traffic growth and economic growth. *Transport Policy*, Volume 14, 39–48.

Lakshmanan, T. & Han, X., 1997. Factors underlying transportation CO_2 emissions in the USA: a decomposition analysis. *Transportation Research Part D*, 2(1), 1–15.

Lee, K. & Oh, W., 2006. Analysis of CO_2 emissions in APEC countries: A time-series and a cross-sectional decomposition using the log mean Divisia method. *Energy Policy*, Volume 34 (17), 2779–2787.

Liaskas, K., Mavrotas, G., Mandaraka, M. & Diakoulaki, D., 2000. Decomposition of industrial CO_2 emissions: The case of European Union. *Energy Economics*, Volume 22 (4), 383–394.

Lin, J., Zhou, N., Levine, M. & Fridley, D, 2008. Taking out 1 billion tons of CO_2: The magic of China's 11th Five-Year Plan. *Energy Policy*, Volume 36 (3), 954–970.

Lise, W., 2006. Decomposition of CO_2 emissions over 1980–2003 in Turkey. *Energy Policy*, Volume 34 (14), 1841–1852.

Liu, E., Yue, S.Y. & Lee, J., 1997. A study on LPG as a fuel for vehicles. Research and Library Services Division, Legislative Council Secretariat, Government of Hong Kong.

Liu, L.C., Fan, Y., Wu, G. & Wei, Y.M., 2007. Using LMDI method to analyze the change of China's industrial CO_2 emissions from final fuel use: An empirical analysis. *Energy Policy*, Volume 35 (11), 5892–5900.

Lu, I.J., Lin, S.J. & Lewis, C., 2007. Decomposition and decoupling effects of carbon dioxide emission from highway transportation in Taiwan, Germany, Japan and South Korea. *Energy Policy*, Volume 35 (6), 3226–3235.

Luukkanen, J. & Kaivo-oja, J., 2002a. ASEAN tigers and sustainability of energy use – decomposition analysis of energy and CO_2 efficiency dynamics. *Energy Policy*, Volume 30 (4), 281–292.

Luukkanen, J. & Kaivo-oja, J., 2002b. A comparison of Nordic energy and CO_2 intensity dynamics in the years 1960–1997. *Energy*, Volume 27 (2), 135–150.

Nag, B. & Kulshrestha, M., 2000. Carbon emission intensity of power consumption in India: A detailed study of its indicators. *Energy Sources*, Volume 22 (2), 157–166(10).

Rhee, H.C. & Chung, H.S., 2006. Change in CO_2 emission and its transmissions between Korea and Japan using international input-output analysis. *Ecological Economics*, Volume 58 (4), 788–800.

Saikku, L., Rautiainen, A. & Kauppi, P.E., 2008. The sustainability challenge of meeting carbon dioxide targets in Europe by 2020. *Energy Policy*, Volume 36 (2), 730–742.

Schäfer, A., 2000. Regularities in travel demand: an international perspective. *Journal of Transportation and Statistics*, Volume 3 (3), 1–31.

Schipper, L., Marie-Lilliu, C. & Gorham, R., 2000. Flexing the Link between Transport Greenhouse Gas Emissions: A Path for the World Bank. Paris: International Energy Agency.

Schipper, L., Murtishaw, S., Khrushch, M., Ting, M., Karbuz, S. & Unander, F., 2001. Carbon emissions from manufacturing energy use in 13 IEA countries: long-term trends through 1995. *Energy Policy*, Volume 29 (9), 667–688.

Schipper, L., Scholl, L. & Price, L., 1997. Energy use and carbon from freight in ten industrialized countries: an analysis of trends from 1973–1992. *Transportation Research Part D*, Volume 2 (1), 57–76.

Scholl, L., Schipper, L. & Kiang, N., 1996. CO_2 emissions from passenger transport: a comparison of international trends from 1973 to 1992. *Energy Policy*, Volume 24 (1), 17–30.

Shrestha, R.M. & Marpuang, C.O.P., 2006. Integrated resource planning in the power sector and economy-wide changes in environmental emissions. *Energy Policy*, Volume 34 (18), 3801–3811.

Shrestha, R.M. & Timilsina, G.R., 1996. Factors affecting CO_2 intensities of power sector in Asia: a Divisia decomposition analysis. *Energy Economics*, Volume 18 (4), 283–293.

Timilsina, G.R. & Shrestha, A., 2009. Factors affecting transport sector CO_2 emissions growth in Latin American and Caribbean countries: An LMDI decomposition analysis. *International Journal of Energy Research*, Volume 33 (4), 396–414.

Wang, C., Chen, J. & Zou, J., 2005. Decomposition of energy-related CO_2 emission in China: 1957–2000. *Energy*, Volume 30 (1), 73–83.

Webster, F.V., Bly, P.H., Johnson, R.H. & Dasgupta, M., 1986a. Part 1: urbanization, household travel, and car ownership. *Transport Reviews*, Volume 6 (1), 49–86.

Webster, F.V., Bly, P.H., Johnson, R.H. & Dasgupta, M., 1986b. Part 2: public transport and future patterns of travel. *Transport Reviews*, Volume 6 (2), 129–172.

World Bank, 2008. World development indicators. Washington, DC: World Bank. http://wdi.worldbank.org/tables (Accessed on August 12 2016).

Wu, L., Kaneko, S. & Matsuoka, S., 2005. Driving forces behind the stagnancy of China's energy-related CO_2 emissions from 1996 to 1999: the relative importance of structural change, intensity change and scale change. *Energy Policy*, Volume 33 (3), 319–335.

Yabe, N., 2004. An analysis of CO_2 emissions of Japanese industries during the period between 1985 and 1995. *Energy Policy*, Volume 32 (5), 595–610.