AIR POLLUTION FROM ENERGY USE IN A DEVELOPING COUNTRY CITY: THE CASE OF KATHMANDU, NEPAL †

RAM M. SHRESTHA‡ and SUNIL MALLA
Energy Program, School of Environment, Resources and Development
Asian Institute of Technology, P. O. Box 2754, Bangkok 10501, Thailand

Abstract - We examine sectoral energy-use patterns and estimate the associated emission of key air pollutants in Kathmandu Valley in 1993, as well as the levels of pollutant emissions from fuel use in 2013 under business-as-usual (BAU) scenario. Total emissions of the selected pollutants are estimated to be over 63,000 tons in 1993, and to increase five fold by 2013 under the BAU scenario. The transport sector contributes the largest share of pollutants, followed by the household and industrial sectors. Among fuels, gasoline, fuelwood, and coal were the dominant contributors to the total emissions. CO was the dominant pollutant resulting from fuel use in the city.

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‡ To whom all correspondence should be addressed.

1. INTRODUCTION

Kathmandu Valley (approximately 300 km^2) is the largest urbanized area and the capital city of Nepal, with a population of 1.1 million (1991). The city is known as the City of Temples and is the treasure house of Nepalese culture, arts, and architecture. In recent years, air pollution has been emerging as a major environmental problem in the city. It is now not uncommon to see people in the city wearing face masks or putting shawls or handkerchiefs over their mouths and noses. The city is especially vulnerable to air pollution due to its bowl-like topography which restricts wind movements and retains air pollutants in the atmosphere during thermal inversions. The ambient concentrations of total suspended particulates (TSPs) in major urban locations have regularly exceeded World Health Organization (WHO) guidelines.[1] The number of days with a visibility of more than 8,000 m (at 11:45 local time) during the period from November to February, the months with lowest visibility, has decreased from 115 days in 1970 to only about 20 days in 1993.[2] With rapidly growing fuel use due to increasing urbanization and industrialization, air quality in the city is likely to deteriorate further. It is of interest to identify the major types of pollutants and their sources in Kathmandu so that effective mitigation programs and policies may be formulated.

There exist a few studies on air quality measurements in Kathmandu.[1-4] However, these focus mainly on ambient air-quality issues and do not deal with levels of air pollutants from various sources. There are also a few studies on the estimation of air pollutants from fuel use in Kathmandu.[5-7] While these studies provide valuable insight, their coverage is limited to emissions from selected sectors only.

2. METHODOLOGY AND DATA SOURCES

The anthropogenic emissions in Kathmandu arise from mobile (e.g. road vehicles) and stationary (e.g. households, industries and commercial enterprises) sources. Here, we estimate sectoral emissions of CO, hydrocarbons (HCs), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and TSPs. The methodologies used to estimate these emissions will now be described.

A. Mobile Sources

We define $F_i(t)$= average fuel consumption† by vehicle type i in year t, $FE_i(t)$= fuel efficiency‡ of vehicle type i in year t, $vkm_i(t)$= average vehicle-km travelled by vehicle type i in year t, $s_i(t)$=speed-correction factor§ for vehicle type i in year t, $d_i(t)$= age-correction factor¶

† Figures per vehicle are taken from Ref.8. They are (litres/yr) as follows: truck= 8,704, bus= 8,418, minibus= 7,373, jeep= 2,315, tractor= 4,785, car= 1,595, 3-wheeler (diesel)= 2,592, 3-wheeler (gasoline)= 1,479, and 2-wheeler= 341.

‡ Fuel efficiency is defined as distance travelled per unit of fuel consumption. The figures (in km/l) are taken from Ref.8 and are: truck= 4.5, bus= 3.0, minibus= 4.5, jeep= 8.0, tractor= 4.4, car= 10.6, 3-wheeler (diesel)= 12.5, 3-wheeler (gasoline)= 11.0, and 2-wheeler= 45.5.

§ The speed-correction factor is defined as the ratio of pollutant exhaust emission rate at any km to the pollutant exhaust-emission rate at a specified km. This figure is assumed to be the same for all vehicle types due to lack of data relating specific emission rate with speed by vehicle category in Kathmandu.

¶ The age-correction factor is used to adjust for deteoriation of vehicle performance with vehicle age. This figure is assumed to be the same for all vehicle types in the absence of better data.

for vehicle type i in year t, EF_{ij}= exhaust emission factor† by vehicle type i for pollutant type j, $N_i(t)$= number of vehicles in operation‡ by vehicle type i in year t, and $M_{ij}(t)$= exhaust emission by vehicle type i for pollutant type j in year t.

Since fuel efficiency is a function of speed and vehicle age[9], the average vehicle-km travelled for vehicle type i in year t is

$$vkm_i(t) = F_i(t)\, FE_i(t)\, s_i(t)\, d_i(t) \,. \quad (1)$$

The exhaust emission by vehicle type i for pollutant type j in year t is

$$M_{ij}(t) = N_i(t)\, vkm_i(t)\, EF_{ik} \,. \quad (2)$$

B. Stationary Sources

Let $F_{ks}(t)$ = fuel consumption§ of type k used in sector s in year t, EF_{jks} = emission factor¶ of pollutant type j for fuel type k used in sector s, and $P_{jks}(t)$ = emission of pollutant type j for fuel type k used in sector s in year t. The emission of pollutant type k from the use of fuel type j used in sector s in year t is estimated to be

$$P_{jks}(t) = F_{kls}(t)\, EF_{jks} \,. \quad (3)$$

† The exhaust-emission factor for a mobile source is expressed as mass of a pollutant emitted per unit of distance travelled. Table A.1 in Appendix 1 is a summary of the emission factors for mobile sources.

‡ Figures taken from Ref.8. They are: trucks= 736, buses= 110, minibuses= 372, jeeps= 3,555, tractors= 822, cars= 10,664, 3-wheelers (diesel)= 335, 3-wheelers (gasoline)= 1,588, and 2-wheelers= 30,220.

§ The shares of fuel consumption for stationary sources are discussed in detail in Table 1.

¶ Emission factors for stationary sources are expressed as mass of a pollutant emitted per unit of fuel consumed. Table A.2 in Appendix 1 is a summary of the emission factors for stationary sources.

3. FUEL-USE PATTERNS

Nepal has no indigenous fossil fuels. The use of fossil fuels imposes heavy pressure on the country's trade balance, with oil imports alone requiring about one-third of total export earnings.[10] Almost half of the country's total fossil-fuel imports in 1993 are estimated to have been consumed in the valley. However, the city's share in the total national consumption of biomass as fuel is negligible (less than 1.0%).[11] In 1993, total fuel consumption in the city was estimated to be about 203 ktoe. The estimated fuel shares by sectors in 1993 are presented in Table 1.

Table 1. Estimated sectoral shares (%) of fuel consumption in Kathmandu in 1993 (Ref.8).

Fuel Type	Household		Industrial			Transport	Commercial	Total
	Urban	Rural	Brick	Cement	Others†			
Biomass fuels								
Animal waste	-	0.2	-	-	-	-	-	0.2
Agricultural residues	0.7	6.6	0.5	-	0.7	-	-	8.5
Fuelwood	11.6	10.8	3.8	-	3.2	-	<0.0	29.2
Charcoal	0.2	-	0.7	-	0.1	-	0.2	1.2
Fossil fuels								
Coal	-	-	14.6‡	4.9	1.4	-	-	20.8
Kerosene	9.3	5.5	<0.0	-	<0.0	-	0.3	15.2
Light diesel oil	-	-	0.3	-	-	10.1	-	0.3
High speed diesel	-	-	-	-	-	11.4	-	10.1
Gasoline	-	-	-	-	-	-	-	11.4
LPG	2.3	0.3	-	-	-		0.2	2.8
Total	24.0	23.3	19.9	4.9	5.5	21.5	0.9	100.0

† Other industrial activities include industries such as food, textile, wood, paper, chemicals, machinery, leather and miscellaneous based on Nepal Industrial Standard Code (NISC). ‡ Figure taken from Ref.5.

As can be seen from Table 1, the household sector had the largest share in total fuel consumption, followed by the industrial and transport sectors. The fuels used in the commercial sector is rather negligible. Household sector accounts for almost four-fifth of the total biomass fuels used, while industrial and transport sectors account for more than two-thirds of the total fossil fuels used in the city. Among the fuels, fuelwood, coal, and kerosene are the dominant fuels used in the city. The sectoral fuel use is summarized as follows:

Household sector- Biomass and kerosene are found to be the main fuels used in this sector. However, there are indications of rapidly growing substitution of biomass with fossil fuels in the household sector, which may be inferred from the differences in per capita fuel consumption figures reported by Shrestha[12] and ESEC[13]. The weighted average per capita fuel consumption of biomass fuels in 1993 was found to be lower than in 1985, while the opposite was observed for modern fuels during the same periods. Apart from changes in household income, this might have occurred as the result of a kerosene subsidy and growing scarcity of fuelwood in the market. Table 2 presents the estimated values of average annual per capita fuel consumption by urban and rural households in the valley. As can be seen, urban households are found to use less primary energy per capita than the rural households, while the opposite is found to be the case in terms of useful energy consumption per capita. This is primarily due to the relatively high level of consumption of biomass fuels through less efficient appliances by rural households.

Table 2. Estimated per capita consumption of fuels in urban and rural areas in Kathmandu in 1993 (kgoe). Figures in parentheses represent useful energy consumption per capita (kgoe)†.

Area	Agricultural residues	Animal waste	Fuelwood	Kerosene	Charcoal	LPG	Total
Urban	2.18 (0.26)	- -	36.46 (4.38)	29.05 (14.53)	0.55 (0.12)	7.18 (4.67)	75.45 (23.96)‡
Rural	25.11 (3.01)	0.67 (0.32)	40.76 (4.89)	20.84 (10.42)	- -	1.03 (0.67)	88.44 (19.31)

† The assumed value of appliance efficiency are: 0.12 for traditional (i.e., agricultural residues, animal waste and fuelwood) stoves, 0.22 for charcoal stoves, 0.50 for kerosene stoves, and 0.65 for LPG stoves. Source Ref.10.
‡ The corresponding figure in 1990 was 33.5 kgoe in Beijing (Source: Ref.14) and 94-168 kgoe in Hongkong (Source: Ref.15).

Industrial sector- Coal (78%) and fuelwood (17%) are the dominant fuels used in this sector. Brick-making alone was found to be responsible for about two-thirds of total fuels used and the largest amount of emission from the sector. This is to be expected, as brick-making (a basically fuel intensive industry) is not only the major industrial activity, but also in the case of Kathmandu, it is mainly based on relatively fuel inefficient technology. The average specific fuel consumption of fired-brick production (a brick weighs approximately 2 kg) in the city ranges from 400 to 500 kcal/kg as compared to 245 kcal/kg of brick produced with the Vertical Shaft Brick Kilns (VSBK) technology.[16] The shares of cement industry and other industrial activities in total industrial fuels used are 16 and 18% respectively.

Transport sector- All high speed diesel and gasoline in the city are used in the transport sector. The registered vehicle population in the valley has almost been doubled during the last decade.[17] The average fuel efficiency of car (i.e. 10.6 km/l) in Kathmandu in 1993 was found to be much lower than that of Japanese, Taiwanese and German cars of comparable size of 1985.[18] The low average fuel efficiency in the city partly reflects the bad road conditions, and poor maintenance and dominance of the aged and/or "reconditioned" cars in the city. Vehicle ownership in Kathmandu (47 vehicles per 1,000 persons) in 1990 appears to be among the lowest in developing country cities. For e.g., the corresponding figures in Bangkok, Bombay, Jakarta, Karachi, and Mexico City were 246, 58, 165, 95, and 137 per 1,000 persons, respectively.[19]

4. EMISSION OF AIR POLLUTANTS

A. Air Quality Situation in Kathmandu

Limited studies that exist on air quality in the valley suggest that the city suffers from severe street-level air pollution. In many parts of the city, TSPs concentrations are reported to exceed WHO guidelines and are comparable with that of Mexico City (with an average of 100 to 500 $\mu g/m^3$) in 1992, WHO (Ref.19). CO, SO_2, and NO_2 concentrations are found to be relatively lower in most urban areas of the valley. The ambient concentration of selected pollutants in Kathmandu Valley are presented in Table 3.

Table 3. Ambient air quality concentration ($\mu g/m^3$) in Kathmandu valley in 1993 (Ref.19).

Site	24-hour Concentration				
	TSPs	PM_{10} †	SO_2	NO_2	CO ‡
Commercial (traffic) sites					
Average	187 - 391	67 - 142	17 - 77	11 - 37	-
Maximum	319 - 867	86 - 201	64 - 202	16 - 64	-
Residential sites					
Average	191 - 228	72 - 113	13 - 110	12 - 49	-
Maximum	270 - 350	126 - 161	13 - 225	14 - 126	-
Industrial sites					
Average	87 - 430	40 - 166	13 - 58	20 - 40	-
Maximum	102 - 560	53 - 194	13 - 79	24 - 83	-
WHO guidelines					
Average	150 - 230	100 §	100 - 150	150	30,000 ¶

† PM_{10} is the fraction of TSPs less than 10 microns in diameter. Essentially all particulates derived from combustion are less than 10 microns in size, while particulates derived from mechanical action, such as road dust, are larger. ‡ The average value ranges from 18,750 to 25,000 $\mu g/m^3$ for 1-hour average. Source: Ref.5. § Figure is for 24-hour time weighted average for Japan. ¶ Figure is for 1-hour average.

B. Emission Inventory of Air Pollutants

Table 4 is an inventory of sectoral emissions of TSPs, CO, HCs, NO_x, and SO_2 in the valley. The transport sector was found to have made the largest contribution to the total emissions of the selected pollutants. The household sector ranked second, while the industrial sector ranked a close third. Total emissions for the commercial sector were found to be almost insignificant.

The total emissions from the use of fossil fuels are much higher (almost 3 times) than that from biomass fuels. Gasoline is found to be the largest contributor (55%) to the total combined emission of all pollutants, while fuelwood and coal were the other two major contributors with shares of 16 and 14% respectively. Gasoline alone contributed 59 and 70% of the total CO and HCs emissions respectively. Overall, gasoline, fuelwood, coal, and agricultural residues were found to emit about 93%

of the total emissions. Table 5 presents emissions of pollutants by fuel types in the valley in 1993. The sectoral emission of pollutants are summarized as follows:

Table 4. Estimated total emissions of selected pollutants from energy use in Kathmandu in 1993 (tons)[†]. Figures in parentheses are shares (in %) of pollutants in total emissions.

Source	TSPs	CO	HCs	NO_X	SO_2	Total
Trucks	86	346	107	375	50	964
Buses	8	33	10	36	5	92
Minibuses	19	28	16	160	5	228
Jeeps	59	207	86	92	25	469
Tractors	2	39	22	24	7	94
Cars	38	11,178	1,496	487	23	13,222
3-wheelers	29	609	379	146	5	1,168
2-wheelers	234	11,253	8,908	33	9	20,437
Sub total (Transport[‡])	475	23,693	11,024	1,353	133	36,678
Urban	1,028	3,672	500	112	139	5,451
Rural	1,354	6,195	781	101	364	8,795
Sub total (Household)	2,382	9,867	1,281	213	503	14,246
Brick						
Bull Trench	2,018	3,088	558	359	774	6,797
Chinese	328	410	91	67	164	1,060
Cement	615	769	171	127	308	1,990
Others	613	953	672	75	103	2,416
Sub total (Industrial)	3,574	5,220	1,492	628	1,349	12,263
Commercial	24	234	11	5	3	277
Total	6,455 (10.2)	39,014 (61.5)	13,808 (21.7)	2,199 (3.5)	1,988 (3.1)	63,464 (100.0)

[†] These estimates are likely to underestimate the total emissions from fuel use, since they do not include emissions from unregistered commercial enterprises, cottage industries and from open refuse burning. Also, emissions of lead from household, industries and commercial sector are not included in the study due to lack of relevant data. Emission of lead is estimated only for transport sector and they are 4, 1, and 1 tons from cars, 3-wheelers (gasoline), and 2-wheelers respectively. [‡] Figures are only from the exhaust tailpipes and did not include crankcase blowby and evaporative emission. About 20% of the TSPs emitted by vehicles are from crankcase blowby while 20% of the total HCs emissions are from evaporative emissions. Source: Ref.20.

Transport Sector- The total vehicular exhaust emissions were estimated to be over 36,000 tons. CO accounted for the largest share (65%) from the sector, followed by HCs (30%), and NO_x (3%). The shares of TSPs and SO_2 were relatively very small. Total emission of all pollutants combined per vehicle together was 0.76 ton in 1993.[†]

Among the vehicles, 2-wheelers were found to contribute the largest share (56%) to total vehicular emissions, followed by cars (36%) and 3-wheelers (3%). All other vehicles accounted for only about 5% of total emissions from this sector. The high share of 2-wheelers is expected, as 2-wheelers represent the largest single group of vehicles in the city, accounting for over two-thirds of the total vehicle registration. This is probably due to the relatively high intensity of use of 2-wheelers. Furthermore, the average fuel efficiency of 2-wheelers in the city is low as compared with that of countries like Thailand, Indonesia, and Taiwan.† The contribution of 3-wheelers (in particular, diesel operated "vikram tempos") in total vehicular emissions at the overall city level was found to be relatively small. This is primarily due to lower share of 3-wheelers (5%) in total vehicles registered, and their relatively lower emission of CO and HCs in total vehicular emissions as compared to that of gasoline vehicles. This finding, however, need

† This seems to be much higher as compared to some of the selected cities in India during 1982. The figures were 0.20, 0.34, 0.22, 0.19 and 0.22 ton for Bangalore, Bombay, Calcutta, Delhi and Madras respectively.[20] The difference might be due to the fact that, unlike in the Indian cities, the share of gasoline vehicles in Kathmandu is much higher than that of diesel vehicles.

† The average fuel efficiency of 2-wheelers in Kathmandu is 45.5 km/l in 1993 (Ref.8). This is significantly low as compared to 62.5 km/l for 4-stroke engine models in Thailand and 51 km/l (for 1992 model of less than 125 cc) in USA.[21]

not be seen as contradicting the popular view that the 3-wheelers are mainly responsible for "blue smoke" emissions in the city center, as they could still be the major polluters at street level, especially during the peak hours.

Our estimates suggest that the combined emission of CO and HCs from the vehicles accounted for almost 95% of the total vehicular emissions. Although gasoline consumption in the valley was only about 28% more than diesel consumption, 94% of the total emissions from the transport sector were due to gasoline vehicles. This is mainly due to the substantially higher rate of emissions of CO and HCs of gasoline vehicles than that of diesel vehicles‡: For e.g., the specific emissions of CO and HCs from gasoline vehicles are 778 and 361 kg/kl respectively as compared to 29 and 11 kg/kl from diesel-driven vehicles.[23]

Household Sector- Total emissions from this sector in 1993 were estimated to be over 14,000 tons, of which more than two-thirds was in the form of CO. The shares of TSPs and HCs were 17 and 9% respectively. The total emissions by rural households (62%) is much higher than that by urban households (38%). Biomass fuels are found to have contributed to about 89% of the total emissions from the household sector in the city.

In per capita terms, the level of emission of pollutants from fuel use by rural households was found to be significantly higher than that by urban households: Urban households were found to emit only 5.7 kg of CO per annum per capita as compared to 11.6 kg per capita emitted by rural households. In the case of TSPs, the per capita emission of rural households is estimated to be 2.5 kg as compared to 1.6 kg by urban households.

‡ Exhaust emission from gasoline vehicles consist mainly of CO, HCs and NO_x. On the other hand, emission from diesel vehicles have low CO and HCs emission and high NO_x concentration.[22]

Industrial Sector- Brick-making was found to account for about two-thirds of the total industrial sector emissions. Most (about 55%) of the sectoral emissions were from the Bull Trench (BT) type of brick-making. Of the fuels, coal contributed over three fourth of total emissions, whereas fuelwood accounted for about one-sixths.

Commercial Sector- Commercial sector's contribution to the total emission of all pollutants was negligible, as it accounted for less than 1% of the total emission of all pollutants considered in the study.

Table 5. Total emissions by fuel type from mobile and stationary sources in Kathmandu in 1993 (tons).

Fuel Type	Sector	TSPs	CO	HCs	NO_x	SO_2	Total
Animal waste	Household	14	72	11	1	9	107
Agricultural residues	Household	513	3,843	381	35	307	5,082
	Industrial	238	287	41	10	28	604
Fuelwood	Household	1,748	4,660	874	81	70	7,432
	Industrial	661	1,047	697	70	3	2,478
	Commercial	7	18	3	<1	<1	29
Charcoal	Household	10	129	5	1	<1	146
	Industrial	48	603	24	5	1	681
	Commercial	15	183	7	2	<1	207
Sub total (Biomass fuels)		3,254	10,842	2,046	204	420	16,766
Coal	Industrial	2,627	3,283	730	540	1,313	8,493
Kerosene	Household	97	1,052	5	69	118	1,341
	Industrial	<1	<1	<1	2	1	3
	Commercial	2	23	<1	2	3	30
Light diesel oil	Industrial	<1	<1	<1	<1	3	5
High speed diesel	Transport	192	677	254	829	96	2,046
Gasoline	Transport	285	23,016	10,770	525	34	34,630
LPG	Household	<1	110	1	26	<1	137
	Commercial	<1	9	<1	2	<1	12
Sub total (Fossil fuels)		3,201	28,172	11,762	1,995	1,568	46,698
Total		6,455	39,014	13,808	2,199	1,988	63,464

C. Pollutant Mix

CO was predominant (61%) among the pollutants emitted from fuel use in the valley followed by HCs (22%), TSPs, NO_x and SO_2. In terms of sectoral contribution to emission of individual pollutants, transport and household sectors contributed most to CO and HCs emissions, while the industrial sector contributed most to CO and TSPs emissions. It should, however, be noted here that although the emission of TSPs from fuel use appears to be relatively small, it is likely that large quantities of TSPs are also emitted due to non-energy sources, such as poor road quality, construction activities, rice and saw milling, brick-farming production, and lack of regular road cleaning. The estimation of TSPs emissions from non-energy sources are, however, beyond the scope of the present paper.

Per capita emission and emission density (defined as emissions per unit of area) of TSPs and CO in Kathmandu Valley from fuel use is found to be relatively higher as compared to many cities in developing countries in 1990. The per capita emission of TSPs in Kathmandu (i.e. 5.47 kg) is higher than in Bombay (4.49 kg), Buenos Aires (0.34 kg), and Sao Paulo (4.18 kg). Likewise, per capita emission of CO in Kathmandu (i.e. 36.06 kg) is higher than in Bombay (16.89), Buenos Aires (20.73) and Calcutta (14.96 kg). The emission density of TSPs, CO, and NO_x in Kathmandu were 21.5, 130.0, and 7.3 tons/km^2, where as these were 18.0, 118.0, and 7.0 tons/km^2 in Mexico City respectively, WHO (Ref.19).

Table 6. Sectoral emission in Kathmandu in 2013 under the business-as-usual scenario (tons).

Sector	TSPs	CO	HCs	NO_x	SO_2	Pb	Total
Transport	3,441	141,981	90,238	6,015	693	32	242,400
Household	4,809	19,512	2,549	443	963	-	28,275
Industrial	11,113	16,542	4,488	1,943	4,143	-	38,229
Commercial	54	535	25	12	7	-	634
Total	19,417	178,570	97,300	8,413	5,806	32	309,538

D. Future emissions under business-as-usual scenario

The estimated levels of sectoral emission in year 2013 under BAU scenario are presented in Table 6 based on the following assumptions: (1) Transport sector- The average annual growth rates (AAGRs) of gasoline and diesel in the valley are 8.5 and 8.9% during 1993-2013 (Ref.10). The shares (in %) of 2-wheelers, cars, and 3-wheelers in total gasoline consumption in 2013 are 45, 40, and 15 respectively. The shares of diesel using vehicles in total diesel consumption are the same as in 1993; (2) Household sector- The AAGRs for urban and rural population in the valley are 4.50 and 2.75% respectively (Ref.24). The per capita fuel consumption in 2013 is assumed to be the same as in 1993. This is rather simplistic approach and ignores the changing fuel mix in the household sector from fuel-switch; (3) Industrial sector- Production of bricks in 2013 is derived as the product of population increase in the valley during 2013 and brick requirement per capita. Production of cement is assumed to remain at the same level as in 1993. Fuel requirements for the other industrial activities in 2013 are assumed to grow at the same rate as national industrial GDP during 1981-1991 (Ref.25); and (4) Commercial sector- Fuel requirements for the sector in 2013 are assumed to grow at the same rate as national commercial GDP during 1981-1991 (Ref.25).

As can be seen from Table 6, the combined emission of all pollutants in 2013 under the scenario is estimated to be about five times of that in 1993. If no measure is undertaken to mitigate or control the level of emissions, the per capita emission of all pollutants combined in year 2013 would be more than three times that of 1993. Under the BAU scenario, more than two-thirds of the increase in the emission is to be contributed by the transport sector and about one-sixths by the industrial sector. Household and commercial sectors would account for only about 10% of the additional emissions.

5. CONCLUSIONS AND FINAL REMARKS

This study has estimated the levels of emission of selected air pollutants from fuel use in Kathmandu Valley. Combined emission of CO, HCs, SO_2, TSPs, and NO_x from fuel use in the city was more than 63,000 tons in 1993. Of this, about two-thirds was CO. Among fuels, gasoline was the largest contributor; and the transport sector contributed the most in the total emission of the selected pollutants.

In the transport sector, two categories of gasoline using vehicles viz. 2-wheelers and cars accounted for over 92% of the total emission. Rural households, despite their lower share in the total population of the valley, were found to have a larger share in the total household sector emission than urban households due to the former's heavy dependence on biomass fuels. In industrial sector, brick-making was the most polluting industry.

Under the BAU scenario, the total emissions in the city in 2013 is estimated to be about five times that of 1993 and two-thirds of the increase in emissions in 2013 from that in 1993 would be from transport sector. These estimates should, however, not be treated as the precise values; rather they should be seen representing the orders of magnitude involved because of a number of assumptions made on emission factors and fuel use. Due to rapid industrialization and urbanization, emissions of air pollutants are expected to be much higher in the coming decades if effective mitigation measures are not adopted.

There seems to exist a large potential for mitigation of major air pollutants in the city through fuel quality and energy efficiency improvements, use of emission control technologies, and efficient fuel pricing. Introduction of electric vehicles, unleaded gasoline, low sulfur diesel, and mandatory use of emission control devices are some of the possible options for mitigating emissions from the transport sector. Furthermore, implementation of schemes like inspection and maintenance, improvement and expansion of mass-transit system i.e. diesel operated buses and electrical trolley bus systems could be seriously considered. In the household sector, the options of inter-fuel substitution and efficiency improvements through the introduction of improved cook stoves (ICS) could be considered. Environmentally efficient pricing of household fuels and the related devices would also have to be considered. As brick-making is one of the major sources of industrial air pollution in the city, economic viability of the efficient VSBK technology (similar to the one being widely used in China) could be studied.

The various options mentioned above remain mostly untapped, as they involve substantial investments. Financing of the options and the associated pricing implications are the major problems confronted by policy makers. We intend to examine the mitigation potential of the energy efficiency, fuel substitution and emission control options as well as the associated costs in a subsequent paper.

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APPENDIX 1

Table A.1. Emission factors for mobile sources (g/km).

Fuel Type	Vehicle Type	TSPs[†]	CO[‡]	HCs[‡]	NO_x[†]	SO_2[‡]	Pb[§]
High speed diesel	Truck	3.00	12.00	3.70	13.00	1.75	-
	Bus	3.00	12.00	3.70	13.00	1.75	-
	Minibus	1.50	2.25	1.26	13.00	0.39	-
	Jeep	0.90	3.10	1.30	1.40	0.38	-
	Tractor	0.90	2.25	1.26	1.40	0.39	-
	3-wheeler	1.50	2.25	1.26	13.00	0.39	-
Gasoline	Car	0.20	62.00	8.30	2.70	0.13	0.02
	3-wheeler[¶]	0.21	22.64	14.13	0.20	0.05	0.02
	2-wheeler	0.50	24.00	19.00	0.07	0.02	0.003

[†] Figures taken from Ref.5. [‡] Figures for truck, bus, jeep, car and 2-wheeler taken from Ref.26. Figures for truck, bus and car are based on urban driving conditions (24 km/hr) for uncontrolled vehicles. Figures for jeep and 2-wheeler are based on the driving conditions for Medan City of Indonesia in 1993 for uncontrolled vehicles. Figures for minibus is taken from Ref.23. Figures of minibus are assumed to be the same for the tractor and diesel operated 3-wheeler. [§] Gasoline contains 0.18 g/l of lead. 70% of lead supplied to engine is released from exhaust tailpipe. Figures taken from Ref.27. [¶] Figures taken from Ref.27.

Table A.2. Emission factors for stationary sources (g/kg).

Fuel Type	Sector	TSPs	CO	HCs	NO_x	SO_2
Animal waste	Household	10.0[†]	50.0[‡]	7.5[a]	0.7[a]	6.0[a]
Agricultural residues	Household	10.0[†]	75.0[‡]	7.5[a]	0.7[a]	6.0[a]
	Industrial	29.0[‡]	35.0[¶]	5.0[¶]	1.2[‡]	3.4[‡]
Fuelwood	Household/Commercial	15.0[†]	40.0[‡]	7.0[a]	0.7[a]	0.6[a]
	Industrial	18.0[‡]	28.5[§]	35.7[§]	1.9[‡]	0.07[‡]
Charcoal	Household/Commercial	20.0[†]	250.0[‡]	10.0[a]	2.25[b]	0.39[b]
	Industrial[c]	20.0	250.0	10.0	2.25	0.39
Coal	Industrial	36.0[‡]	45.0[¶]	10.0[¶]	7.4[‡]	18.0[‡]

Kerosene	Household/Commercial Industrial	3.5[‡] 0.69[§]	38.0[‡] 0.63[§]	0.2[¶] 0.12[¶]	2.49[b] 7.46[b]	4.25[†] 5.0[b]
Light diesel oil	Industrial	0.3[‡]	0.63[§]	0.12[§]	2.4[‡]	6.0[‡]
LPG	Household/Commercial	0.1[‡]	24.0[‡]	0.2[¶]	5.25[§]	0.02[†]

[†] Figures are from Ref.5. The average maximum sulfur contents of kerosene and LPG are 0.25 and 0.02%, respectively, by weight on a dry basis. [‡] Figures are from Ref.10. [§] Figures are from Ref.27. [¶] Figures are from Ref.8. [a] Figures are from Ref.28. [b] Figures are from Ref.29. [c] Figures assumed to be the same as for the household sector.