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ORIGINAL PAPER

Emissions of greenhouse and non-greenhouse air pollutants from fuel combustion in restaurant industry

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Abstract Information on emissions from restaurant industry is limited in scientific literature. Emission inventory of greenhouse and non-greenhouse air pollutants from restaurant industry was prepared for two Class 1 Indian cities, viz. Nagpur and Raipur for 2010. Emissions were estimated from a primary database on type and amount of cooking fuel combusted in restaurant industry in the selected cities. Liquefied petroleum gas, charcoal, wood, coal, diesel and candy coal are used in this industry, first three being the major ones. Carbon dioxide emission was highest in both cities and liquefied petroleum gas, charcoal and wood were the major contributors to emissions. Total annual emissions of greenhouse gases, viz. carbon dioxide, methane and nitrous oxide were estimated to be 19,251, 27 and 1 Mg year^{-1} in Nagpur and 21,207, 34 and 1 Mg year^{-1} in Raipur, whereas total annual emissions of non-methane hydrocarbon (NMHC), carbon monoxide, total suspended particulate (TSP), sulphur dioxide, nitrogen oxides and black carbon (BC) were 96, 959, 31, 12, 19, 3 Mg year^{-1} and 87, 1141, 78, 37, 28, 6 Mg year^{-1} in Nagpur and Raipur, respectively, from all the fuels used in restaurant industry. Considering the huge growth of Indian restaurant industry in the last decade and the predicted growth in future, emissions from this industry is assumed to grow and will play a major role in governing regional and national emissions in India.

Keywords Air pollution · Atmosphere · Commercial cooking · Energy · Global warming

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Introduction

Indian restaurant industry has seen tremendous growth in the last several years due to growing tourism, increase in disposable income and increasing trend of dining outside (Federation of Hotels and Restaurant Associations of India 2004). Most of the Indian restaurants are in the unorganized sector while the organized restaurant market share is only about 16 % of the estimated 43,000 crore (i.e. 430 billion Indian rupees or about 7.9 billion US dollars; 1 US dollar = 54.47 Indian rupees, as on 11.3.2013) Indian restaurant Industry, which may grow up to 45 % by 2015, opined National Restaurant Association of India (Financial Chronicle 2010). It is generally believed that the number of people eating outside is increasing, especially in urban areas (Pandey 2002). As per a survey (Federation of Hotels and Restaurant Associations of India 2004), 2.5 % of surveyed population dined out once in a week while 1.7 % dined more than once per week while 2.1 and 5.5 % dined once and in a fortnight and month, respectively.

Fuel combustion generates a variety of air pollutants, notable being carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), volatile organic carbon (VOCs), poly-aromatic hydrocarbons (PAHs), formaldehyde, particulate matter, black carbon (BC), etc. (Zhang and Smith 2007), apart from greenhouse gases like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Pearson and Palmer 2000). CH_4 and N_2O have much higher global warming potential than CO_2 at all time scales, making them extremely important in earth's radiation budget. Further, CH_4 along with non-methane hydrocarbons (NMHCs) and CO may contribute to the rise of regional ground-level ozone levels causing damage to human and plant life (West et al. 2006).

Various emission inventory estimates prepared for Indian cities have ignored the emissions contributed by restaurant industry, as emissions from this industry is seemingly lower than industrial or transport sectors, for example. Even, the commercial sector inclusive of restaurants has rarely been considered in the emission inventories published in scientific literature. In India, Ministry of Environment and Forests (MoEF) estimated total CO_2 equivalent emission from residential and commercial/institution sector to be 139.51 million tons in 2007 (Ministry of Environment and Forests 2010), but did not specify the sub-sectors considered within commercial sector. In 1990 and 1995, Maharashtra closely followed Uttar Pradesh as the highest SO_2 emitter state in India, primarily driven by use of coal in power sector and high-speed diesel (HSD), fuel oil and petrol in industrial and transport sectors (Garg and Shukla 2002). The official Indian estimate of CO_2 emissions in 1994 of 817 Tg CO_2 (terra gram CO_2) were estimated to have grown to 1,229 Tg CO_2 in 2005, growing about 4 % per annum (Garg et al. 2006), in which removals by land use and land-use change activities were not considered.

Emissions from restaurants may contain appreciable load of fine particle matter also apart from gaseous pollutants (Rand and Scatena 2006). A study conducted in New Jersey reported that the main source of particulate emissions may be the charbroiling equipments, with under-fired charbroiling contributing about 84 % of this particulate matter (Rand and Scatena 2006). Importance of charcoal as an energy source is thus far not realized significantly, as its use is limited in household sector and industrial sector, but in restaurant industry it plays the role of a prime energy source particularly in India due to the popularity of charcoal-fired preparations. Liquefied petroleum gas (LPG), being the cleanest fuel, has lesser contribution to air pollution but may be an important contributor to carbon dioxide. In another study, a VOC like toluene was the found to be the most abundant in charcoal emissions during cooking and carbonyls like formaldehyde and acetaldehyde were found in substantial amounts (Kabir et al. 2010). Fuels like coal, wood, crop residues are appreciably more polluting per meal than liquid and gaseous fuels. Evidently, use of unprocessed solid fuels in restaurants has the potential of causing substantial air pollution.

According to Bhattacharya et al. (2002), biomass fuels are likely to continue to meet the cooking energy needs of the majority of population in the poor countries. Without doubt, a substantial amount of fuel is used in restaurant industry in India, including polluting fuels like low-grade coal, cow dung, fuelwood, coal balls, etc., especially in small cities and towns. There are numerous small eating joints, mostly mobile, who also commit serious air pollution by burning fuels like charcoal, coal, wood, kerosene, dung cakes, coal balls, LPG, diesel, etc. The fact that India is a large country with a huge population and large number of restaurants, fuel consumption and resultant air pollution from this sector is likely to be substantial. Although several emission inventories have been prepared worldwide and in India for important sectors like industry, domestic, commercial, agriculture, vehicular (Garg et al. 2001, 2006), very little or no exclusive emission estimate from fuel consumption in restaurant industry is available till date. The authors opine that restaurant industry in all medium and big cities in India are potentially big emitters of greenhouse and non-greenhouse air pollutants and this industry may be contributing heavily to the emissions of greenhouse gases and other air pollutants. Preparing all India emission inventory from restaurant industry may be a difficult task considering the lack of all India database on fuel usage in restaurants. So, as a beginning, city-based emission inventories can be attempted. This will throw light not only on the emission potential of restaurant industry of individual cities, but may also roughly indicate the emission potential of the same in the country. This industry may prove to be a significant contributor to total national emissions.

Keeping in view the lack of emission estimates from this sector in India or elsewhere, the present study was carried out to prepare an emission inventory of greenhouse gases and other air pollutants from fuel consumption in the restaurant industry for the year 2010 in two Class 1 Indian cities, namely Nagpur and Raipur, former the erstwhile capital of Maharashtra State and the later present capital of Chhattisgarh State. The study addresses the need of understanding emission potential of restaurant industry, at least on a regional basis, on which very limited information is available. The study would help in bridging the knowledge gap on the extent of contribution of restaurant industry in regional and national emissions of greenhouse and non-greenhouse air pollutants and would help in formulating necessary policy decisions on this sector.

Materials and methods

Description of selected cities

Nagpur is the erstwhile capital of the State of Maharashtra. As per Government of India classification based on city population, Nagpur with a population of 2,122,965 is classified as Class 1 city (Bhonsle 2010). It is the largest city in Central India and third largest by population in Maharashtra and 13th largest city in India (Bhonsle 2010). Being at the centre of India, Nagpur is at the junction for India's two major national highways viz. NH 7 and NH 6 and two Asian highways, namely AH43 and AH46 and so cater to appreciable number of people in transit (Bhonsle 2010). Nagpur's own industrial and business potential makes it an important commercial and industrial centre of India, underlining the huge importance of the restaurant industry in commerce and business. Maharashtra had 4.6 and 10.7 % growth rate in trade, hotels and restaurant sector in 2001–2002 and 2002–2003 over the previous years at constant 1993–1994 prices (Government of Maharashtra, http://www.maharashtra.gov.in/english/ecoSurvey/ecoSurvey1/esm_e/cha05e.pdf, accessed on 8.8.2010). Nagpur had been listed amongst the top ten SO_2-emitting districts in India (Garg et al. 2001). The sectoral composition of SO_2 emissions indicated a predominance of electric power generation sector (46 %). District-level analysis indicated diverse spatial distribution with the top 5 % emitting districts contributing 46.5 of total national SO_2 emissions (Garg et al. 2001).

On the other hand, Raipur is the present capital of State of Chhattisgarh. As per 2001 India census, Raipur had a population of 1,605,131 (Census of India 2001) and is also categorized as a Class 1 city on the basis of city population (Census of India 2001). Raipur being an important industrial city has large number of non-resident and non-permanent population, comprising mostly of visitors on business errand and thus the restaurant industry is one of the most lucrative commercial and business aspects of this city.

There is no authentic and comprehensive database on the restaurants under organized or unorganized category in Nagpur or Raipur vis-à-vis Indian towns and cities. In the organized restaurant sector though, city-specific databases on registered restaurants are maintained by some major city municipalities, but there is no comprehensive or compiled database on number of registered restaurants in India. The city-based details on restaurants, wherever available, are limited to only name/address and sometimes the category of restaurants. There is no open access database available on kind and quality of fuel used in this sector for cooking in the selected cities in India. Moreover, the numerous mobile and semi-mobile food vendors in Indian cities and towns are hardly included in any database.

Collection of fuel consumption data

Lists of restaurants registered under respective Municipal Corporations and their addresses were collected from respective city municipality offices. 569 and 513 restaurants, respectively, under 10 and 8 municipal zones in Nagpur and Raipur were registered at the time of survey in January 2010. A preliminary survey was conducted in all the zones in Nagpur and Raipur to collect information on the listed restaurants. Finally, restaurants numbering 68 in Nagpur and 48 in Raipur, having a mix of small, medium and big ones based on the number of persons that could be served at a time, were selected for a questionnaire survey. The restaurants were so selected that they represented the whole range of fuels used in the restaurant sector of the cities. More numbers of restaurants could not be included in questionnaire survey due to limited willingness of the restaurant owners to participate in the survey. The selected restaurants in Nagpur comprised categories like A/B/C designated by the Nagpur Municipal Corporation. Information on types and amount of fuels used per day was collected through the survey undertaken in the selected registered restaurants. Based on the feedback from selected restaurants, percentage of restaurants using each fuel was calculated and probable number of restaurants using the same fuel in the entire city was estimated for calculation of annual fuel consumption (Table 1). The unregistered and mobile food vendors were not selected for this study as their number could not be reliably estimated due to their constant mobility and temporary nature.

Emission calculations

Emission of each air pollutant can be attributed to combustion of various fuels, viz. LPG, charcoal, coal, wood, candy coal and diesel that are used in restaurant industry in the selected cities. Annual consumption of a given fuel was multiplied by the specific emission factor of a pollutant for the given fuel to obtain total annual emission of the pollutant from the given fuel. To calculate total emission of a pollutant from all the fuels together, individual fuel-wise emissions were added. The following equation was used for calculating emission of an air pollutant from a source category, i.e. fuel:

$$\mathrm{Emission}_{\mathrm{air\,pollutant,fuel}} = \mathrm{Consumption}_{\mathrm{fuel}} \times \mathrm{EF}_{\mathrm{air\,pollutant,fuel}} \quad (1)$$

where $\mathrm{Emission}_{\mathrm{air\ pollutant,\ fuel}}$ is the emission of a given air pollutant from a given fuel, $\mathrm{Consumption}_{\mathrm{fuel}}$ is consumption of the given fuel, $\mathrm{EF}_{\mathrm{air\ pollutant,\ fuel}}$ is emission factor of a given pollutant for a given fuel

Subsequently, total emission of each pollutant from all the fuels in restaurant industry was calculated the following way:

Table 1 Fuel consumption by restaurants in Nagpur and Raipur

Fuel[a]	Percent usage in surveyed restaurants[b]	Usage in most probable number of restaurants[c]	Mean consumption[d] (kg day^{-1})	Annual consumption (kg year^{-1})	Usage in surveyed restaurants (%)[b]	Usage in most probable number of restaurants[c]	Mean consumption[d] (kg day^{-1})	Annual consumption (kg year^{-1})	Per capita consumption (kg year^{-1})	
	A	*B* = *A*/100*569	*C*	*D* = *B***C**365	*E*	*F* = *E*/100*513	*G*	*H* = *F***G**365	Nagpur	Raipur
	Nagpur				Raipur					
Charcoal	70	398	20	29,05,400	60	308	25	28,10,500	1.4	1.8
Coal	10	57	21	4,36,905	25	128	35	16,35,200	0.2	1.0
Wood	10	57	39	8,11,395	15	77	82	23,04,610	0.4	1.4
LPG	93	529	16	30,89,360	70	359	15	19,65,525	1.5	1.2
Diesel	–	–	–	–	6	31	7[e]	79,205[f]	–	0.05[f]
Candy coal	7	40	15	2,19,000	13	67	18	4,40,190	0.1	0.3

[a] Soybean cake is ignored as it was found in 1 restaurant only in Nagpur

[b] Percentage value is rounded up to the nearest whole number

[c] Total number of registered restaurants in Nagpur and Raipur were 569 and 513, respectively (as in February 2010)

[d] Average of surveyed restaurants

[e] Unit—L day^{-1}

[f] Unit—L year^{-1}

$$\text{Emission}_{\text{air pollutant,fuels}} = \sum_{\text{fuel}} \text{Emission}_{\text{air pollutant,fuel}} \quad (2)$$

Emissions of CH_4 and N_2O were converted to respective CO_2-equivalent emissions by multiplying with respective global warming potentials reported by IPCC (2001) for different time horizons, i.e. 20, 100 and 500 years.

Emission factors

Emission factors for all the selected pollutant–fuel combinations were compiled from scientific literature, scrutinized and suitable ones were chosen for usage in Eq. (1). India-specific emission factors have been used wherever available or otherwise, emission factors reported by Intergovernmental Panel on Climate Change (IPCC), United States Environmental Protection Agency (USEPA), US Energy Information Administration (EIA) and various researchers have been used. Emission factors were finally used as gram of pollutant per kilogram of fuel (g kg^{-1}) for calculation and so, reported emission factors in units like lb MMBTU^{-1}/Mt kL^{-1}/kg Mt^{-1}/kg TJ^{-1}/kg m^{-3}/lbs ton^{-1}/kg kL^{-1} or any other, were converted to g kg^{-1}. For solid fuels like charcoal and wood, all the emission factors were available in g kg^{-1} and so were directly used for calculation. For another solid fuel coal, several emissions factors had to be converted to g kg^{-1} (Table 2). Emission factors of CO_2, CH_4, N_2O, CO and NMHC for LPG were available as g kg^{-1} and used in toto but SO_2, NO_x and TSP emission factors had to be converted to g kg^{-1}. Similarly for diesel, emission factors reported in various other units were converted to g kg^{-1} by suitable calculations (Table 3). Conversion of all the EFs to a common unit (g kg^{-1}) made it easier to comparatively evaluate all the emission factors used in this study.

Results and discussion

Fuel consumption scenario

Several fuels were found to be used in the restaurant sectors of the two cities and barring diesel in Raipur, all other fuels like LPG, charcoal, coal, wood and candy coal were common to both cities (Table 1). LPG and charcoal usage were more predominant in Nagpur, while in Raipur charcoal and wood were predominant. A few restaurants, more in number in Raipur than Nagpur, used a cheap and locally available fuel like coal balls, called candy coal in vernacular, which are prepared from coal dust mixed with traces of clay or silt as binders. Consumption of candy coal was more than double in Raipur than Nagpur. In Nagpur, candy coal is used in only a few small restaurants in the city outskirts, where wood is also frequently used because of its low price and easy availability from nearby villages. Diesel-run stoves were found to be used in several small restaurants in Raipur only. Very few restaurants depended on any one particular fuel for cooking; a mixture of various fuels was common in both the cities. Other common Indian household fuels like kerosene and dung cake were not found in any restaurant, although some restaurant owners

Table 2 Emission factors for solid fuels (charcoal, wood, coal and candy coal)

Air pollutant	Charcoal (g kg^{-1})	Wood (g kg^{-1})	Coal/candy coal[i]	
			Reported emission factor[o] (g kg^{-1} unless specified)	Calculated emission factor (g kg^{-1})
CO_2	2411[a]	1830[d]	212.7 lb $MMBTU^{-1}$[j]	1875.9[j]
CH_4	8[a]	5[e]	0.00141 lb $MMBTU^{-1}$[j]	0.012436[j]
N_2O	0.24[a]	0.06[e]	0.00326 lb $MMBTU^{-1}$[j]	0.028752[j]
CO	275[a]	80[e]	73.7[k]	–
SO_2	0.34[b]	0.48[f]	16.5 × S kg MT^{-1}[l]	16.5
NMHC	10.5[a]	9[e]	0.03 lb ton^{-1}[m]	0.013608
NO_x	2.34[b]	1.4[g]	2.61[k]	–
TSP	1.95[b]	21[g]	11.2[k]	–
BC	0.4[c]	0.41[h]	1.83[n]	–

[a] Weighed average EF for India (1990–1991) (USEPA 2000a)

[b] Calculated for commercial charcoal use in India (Bhattacharya et al. 2000)

[c] Residential charcoal consumption (Parashar et al. 2005)

[d] IPCC default emission factor for wood (IPCC, 2006)

[e] Default (uncontrolled) emission factor for residential fuel combustion (IPCC, 1997)

[f] Based on 0.04 % S in wood (Smith et al. 2000) used in cookstoves (Reddy and Venkataraman 2002a; Ballard-Tremeer 1997; Ballard-Tremeer and Jawurek 1996)

[g] Emission factor for wood used in domestic heating (Bhattacharya et al. 2000)

[h] Emission factor for fuelwood combustion (Reddy and Venkataraman 2002a)

[i] Emission factors for candy coal are treated equivalent to coal as emission factor for candy coal is not available

[j] Calculated from calorific value of bituminous Indian coal Indian coal: 4,900 kcal kg^{-1} or 0.01944477 MMBTU kg^{-1} (Energy Information Administration 2001; Standing Committee on Energy, Government of India, 2001 http://164.100.24.208/ls/committeeR/Energy/18th/chapter6.htm)

[k] EF for bituminous coal (Donaldlucas et al. 2008)

[l] USEPA (2000b)

[m] Lignite combustion derived for bituminous data, C2–C16 alkane eq. for stoker feeder (USEPA 2000b)

[n] EF for domestic coal (uncontrolled) (Reddy and Venkataraman 2002b)

[o] Percent S is assumed as 1 % for average Indian coal (Tiwary and Dhar 1994)

use little amount of kerosene for fuel ignition. As the kerosene stoves are too inefficient for commercial cooking and kerosene imparts its smell to food if handled poorly, these stoves are not used in restaurant sector in these two cities. Per capita consumption, calculated by using the entire city population, of all the fuels except LPG was higher in Raipur. Higher per capita charcoal, coal, wood and candy coal consumption in Raipur is a result of lower usage of LPG and dependence on these former fuels to compensate the energy deficit. Studies conducted on fuel usage in restaurants in Taiwan indicated that wood and charcoal were the major cooking fuel for restaurants and small food industries (Chaiklangmuang et al. 2008; Pinnium 2000; Suntisirisomboon and Milintale 2001 check sequence). Chaiklangmuang et al. (2008) reported that biomass and coal constituted 96 and 4 % of the raw materials used for briquette preparation for usage as fuel in restaurants in Chiang Mai province in Thailand.

Inventory assessment

Greenhouse gases

Emission of CO_2 from fuel combustion depends on carbon content of the fuel, e.g. roughly for each unit of energy produced, natural gas emits about half and petroleum fuels about three-quarters of the CO_2 produced by coal (The Ames laboratory, US Department of Energy, http://www.ameslab.gov, accessed on 29.5.2012). Even, a clean fuel like LPG is a strong source of CO_2 (USEPA 2000a). In Nagpur, annual emissions of CO_2, CH_4 and N_2O were estimated to be 19,251, 27 and 1 Mg $year^{-1}$ (mega gram per year) from all the fuels used in the restaurant industry. In both the cities, combined CO_2 emission from all the fuels was substantially higher than CH_4 and N_2O (713 and 19,251 times in Nagpur and 624 and 21,207 times in Raipur, respectively) due to substantially higher CO_2 emission factors of all the fuels (Table 4). In Nagpur, LPG

Table 3 Emission factors for liquid fuels (LPG and diesel)

Air pollutant	LPG		Diesel	
	Reported emission factor ($g\ kg^{-1}$ unless specified)	Calculated emission factor ($g\ kg^{-1}$)	Reported emission factor ($g\ kg^{-1}$ unless specified)	Calculated emission factor ($g\ kg^{-1}$)
CO_2	3085[a]	–	2.68 MT kL^{-1}[f]	3243.37[g]
CH_4	0.05[a]	–	0.134396 kg MT^{-1}[h]	0.134396
N_2O	0.15[a]	–	0.026879 kg MT^{-1}[h]	0.026879
CO	15[a]	–	0.95 lb $MMBTU^{-1}$[i]	17.699[j]
SO_2	0.01 × S kg m^{-3}[b]	0.00037[b]	0.005 kg kg^{-1}[i]	5
NO_x	66 g GJ^{-1}[c]	3.04[c]	4.41 lb $MMBTU^{-1}$[i]	82.16
NMHC	18.8[a]	–	–	–
TSP	0.21 kg m^{-3}[d]	0.388[d]	0.25 kg kL^{-1}[k]	0.3025[l]
BC	0.01[e]	–	0.08 [m]	–

[a] Weighed average EF for India (1990–1991) (USEPA 2000a)

[b] TERI (1992); S content of LPG assumed as 0.02 % (Reddy and Venkataraman 2002a) and LPG sp. gr. taken as 540 kg m^{-3}

[c] Calorific value LPG taken as 46.1 MJ kg^{-1} (US Dept of Energy 1995)

[d] TERI (1992); Sp. gr. of LPG taken as 540 kg m^{-3}

[e] EF for residential LPG (Reddy and Venkataraman 2002a)

[f] Derived from reported EF for diesel fuel (No. 1 and No. 2) of 22.37 lb $gallon^{-1}$ (US Energy Information Administration 2007)

[g] Density of diesel taken as 826.3 kg kL^{-1}

[h] Calculated from IPCC (2006) reported emission factor of 3 kg TJ^{-1} for LDO, using net calorific value (NCV) in J kg^{-1} of the fuels reported by IEA (Treanton 2004)

[i] USEPA AP 42 for industrial diesel engines (Eastern Research Group 1996)

[j] Calorific value of diesel is taken as 43333 kJ kg^{-1} or 0.04107176 MMBTU kg^{-1}

[k] TERI (1992); diesel assumed as distillate oil

[l] Density of diesel taken as 826.3 kg kL^{-1}

[m] EF for diesel oil in industrial application (Reddy and Venkataraman 2002a)

had greatest contribution to CO_2 emissions as LPG consumption was the highest and it has the second largest CO_2 emission factor (behind diesel) amongst all the fuels. Contribution of LPG in CO_2 emissions in Nagpur was 50 % of the total (9,531 Mg $year^{-1}$), followed by charcoal (7,005 Mg $year^{-1}$, 36 %), wood (1,485 Mg $year^{-1}$, 8 %), coal (820 Mg $year^{-1}$, 4 %) and candy coal (411 Mg $year^{-1}$, 2 %) (Fig. 1). Contribution of coal in CO_2 emissions was almost four times more in Raipur than Nagpur as coal consumption was almost four folds higher in the former. Similarly, CO_2 emissions from wood were also higher in Raipur than Nagpur due to its much higher consumption in the former. Total CO_2 emission was higher in Raipur than Nagpur, driven by much higher consumption of coal, candy coal and wood.

Annual emissions CO_2, CH_4 and N_2O were 21,207, 34 and 1 Mg $year^{-1}$ in Raipur from all the fuels used in the restaurant industry. Charcoal was the major contributor to CO_2 emissions (6,776 Mg $year^{-1}$, 32 %), followed by LPG (6,064 Mg $year^{-1}$, 29 %), wood (4,217 Mg $year^{-1}$, 20 %), coal (3,068 Mg $year^{-1}$, 14 %), candy coal (826 Mg $year^{-1}$, 4 %) and diesel (257 Mg $year^{-1}$, 1 %) (Fig. 1). Total CH_4 emission was higher than Nagpur, while N_2O emissions were almost at par in both cities. Charcoal combustion was the primary source of CH_4 and N_2O in terms of absolute emission amounts in both cities; more in Nagpur (85 %) than Raipur (66 %), substantially more than the next contributor, wood, at 15 and 34 %, respectively. Other fuels had near or lesser than 1 % share in CH_4 emissions (Fig. 1). Charcoal, LPG and wood were the primary contributor to N_2O emissions, in that order, in both cities. In Nagpur, charcoal had highest share in CH_4 and N_2O emissions as emission coefficients for CH_4 and N_2O from charcoal were highest amongst all the fuels and charcoal usage was also high. But, in Raipur, charcoal had the highest share in all the three greenhouse gas emissions since its usage was much higher than all other fuels and its emission coefficient for all three gases were also high. Charcoal's contribution to N_2O emissions were almost uniform in both cities at about 57–58 %, followed by LPG (38 and 25 %, respectively). Raipur contributed 3 and 4 times more N_2O emissions from wood and coal, respectively, than Nagpur, as the usage of these two fuels were higher in the former. Contribution of diesel in N_2O emissions was lower than 1 % while its contribution to CH_4 emissions was even lower at 0.03 % in Raipur. Total CH_4

Table 4 Total annual emissions of greenhouse gases and air pollutants from fuel consumption in restaurant sectors of Nagpur and Raipur

Air pollutant	Nagpur						Raipur							Per capita emission ($kg\ year^{-1}$)	
	Charcoal ($kg\ year^{-1}$)	Coal ($kg\ year^{-1}$)	Wood ($kg\ year^{-1}$)	LPG ($kg\ year^{-1}$)	Candy coal ($kg\ year^{-1}$)	Total emission ($Mg\ year^{-1}$)	Charcoal ($kg\ year^{-1}$)	Coal ($kg\ year^{-1}$)	Wood ($kg\ year^{-1}$)	LPG ($kg\ year^{-1}$)	Diesel ($kg\ year^{-1}$)	Candy coal ($kg\ year^{-1}$)	Total emission ($Mg\ year^{-1}$)	Nagpur	Raipur
CO_2	7,004,919	819,590	1,484,853	9,530,676	410,822	19,251	6,776,116	3,067,472	4,217,436	6,063,645	256,891	825,752	21,207	9.067	13.212
CH_4	23,243	5	4,057	154	3	27	22,484	20	11,523	98	11	5	34	0.013	0.021
N_2O	697	13	49	463	6	1	675	47	138	295	2	13	1	0.0005	0.001
NMHC	30,507	6	7,303	58,080	3	96	29,510	22	20,741	36,952	–	6	87	0.045	0.054
CO	798,985	32,200	64,912	46,340	16,140	959	772,888	120,514	184,369	29,483	1,402	32,442	1,141	0.451	0.711
TSP	5,666	4,893	17,039	1,199	2,453	31	5,480	18,314	48,397	763	24	4,930	78	0.015	0.049
SO_2	988	7,209	389	1	3,614	12	956	26,981	1,106	1	396	7,263	37	0.006	0.022
NO_x	6,799	1,140	1,136	9,392	572	19	6,577	4,268	3,226	5,975	6,507	1,149	28	0.009	0.017
BC	1,162	800	333	31	401	3	1,124	2,992	945	20	6	806	6	0.001	0.004

All the values are rounded up

emission from fuel consumption in restaurant industry was comparatively higher in Raipur while N_2O emissions were almost similar in both cities. Total greenhouse gas emission was more in Raipur, primarily driven by the usage of substantially higher quantity of coal, candy coal and wood.

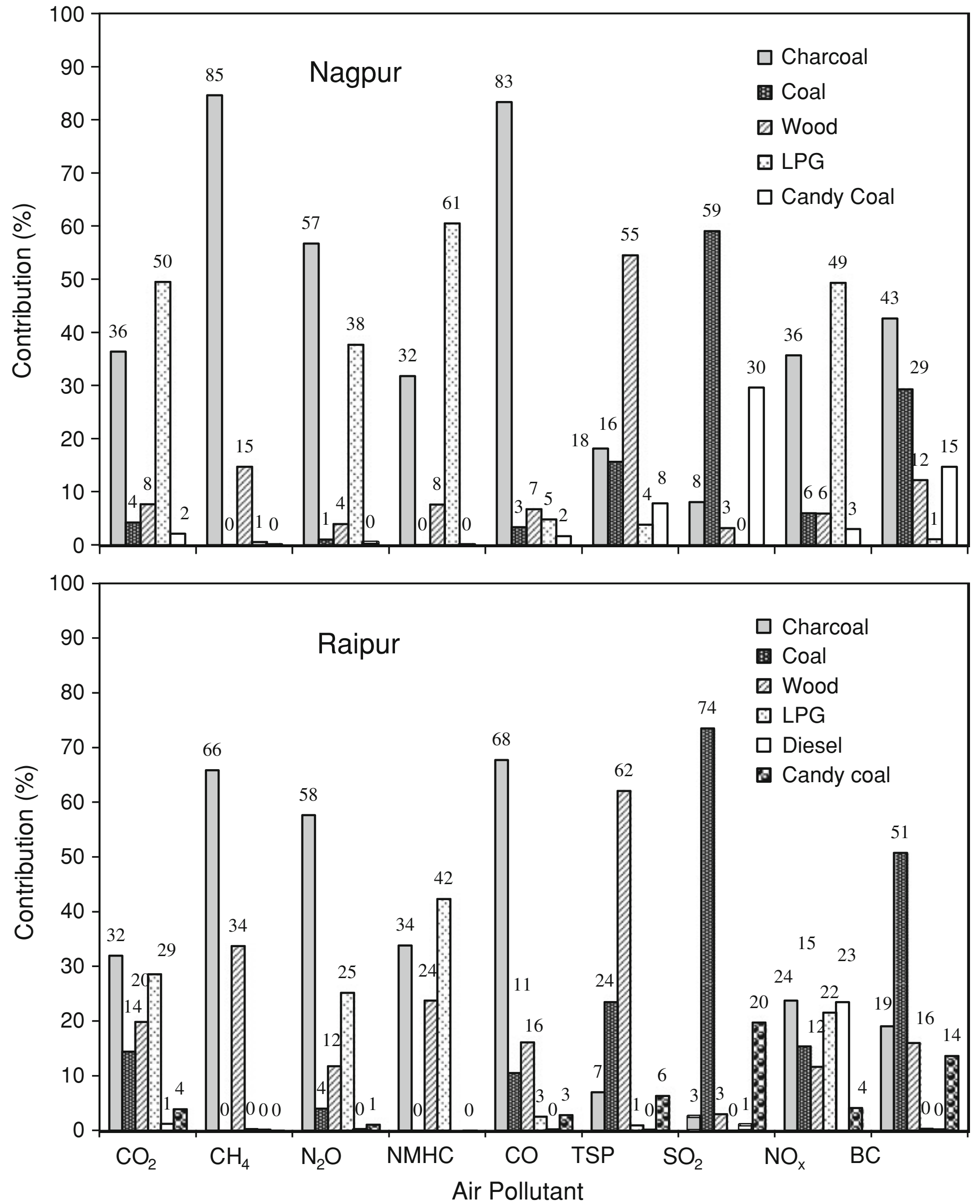
Global warming commitment (GWC), i.e. the future warming which has not yet occurred, of CH_4 and N_2O in terms of CO_2-equivalent emissions at various time horizons underlined their contribution to global warming in coming time horizons (Table 5). GWC was higher on 20-year time horizon for CH_4 and 100-year time horizon for N_2O as their respective global warming potential (GWP), i.e. the ratio of the radiative forcing that would result from the emission of 1 kg of a greenhouse gas to that from the emission of 1 kg of CO_2 over a specific time period, were higher in these respective time horizons. GWC of CH_4 and N_2O emitted from charcoal were the highest amongst all due to sheer dominance of charcoal over other fuels in emissions of these two gases, followed by wood and LPG in both cities. GWC of CH_4 was higher than N_2O for charcoal and wood, whereas GWC of N_2O emitted from coal, LPG and candy coal were higher than CH_4 in Nagpur. In Raipur, global warming commitment of CH_4 was higher than N_2O for charcoal, wood and diesel, whereas for the other fuels it was the reverse. Percent contributions of different fuels in total CO_2-eq. emissions over a 100-year time horizon in Nagpur were the following: charcoal (74.5 %), LPG (14.1 %), wood (10.8 %), coal (0.4 %) and candy coal (0.2 %). The same for Raipur were: charcoal (63.4 %), wood (27 %), LPG (8 %), coal (1.3 %), candy coal (0.35 %) and diesel (0.07 %).

Non-greenhouse air pollutants

Amongst all non-greenhouse air pollutants, CO emission was substantially higher than other pollutants in both the cities from all fuels except for diesel in Raipur due to higher CO emission factors reported for the fuels. Total CO emission from Raipur (1,141 $Mg\ year^{-1}$) was more than Nagpur (959 $Mg\ year^{-1}$), primarily influenced by high consumption and emission from coal and wood in the former. The major source of CO emission was charcoal in both cities followed by wood and LPG in Nagpur and wood and coal in Raipur. The share of various fuels towards total CO emission was highly variable ranging from 2 to 83 % and from negligible to 68 % in Nagpur and Raipur, respectively (Fig. 1). The contribution of coal was three times more, while wood had two times more contribution in total CO emission in Raipur than Nagpur. But, LPG had a two times higher share in CO emissions in Nagpur. Contribution of diesel was negligible in Raipur city at 0.13 % (Fig. 1).

In Nagpur, LPG had highest contribution in NMHC and NO_x emissions, because of high emission coefficients and

Fig. 1 Contribution of different fuels in annual emissions from restaurant sector of Nagpur and Raipur



substantial LPG usage, followed by charcoal (Fig. 1). In Raipur, LPG had higher contribution than other fuels in NMHC emissions, because of higher EF and substantial usage while charcoal had highest contribution in NO_x emissions. The contribution of LPG in NMHC emissions were 61 and 42 % in Nagpur and Raipur, respectively. Charcoal had second major share in NMHC emissions contributing 32 % in Nagpur and 34 % in Raipur (Fig. 1). Coal contributed to three times more NMHC emissions in Raipur. The emission contributions ranged from 6 to 51 % for different fuels in Nagpur and 12 to 25 % in Raipur.

In both the cities, coal had the highest contribution in SO_2 emissions, as Indian coal has substantial amount of sulphur which contributes to SO_2 formation during combustion. Contribution of different fuels in SO_2 emissions ranged in between 0.01 and 59 % in Nagpur, whereas in Raipur this range was slightly wider at 0.003–74 %. The highest emission contribution was from coal followed by wood and LPG in both the cities (Fig. 1). SO_2 emissions hold a major importance in atmospheric chemistry, smog formation and acid rain formation and a significant reduction in S levels in fuels may reduce it emission significantly. Raipur emitted more than three times SO_2 over Nagpur.

One of the major pollutants emitted by combustion of fuels particularly solid fuels like coal, charcoal and wood is suspended particulate matter. Wood combustion releases maximum total suspended particulates (TSP) and wood

Table 5 Global warming commitment of CH_4 and N_2O (as kg CO_2-Eq) emitted in Nagpur and Raipur at different time horizons

Fuel	20 year		Fuel Total (kg CO_2-eq.)	100 year		Fuel Total (kg CO_2-eq.)	500 year		Fuel Total (kg CO_2-eq.)
	CH_4 (kg CO_2-eq.)	N_2O (kg CO_2-eq.)		CH_4 (kg CO_2-eq.)	N_2O (kg CO_2-eq.)		CH_4 (kg CO_2-eq.)	N_2O (kg CO_2-eq.)	
Nagpur									
Char coal	1,441,066	191,675	*1632,741*	534,589	206,312	*740,901*	162,701	108,732	*271,433*
Coal	310	3,575	*3,885*	115	3,848	*3,963*	35	2,028	*2,063*
Wood	251,534	13,475	*265,009*	93,311	14,504	*107,815*	28,399	7,644	*36,043*
LPG	9,548	127,325	*136,873*	3,542	137,048	*140,590*	1,078	72,228	*73,306*
Candy coal	186	1,650	*1,836*	69	1,776	*1845*	21	936	*957*
City Total	*1,702,644*	*337,700*	*2,040,344*	*631,626*	*363,488*	*995,114*	*192,234*	*191,568*	*383,802*
Raipur									
Charcoal	1,394,008	185,625	*1,579,633*	517,132	199,800	*716,932*	157,388	105,300	*262,688*
Coal	1,240	12,925	*14,165*	460	13,912	*14,372*	140	7,332	*7,472*
Wood	714,426	37,950	*752,376*	265,029	40,848	*305,877*	80,661	21,528	*102,189*
LPG	6,076	81,125	*87,201*	2,254	87,320	*89,574*	686	46,020	*46,706*
Candy coal	310	3,575	*3,885*	115	3,848	*3,963*	35	2,028	*2,063*
Diesel	682	550	*1,232*	253	592	*845*	77	312	*389*
City total	*2,116,742*	*321,750*	*2,438,492*	*785,243*	*346,320*	*1,131,563*	*238,987*	*182,520*	*421,507*

Italics indicate to differentiate from others as former is city/fuel total

smoke is known to have approximately 80–90 % of particulates (Bay Area Air Quality management District; http://www.baaqmd.gov/Divisions/Communications-and-Outreach/Air-Quality-in-the-Bay-Area/Wood-Burning/Wood-Burning-Rule-Information.aspx; accessed on 26.4.2011) and wood has the highest TSP emission coefficient amongst the used fuels in this study. As coal and wood usage were substantially higher in Raipur, much higher TSP emission was generated from Raipur. Contribution of wood and coal were 55 and 16 % in Nagpur while in Raipur contribution of wood was also appreciable, 62 %. In Nagpur though, contribution of charcoal was more than coal as usage of charcoal was substantially higher than coal here. Although LPG is a poor emitter of TSP, due to its huge consumption in Nagpur, it had 4 % contribution to TSP emissions, approximately four times more than Raipur. Though TSP emissions from charcoal were almost similar in Nagpur and Raipur, charcoal had two times more contribution in TSP emissions compared to Raipur. Raipur emitted almost 61 times more TSP than Nagpur.

Black carbon emission from charcoal and coal was highest in Nagpur and Raipur, respectively. Biomass-based cookstoves have been held responsible by several studies for substantial black carbon emissions and even improved cookstoves may not minimize BC emissions (Bond and Sun 2005). Coal had contributed 51 % in BC emissions in Raipur, whereas in Nagpur its contribution was only 29 %. In Nagpur, charcoal had highest contribution (43 %) to BC emissions, because of its comparatively higher consumption than coal or wood, though it is a cleaner fuel than the two. LPG's contribution was low in both cities and in Nagpur it had three times more contribution in BC emissions than Raipur due to much higher consumption in the former. Total BC emission was two times more in Raipur than Nagpur. Comparative contribution of different fuels towards emissions of the greenhouse gases and air pollutants has been summarized in Table 6, which indicates that charcoal and LPG dominated in most cases over other fuels in terms of their contribution towards majority of pollutants since their usage were substantially higher in many cases than others, particularly in Nagpur.

Per capita emissions

Per capita emission is an important indicator of air pollution potential of a city or a country or a sector, as air pollution is integrally associated with increasing population and consequently energy consumption. Per capita emission is considered an important benchmark for comparison between cities or countries or sectors. Raipur had 1.3–5 times more per capita fuel consumption except LPG and 1.2–4 times more per capita emission of air pollutants including greenhouse gases (1.5–2 times) than Nagpur across all the fuel types. Since there is no database on actual number of people dining in restaurants in a year in these cities, per capita fuel consumption and emission were calculated on total city population. Per capita consumption and emission would have certainly been much higher if only diner population was used for the calculation, as it is generally assumed that only a part of total city population may be dining outside, though this fraction is unknown. As the restaurant industry is growing, total emissions of

Table 6 Contribution of different fuels to annual emissions

Pollutant	Within city		Between cities[b]	
	Nagpur[a]	Raipur[a]	Nagpur	Raipur
CO_2	LPG > charcoal > wood > coal > candy coal	Charcoal > LPG > wood > coal > candy coal > diesel	Charcoal, LPG	Wood, coal, candy coal
CH_4	Charcoal > wood > LPG > coal > candy coal	Charcoal > wood > LPG > coal > diesel > candy coal		
N_2O	Charcoal > LPG > wood > coal > candy coal	Charcoal > LPG > wood > coal > candy coal > diesel		
NMHC	LPG > charcoal > wood > coal > candy coal	LPG > charcoal > wood > coal > candy coal		
CO	Charcoal > wood > LPG > coal > candy coal	Charcoal > wood > coal > candy coal > LPG > diesel		
TSP	Wood > charcoal > coal > candy coal > LPG	Wood > coal > charcoal > candy coal > LPG > diesel		
SO_2	Coal > candy coal > charcoal > wood > LPG	Coal > candy coal > wood > charcoal > diesel > LPG		
NO_x	LPG > charcoal > coal > wood > candy coal	Charcoal > diesel > LPG > coal > wood > candy coal		
BC	Charcoal > coal > candy coal > wood > LPG	Coal > charcoal > wood > candy coal > LPG > diesel		

[a] Fuels are arranged in descending order in terms of emissions

[b] Fuels mentioned under a city had contributed to more emissions in the city than the corresponding fuels in the other city. Diesel was not considered for comparison between cities as it was not under usage in restaurant sector of Nagpur

pollutants would certainly increase in these cities vis-a-vis India, but per capita emission may or may not change drastically depending on population growth.

Conclusion

Total emissions of greenhouse gases and other air pollutants, except N_2O and NMHC, were more in Raipur than Nagpur in the study year of 2010. More usage of highly emitting fuels like wood and coal influenced higher emissions of these few pollutants in Raipur and to offset this trend, large-scale replacement of these fuels with cleaner LPG is necessary. Higher usage of coal in Raipur seems to have been largely driven by abundance of coal supply in this industrial city where a large number of sponge iron, rolling mills, ferro-alloy and captive power plants are operating, all of which use substantial quantity of coal. Much higher per capita income in Maharashtra than Chattisgarh (Department of Planning, Government of Punjab, http://pbplanning.gov.in/pdf/Statewise%20Per%20Capita%20Income%20%20Current.pdf; accessed on 23.5.2011) may have played an important role in influencing the fuel usage, tilting it in favour of more expensive but cleaner LPG in restaurant industry. Though number of registered restaurants per unit area was higher in Raipur (total area: 180 km^2; 2.85 restaurants/km^2) than Nagpur (total area: 218 km^2; 2.61 restaurants/km^2) as per the data collected during this study, this may not ensure better infrastructure, investment and facility in this sector in the former. Being an industrial town, Raipur justifies the presence of more number of restaurants per unit area as industrial workforce and population in transit may constitute a major chunk of diners.

Though the growth of restaurant industry in India has been predicted in financial terms, projections on usage of various fuel types by this sector has not been done yet. There may not be any doubt that along with growing investment in this sector, the number of restaurants and fuel usage will also increase, but region-wise distribution of fuel and their likely magnitude of usage in restaurant industry are difficult to predict. With increasing growth of Indian restaurant industry, availability and supply of a clean fuel like LPG has to also grow to stabilize or reduce the emission levels from this industry. But, future growth in supply of LPG in the restaurant industry may be under cloud in the scenario of increasing demand, restricted production and supply and escalating cost. The production of petroleum products during 2009–2010 was 151.898 million metric tonnes (mMT) which included 2.244 mMT of LPG from natural gas, registering a decrease of 0.51 % over last year's production at 152.678 mMT including 2.162 mMT of LPG (Ministry of Petroleum and Natural Gas 2010). It is also difficult to project fuel usage in restaurant industries of other cities in India based on Nagpur and Raipur experience, as Indian cities are variable in terms of area, spending power, food habit, culture of eating outside, etc., giving every city its very unique identity and emission potential. To calculate an all India emission inventory from restaurant industry, creating an all India database on registered restaurants and their fuel consumption will have to be undertaken and this study may be a stimulant in that direction.

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