Emissions of Air Pollutants and Greenhouse Gases in Nepal

An Integrated Inventory

A study carried out for Regional Resource Centre for Asia and the Pacific (RRC.AP) as a part of activities of Project Atmospheric Brown Cloud

Ram M. Shrestha

ASIAN INSTITUTE OF TECHNOLOGY
RERIC

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Foreword

Many Asian countries are facing air pollution problems and impacts of climate change due to increasing emissions of air pollutants and greenhouse gases (GHGs) as a result of rapid economic growth and lack of adequate planning and policies to deal with air pollution and climate change. In particular, the problems of air pollution and impacts of climate change are quite significant in South Asian countries, which also include countries of the Himalayan region. The main reason behind the lack of adequate planning and policies is an unavailability of reliable estimates of emissions of air pollutants and GHGs. In order to minimize this gap, Professor Ram Manohar Shrestha of Asian Institute of Technology, Thailand has presented in this book detailed estimates of emissions of air pollutants and GHGs for Nepal. Prof. Shrestha has followed a bottom up approach, which is the most appropriate method for estimating emissions of air pollutants and GHGs using activity data of the year 2008/09 from all key emission sectors, such as, energy industry, agriculture, livestock, waste treatment and disposal, power generation, manufacturing and construction, transportation, residential, commercial, crop-residue open burning, forest fires, and municipal solid waste open burning.

To my understanding, the present work represents the most extensive compilation of data on emission related activities in Nepal; it also represents the most comprehensive emission inventory of air pollutants and GHGs in the country. I believe, the book will be highly useful to policy makers dealing with air pollution control and climate change mitigation in Nepal and as well as to atmospheric science researchers working on air pollution and climate change issues of Nepal and the South Asia region.

This work was carried under the Atmospheric Brown Cloud (ABC) Programme, coordinated by the Regional Research Centre for Asia and the Pacific (RRC.AP). The ABC Programme, commissioned by United Nations Environment Programme (UNEP) about a decade and half ago with the support from Swedish International Development Cooperation Agency (Sida), addresses the regional air pollution and associated climate change issues in Asia in order to develop science-based knowledge on regional air pollution and climate change for assisting the policy makers of Asian countries. The ABC Programme, apart from establishing a network of climate observatories in Asia-Pacific region for the measurement of ABC precursors, impact assessment, and demonstration of innovative technology-based emission reduction measures, also involved development of emission inventory of air pollutants and GHGs of Asian countries. The present work on Nepal is one of them.

I truly appreciate the work done by Prof. Shrestha on estimation of emissions of air pollutants and GHGs in Nepal. I do hope policymakers of Nepal would benefit from this book.

Osamu Mizuno
Director
Regional Resource Centre for Asia and the Pacific
Asian Institute of Technology

Preface

Most developing countries are facing the problem of rapidly increasing air pollution and greenhouse gas (GHGs) emissions. Managing air quality is becoming a major challenge in many urban areas of South Asian countries, including Nepal. A sound understanding of the emissions of different kinds of local pollutants and GHGs from energy combustion and non-energy activities is crucially important to formulate policies for both GHG mitigation and local/regional air pollution control. However, Nepal, like most developing countries, lacks systematic and comprehensive assessments of the emissions of air pollutants and GHGs.

This study was carried out for Regional Resource Centre for Asia and the Pacific (RRC.AP) as a part of the activities of Project Atmospheric Brown Cloud. The main focus of the study was to derive detailed estimations of emissions of air pollutants and GHGs (including both short- and long-lived climate forcers) in Nepal for the fiscal year 2008/09, which starts from mid-June. The study presents an integrated inventory of the emissions from different sources, i.e., energy combustion in different sectors, open burning activities, industrial processes, solid waste management and other activities. It also discusses their implications for policymaking on air pollution control and GHG mitigation in the country. Keeping in view the lack of country-specific emission factors in many cases, the study has also carried out sensitivity analyses of emissions considering widely varying emission factors available in the literature.

The author hopes this study will be of significant interest to planners, policy makers, researchers and other stakeholders that are involved in formulating plans, programs and policies for the mitigation of emissions of GHGs and air pollutants in Nepal.

Ram M. Shrestha

Acknowledgement

The author wishes to profoundly thank Ms. Salony Rajbhandari; she provided extensive research assistance in carrying out this study. The author would also like to thank Dr. Ram Lal Verma of the Regional Resource Centre for Asia and the Pacific (RRC.AP) for his useful comments and editorial help in an earlier version of the report; Dr. Verma has been supportive in several ways to get the present work published. Dr. Maheswar Rupakheti and Mr. Mylvakanam Iyngararasan played an instrumental role in initiating the study and provided valuable suggestions on a previous draft of this report. Dr. Prakash Bhave also provided constructive comments in an earlier version of this study. Thanks to Ric Dennis A. Canullas of RRC.AP; he was involved in the cover design and layout of the book. Finally, special thanks to Professor Sivanappan Kumar; the author gratefully acknowledges Prof. Kumar's support to get this work published.

About the Author

Ram M. Shrestha is Emeritus Professor at the School of Environment, Resources and Development, Asian Institute of Technology (AIT). He carries with him over 30 years' teaching and research experience in energy economics and energy/climate policy modeling. He has supervised several sponsored national and regional (multi-country) studies on energy, environment and climate change issues in Asia.

Professor Shrestha has authored/coauthored 10 books (including "Economics of Reducing Greenhouse Gases Emissions in South Asia", "Power Sector Development with Carbon and Energy Taxes – An Assessment of Six Asian Countries", "Climate Policy and Energy Development in Thailand – An Assessment", "Sustainable Energy Access Planning – A Framework", "Baseline Methodologies for Clean Development Mechanism Projects" and "Atmospheric Brown Cloud Emission Inventory Manual") and over 160 scientific papers in refereed international journals and conference proceedings.

Professor Shrestha has served as the editor of International Energy Journal and as an Associate Editor of Energy Economics, Energy – The International Journal and ASCE Journal of Energy Engineering. He has also been a Guest Editor of Energy Policy and a member of International Editorial Board of Carbon Management and of Hydro Nepal. He is a recipient of The Energy Journal's Best Paper Award from International Association for Energy Economics (IAEE).

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List of Abbreviations

ABC	Atmospheric Brown Cloud
AP-42	Common name for the US EPA's compilation of air pollutant emission factors
BC	Black Carbon
CDR	Central Development Region
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EDR	Eastern Development Region
EF	Emission Factor
EPA	(US) Environmental Protection Agency
FWDR	Far-Western Development Region
GHG	Greenhouse Gas
GJ	Gigajoule
ha	Hectare
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
km	Kilometers
LPG	Liquefied Petroleum Gas
ML	Million Liter
MSW	Municipal Solid Waste
MT	Metric Ton
MWDR	Mid-Western Development Region
NH_3	Ammonia
NMVOC	Non-methane Volatile Organic Compound
NO_X	Nitrogen Oxides ($NO + NO_2$)
OC	Organic Carbon
PM_{10}	Particulate Matter of less than or equal to 10 micrometers in aerodynamic diameter
$PM_{2.5}$	Particulate Matter of less than or equal to 2.5 micrometers in aerodynamic diameter
ppm	Parts Per Million
SO_2	Sulphur Dioxide
WDR	Western Development Region

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1. Introduction

1.1. Background

Most countries in Asia are experiencing growing emissions of air pollutants and greenhouse gases (GHGs) with the increasing use of fossil fuels. In several countries, open burning of biomass including agricultural residues and municipal solid waste also contributes significantly to the emissions of GHGs and local/regional pollutants. As a result, several countries in the region are facing the problem of increasing air pollution. The growing air pollution involving fine particulate matters in particular is also a cause of increasing concern in the Asian region. Estimates of burden of disease by WHO (2016) reveal that globally about 6.5 million deaths had occurred by joint effects of household and ambient air pollution in 2012. Majority (about 94%) of these deaths had occured in low and middle income developing countries, which represent 84% of the world population.

Some studies conducted under the Atmospheric Brown Cloud (ABC) programme of the United Nations Environment Programme (UNEP) reveal that the layers of air pollutants, consisting mainly of fine particles or aerosols and combustion trace gases including ozone, are widely spread over the Asian atmosphere, extended up to an altitutde of 3 km (Ramanathan et al., 2008). These air pollution layers absorb or scatter incoming solar radiation in the atmosphere and affect the radiative budget, which, in turn, affects the regional climate (e.g., monsoon patterns and level of precipitation), ecosystem, agriculture, water resources and local/regional environment.

Climate of South Asia is changing rapidly due to an accumulative impact of the short-lived climate warming pollutants (such as black carbon (BC) and tropospheric ozone) and GHGs. The changes in south Asian climate are considered to be affecting significantly the melting rate of Himalayan glaciers and disturbing the Asian monsoon system including the level of precipitation in the region.

Emissions of air pollutants in South Asia are ever increasing with the rise of fossil fuel consumption in the region. According to a study by Ramanathan et al. (2005) the emissions of fossil fuel related sulfur dioxide (SO_2) and BC in South Asia have increased by 6 folds since 1930 resulting in large atmospheric concentration of BC and other aerosol particles.

Rapid economic growth, industrialization and urbanization have resulted in high growth in fossil fuel consumption in most countries of South Asia. The high rise in fossil fuel consumption, burning of biomass as a source of energy, open burning of agro residues and forest fires are considered to be the major factors behind the increasing emissions of local air pollutants and GHGs from the region besides industrial processes and burning of solid waste. The contributions of different sectors and activities in the national emissions of short and long-lived climate forcers as well as local/regional pollutants are, however, not well established in the context of the countries in South Asia.

This study attempts to have a comprehensive assessment of the emissions of air pollutants and GHGs from energy combustion in different sectors as well as those from open burning activities, industrial processes, solid waste management and fugitive emissions in Nepal. It is believed that the emisson estimates carried out by the present study would be helpful to policy makers of Nepal in formulating national policies for mitigation of emissions of GHGs and air pollutants in the country. In many cases, policies to reduce the emissions of local pollutants have climate change co-benefits; similarly, policies related to GHG mitigation could also result in local/regional environmental co-benefits.

1.2. Main Framework

In carrying out the estimation of emissions of air pollutants and GHGs from various sectors in Nepal, this study has followed the methodologies presented in the publication titled "Atmospheric Brown Clouds – Emission Inventory Manual" (hereafter "ABC-EIM") (Shrestha et al., 2013). The steps involved in the estimation of air pollutants and GHGs emissions in the present study are as follows:

a) Review the existing database and estimation of the air pollutants and GHGs emissions

b) Collect the data from sources (both non-open burning and open burning sources to the extent possible), activities and emission factors (applicable to Nepal) and estimate emissions of air pollutants (such as particulate matter (PM), BC, organic carbon (OC), SO_2, nitrogen oxides (NO_X), non-methane volatile organic compound (NMVOC), ammonia (NH_3), carbon monoxide (CO)) for a most possible recent year, i.e., a base year 2008 or more recent.

Figure 1 presents the main framework of the emission inventory activity. The study covers the emissions from both non-open burning and open-burning sectors. The non-open burning sector covers the emissions from energy combustion activities (or the "energy sector") and industrial processes as well as fugitive emissions from fuels and others (which includes emissions from solvents and other product uses, agricultural activities (i.e., non-combustion emissions from livestock management and use of nitrogen-containing fertilizer), waste treatment and disposal). Emissions from the energy combustion (or the energy sector) include emissions due to fuel combustion in power generation, manufacturing and construction, transportation, residential, commercial and agricultural sectors. Emissions from the open-burning sector cover the emissions generated from crop-residue open burning, forest fires and municipal solid waste open burning. Open burning of crop residues includes burning of rice straw and other crop residues (i.e., wheat, maize, potatoes, jute, oil crops, sugarcane, millet, barley and tobacco) in an open area or field. Emissions from forest fires cover the emissions from the on-site burning of forests and natural grasslands (which is mainly man-induced).

This study has generated the inventory of the emissions of air pollutants and GHGs for Nepal for the Fiscal Year (FY) 2008/09. The year 2008/09 is considered due to the availability of most up to date activity data provided by national and district level statistical reports and documents. Emissions for the year are estimated from all types of sources that are believed to contribute significantly to the emissions of air pollutants and GHGs. This emission inventory attempts to relate the emissions in the region to source characteristics such as fuel type, economic sector, energy technology and end-of-pipe controls, if any. The present emission inventory includes major primary pollutants including key gaseous species (i.e., SO_2, NO_X, NH_3, CO, NMVOC), key GHGs (i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)) and primary aerosols (PM_{10}, $PM_{2.5}$, BC and OC) from almost all of the main anthropogenic sources. The activity data collection relies on national publications of Nepal on national statistics covering different sectors and energy consumption patterns as well as publications of international agencies (i.e. International Energy Agency (IEA), Food and Agriculture Organization (FAO), United Nations (UN) etc.). This study also includes sensitivity analyses to see the effects on emission estimates of widely varying emission factors in some sectors. A list of the sectors covered and sources for the activity data used are presented in Annex 1.

A simple approach is used for emission estimation in this study in that the level of emission from an activity is calculated on the basis of the activity level and its associated emission factor. The calculation of emissions is based on ABC EIM Excel-based tool. The temporal variations of total emissions are presented on monthly basis due to lack of daily and hourly data. National level activity data are taken from secondary sources to estimate emissions of air pollutants and GHGs. Due to the lack of country specific emission factors (EFs), relevant EFs from various national and international sources such as United States Environmental Protection Agency (AP-42 USEPA), EMEP/CORINAIR and Intergovernmental Panel on Climate Change (IPCC) as reported in the ABC EIM have been used in the present study. However, an attempt is also made to use the Asia regional EFs, wherever possible.

1.3. Organization of the Study

This report includes 11 chapters. Chapter 2 includes the information on energy situation as well as geographical and socio-economic factors of Nepal. Chapters 3 to 9 present the estimated emissions from different sectors/activities, i.e., energy combustion in different sectors, fugitive emissions, process related emissions from manufacturing/process industries, open burning of crop residues, forest fires, municipal solid waste open burning, and other sectors respectively; each of these chapters also presents the general methodology adopted, as well as emission factors and activity data used for emission estimations. Chapter 10 presents an overall picture of the emissions of different types of pollutants and summarizes the key findings of this study; it also discusses data gaps and the scope for further study. Chapter 11 presents the national environmental policies of Nepal and policy implications of the study.

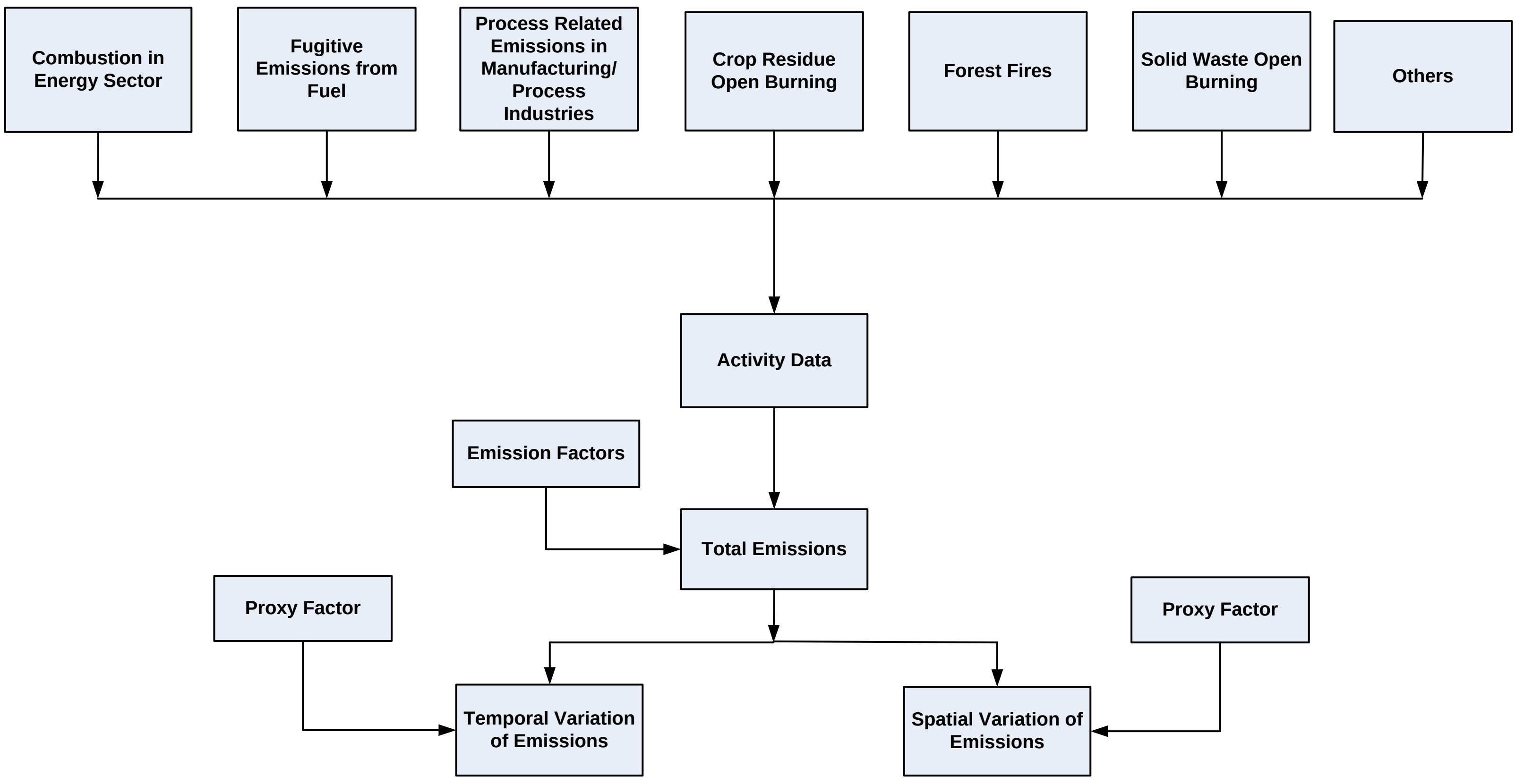

Figure 1: Overall Framework of Emission Inventory in Nepal

2. Socio-economic and Energy Overview of Nepal

2.1. Geographic and Socio-economic Information

Nepal, a landlocked country, situated in South Asia, is topographically divided into 3 ecological regions, namely, the plains (known as the Terai), the mountains and the hills. The country is bordered to the north by the People's Republic of China and to the south, east and west by India. Till the promulgation of the new constitution, the country was administratively divided into five development regions, fourteen zones and seventy-five districts. The five development regions were Far-Western Development Region (FWDR), Mid-Western Development Region (MWDR), Western Development Region (WDR), Central Development Region (CDR) and Eastern Development Region (EDR).[1] Figure 2 shows the map of Nepal showing all the 75 districts of the country in the previous administritative structure. However, with the federal structure adopted by the new constitution, the country comprises of seven states, 77 districts and 753 local level administrative units. As the present study was carried out for the year 2008 (i.e., before the new constitution was adopted), the report considers the structure of 75 districts as were applicable in that year. The different physiographic categories of the 75 districts are presented in Annex 2.

With an area of 147,181 square kilometers, the country was home to around 26.5 million people in 2011, growing at the decadal growth rate of 1.4% during 2001-2011 (CBS, 2017). The population increased to 28.4 million in 2016 (CBS, 2017). More than half of the total population of Nepal (50.3%) live in the Terai - the Southern plain region, followed by 43.0% of the population in the hills and 6.7% in the mountain regions. Around 17% of the total population of the country lived in urban areas in 2011 as compared to 14% in 2001. This shows that the rural population of Nepal decreased from 86% in 2001 to 83% in 2011 (CBS, 2016). Nepal is the world's 96th largest country by land mass and 45th most populous country (CIA, 2017). Nepal occupies 0.03% of the total land area of the world and 0.33% of the total land area of Asia. The Hilly region occupies 42% of the total land area of Nepal, while the Mountain and the Terai regions occupy 35% and 23% respectively.

Nepal is a developing country ranking 144th in terms of the human development index (HDI) (UNDP, 2017). The per capita Gross Domestic Product (GDP) of the country measured at purchasing power parity (PPP) was US$ 1777.3 in 2008 and US$ 2467.8 in 2016 (World Bank, 2017). In 2008, the service sector accounted for 50.6% of Nepal's GDP, while the remaining 49.4% was contributed by the agriculture (35.7%) and industrial (13.7%) sectors (MOF, 2009). In FY 2016/17 the service sector accounted for 52.7% of Nepal's GDP, while the agriculture and industrial sectors accounted for 33.1% and 14.2% respectively (MOF, 2017). Agriculture is the mainstay of the economy, providing livelihood for over 80% of the population.

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[1] *MWDR occupies a biggest share of 43,378 square kilometers or about 28.8% of the total land area while FWDR occupies the least with 19,539 square kilometers, which is about 13.3% of the total. The other three regions, WDR, EDR and CDR occupy almost the same area of about 29,000 square kilometers (CBS, 2006).*

Figure 2: Map of Nepal showing 75 Districts in the Old Administrative Structure

2.2. Energy Situation

2.2.1. Total Primary Energy Mix and Energy Consumption

The total primary energy supply (TPES) of the country in FY 2008/09 was about 402 million gigajoules (GJ). Biomass (i.e., fuelwood, agricultural residue and animal waste) and hydro power are the two significantly used indigenous energy resources in Nepal. Biomass accounted for 86.8% of the TPES of the country; of this, fuelwood accounted for a major share of 89.2%, followed by animal waste (6.6%) and agricultural residue (4.2%) (see Figure 3). The share of non-commercial sources of energy decreased from 91% in FY 1994/95, 88% in FY 2004/05 to 87% in FY 2008/09; accordingly, the share of commercial energy has increased from about 9% in FY 1995/96 to about 13% by FY 2008/09. Figure 4 shows the structure of energy consumption in Nepal by type of energy or fuel during FYs 2000/01-2008/09. As can be seen, the overall energy consumption of Nepal is largely dominated by biomass with its share being fairly constant at around 87% during the period. The total energy consumption of Nepal increased at a compound annual growth rate (CAGR) of about 2.2% during the period, while that of biomass and petroleum products increased at a CAGR of 2.3% and 0.7% respectively. A higher growth rate of 10.6% was observed in the use of renewable energy (i.e. biogas, micro-hydro and solar) during the period while the CAGR of coal consumption was 0.5%.

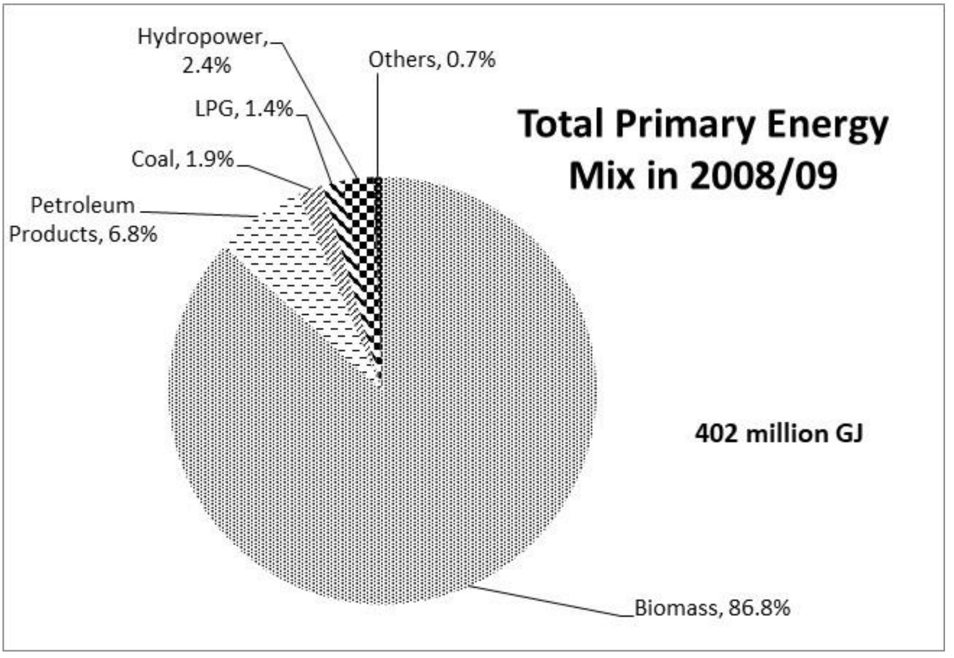


Figure 3: Total Primary Energy Mix in 2008/09

(Source: WECS (2010))

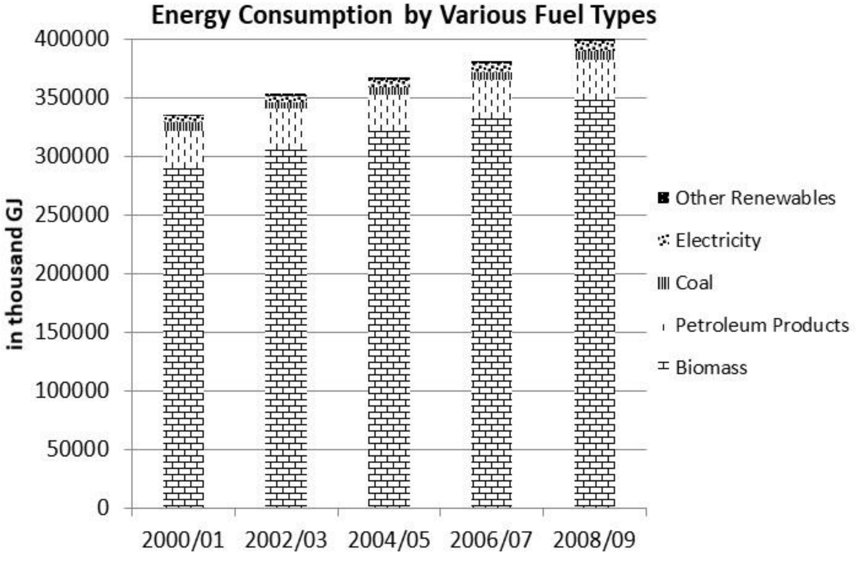


Figure 4: Energy Consumption by Various Fuel Types during FYs 2000/01-2008/09, thousand GJ

(Source: WECS (2010))

2.2.2. Sectoral Energy Consumption

Table 1: Sectoral Energy Consumption in 2008/09, thousand GJ

Energy Type	Agriculture	Commercial	Industrial	Residential	Transport
Biomass	0.0	1841.9	2071.4	344956.2	0.0
Petroleum Products	3472.7	426.6	475.3	2290.5	20645.8
LPG	0.0	2290.4	0.0	3201.4	210.8
Coal	0.0	0.0	7716.4	35.1	0.0
Electricity	173.7	563.3	3106.6	3534.3	19.3
Other Renewables	0.0	0.0	0.0	2734.7	0.0
Total	**3646.4**	**5122.2**	**13369.7**	**356752.2**	**20875.9**

Source: WECS (2010)

Sector wise energy consumption by fuel type for the FY 2008/09 is presented in Table 1. The residential sector was the largest energy consuming sector (the sector accounted for 89.2% in the total final energy consumption in FY 2008/09), followed by transport (5.2%), industrial (3.3%), commercial (1.3%) and agriculture (0.9%). The total consumption of fuelwood, animal waste and agricultural residue in FY 2008/09 was 311.2 million GJ, 23.0 million GJ and 14.6 million GJ respectively (WECS, 2010). More than 99% of the total fuelwood consumption in the country was consumed in the residential sector alone, followed by the industrial and the commercial sectors. Fuelwood is mainly used for cooking, heating and water boiling purposes. Animal waste as an energy resource is used only in the residential sector in the country and contributed to around 6% in the total energy consumption of the country. Animal wastes are mainly used in the Terai region of the country and are used in the gaseous form and also as dry cake. In FY 2008/09 around 4% of the total energy demand of the country was met by agricultural residues. Agricultural residues are mostly used in the residential and the industrial sectors.

Petroleum products (including LPG) accounted for a share of around 8.2% in the total primary energy mix of the FY 2008/09 making them the second largest energy source in the country. The transport sector is the largest user of the total petroleum products (with a share of around 63.2%), followed by residential (16.6%), agriculture (10.5%), commercial (8.2%) and industrial sectors (1.4%). Coal is used mainly in the industrial sector for heating and boiling purposes. Only a small percentage (of around 0.5%) of coal is used in the residential sector. Electricity contributed to a small share of 2% in the total primary energy supply of the country in FY 2008/09. The residential sector is the largest user of electricity (with a share of around 43.4%), followed by industrial (38.2%), commercial (6.9%), agriculture (2.1%) and transport (0.2%) sectors. Remaining 9.1% of electricity is consumed in other[2] sectors.

[2] *The "Other" sector includes street light, temples, mosques, church etc.*

3. Emissions from Energy Industries and Energy Using Sectors

This chapter deals with the estimation of emissions from fuel combustion in the energy industries such as power generation, production of heat, and extraction/processing of fossil fuels.

3.1. Energy Industry

The activities covered in this section include electricity generation and heat production, petroleum refining and manufacture of solid fuels and other energy industries. There are only two thermal power plants and no petroleum refineries in the country; however, due to increasing load-shedding there were numerous diesel based stand-alone power generation system in the country in FY 2008/09.

3.1.1. Overview

Emissions from grid connected power generation activities and diesel based stand-alone generator sets are covered under this sub-sector.

3.1.1.1. Grid Connected Power Generation Activities

The two thermal power plants in the country are located at Sunsari and Makawanpur districts. The total installed capacity of grid connected thermal power plants in the country is 53.41 MW, which comprises of 39.0 MW capacity located at Duhabi, Sunsari and 14.4 MW at Hetauda, Makawanpur. In FY 2008/09, the total electricity generated from these thermal power stations was 9.17 GWh (NEA, 2009).

3.1.1.2. Stand-alone Power Generation Activities

Nepal has been facing a severe shortage of power during the last several years as the total installed power generation capacity is significantly below the electricity demand. The annual peak demand of the Integrated Nepal Power System (INPS) in FY 2008/09 was 812.50 MW. The annual energy demand of Nepal totaled to 3,859 GWh in FY 2008/09, out of which only 3130.77 GWh was served while the rest 728.23 GWh had to be curtailed through load shedding (i.e., scheduled cuts in power supply) (NEA, 2009). Electricity generation from hydro resources contributed to 88.33% of the total power generation in FY 2008/09, while imported electricity accounted for 11.39% and rest 0.29% of electricity was served from thermal power plants. The deficit of almost 19% in electricity supply is the primary reason for load-shedding in the country (NEA, 2009). This caused massive increase in captive power generation through the use of diesel generators in order to cope with the increasing numbers of load-shedding hours in the country. The usage of diesel generators was significant mainly in the industrial and commercial sectors.

3.1.2. Emission Estimation Methodology

The emissions from power generation activities are calculated by using the emission inventory equation as proposed by EMEP/CORINAIR (see Equation 1). This method is generally used, when detailed data are not available. However, for the estimation of SO_2 emissions, which are likely to be more dependent on fuel quality, Equation 2 has been used.

The annual anthropogenic emissions from the power generation sector are estimated on the basis of annual rates of emission-related activities and respective emission factors as described in the general emission inventory equation given as:

$$Em_{j,m,k} = A_{m,k} \times EF_{j,m,k,l} \quad (1)$$

where,

$Em_{j,m,k}$ denotes emission of pollutant type j from the use of fuel type m in power plant type k; $A_{m,k}$ represents the activity level or use of fuel type m in power plant type k; and $EF_{j,m,k,l}$ is the emission factor specific to pollutant type j from the use of fuel type m, power plant type k, and abatement technology l (if any).

Emission factor (EF) values are compiled considering the varying fuel quality with respect to local ash and sulfur content as well as retention of ash and sulfur in boilers during combustion. EF of SO_2 emissions from the energy sector is estimated using the following relation:

$$EF_{SO2} = 2 \times CS_{fuel} \times (1-\alpha_s) \times \frac{1}{H_u} \times 10^6 \times (1-\eta_{cd}) \quad (2)$$

where,

EF_{SO2} denotes the specified emission factor for SO_2, CS_{fuel} represents sulfur content in fuel, α_s is sulfur retention in ash, H_u is the lower heating value of fuel, η_{cd} is the reduction efficiency of the control device.

3.1.3. Data on Activity Levels

The main activity data required for the estimation of emissions from the power generation sector includes annual energy input or fuel consumption of thermal power plants, size of the power plants in thermal capacity unit, installed abatement technologies in the plants, geographical location of thermal power plants for spatial distribution, continuous emission monitoring data of pollutants, flue gas flow rate and fuel related details (such as type, annual consumption, net calorific value, and sulphur content of fuel. The fuel consumption data has been estimated based on NEA (2009), WECS (2010) and IEA (2010). According to IEA (2010) around 125,604 GJ (i.e., approximately 3,000 tonnes) of petroleum products were consumed for generating power from grid connected thermal plants. The fuel quality details such as sulphur content of fuel and sulphur retention in ash are based on USEPA (1995) and Reddy and Venkataraman (2002).

The energy statistics published by the Water and Energy Commission Secretariat (WECS) and the Nepal Electricity Authority (NEA) do not provide data on the amount of electricity generated and fuel consumed by captive power generation sets in Nepal. However, a study conducted by the Sustainable Energy for All (SE4ALL) program, has assumed around 17% (i.e. about 6,900 terajoule (TJ)) of the total petroleum products to have been used by captive electricity generating sets in 2010 (NPC, 2013). Further, SE4ALL has estimated the total installed capacity of the captive generating sets in the country to be in the range of 600 MW in 2010, of which

300 MW is installed in the industry sector alone (NPC, 2013).

Diesel generators are the major type of captive power generators imported into Nepal. In FY 2009/10, diesel generators accounted for around 89% in the total generators imported in Nepal, while the corresponding figures in the FYs 2010/11 and 2011/12 were 75% and 77% respectively. Around 131,000, 50,000 and 18,000 units of diesel generator sets were imported in Nepal in the FYs 2009/10, 2010/11 and 2011/12 respectively (MoCS (2014)[3] and World Bank (2014)). A survey conducted on diesel generator sets in Kathmandu Valley showed that around 90% of the diesel generator sets were purchased during the period of 2007 to 2013 (World Bank, 2014). This shows that the use of diesel generators registered a sharp growth since 2006 due to the increasing power shortages in the country. The survey found that around 2.8% of the diesel generator sets were over 15 years old, which were mainly used in hospitals and industries for emergency backup. Figure 5 shows the distribution of diesel generator sets by their age/purchase year in the Kathmandu valley. According to the World Bank (2014), in FY 2012/13 the total installed captive power generation capacity of diesel generation sets in the Kathmandu valley was estimated to be around 200 MW and the total electricity generated from diesel generator sets was estimated to be 340 GWh. According to NPC (2013), in 2010, the total installed captive power generation capacity of diesel generation sets in Nepal was estimated to be around 600 MW.

In the absence of definitive data on the use of captive generator sets and petroleum products for electricity generation in Nepal in 2008, in this study the amount of petroleum products used for captive power generation in that year has been estimated based on the diesel consumption data given in WECS (2010) and WECS (2014). The diesel consumption data given in WECS (2010) is not disaggregated enough to provide information on diesel consumption for captive power generation. In this study, the amount of “diesel consumed for lighting and appliances use” in the commercial sector in 2008/09 as reported in WECS (2010) has been considered to be that used for captive power generation. As mentioned in WECS (2014), around 82% and 12% of diesel has been consumed for providing motive power and lighting services respectively in the industrial sector of Nepal in the FY 2011/12. Assuming the same share in the FY 2008/09, it has been estimated that around 227 TJ of diesel was utilized for captive power generation in the industrial sector of the country. Similarly, around 123 TJ of diesel has been considered to be consumed by the captive power generation in the commercial sector (WECS, 2010). Thus the total amount of diesel consumption for captive power generation in the FY 2008/09 has been estimated to be 350 TJ, which is equivalent to 9,217 kl of diesel.

[3] *http://www.tepc.gov.np/*

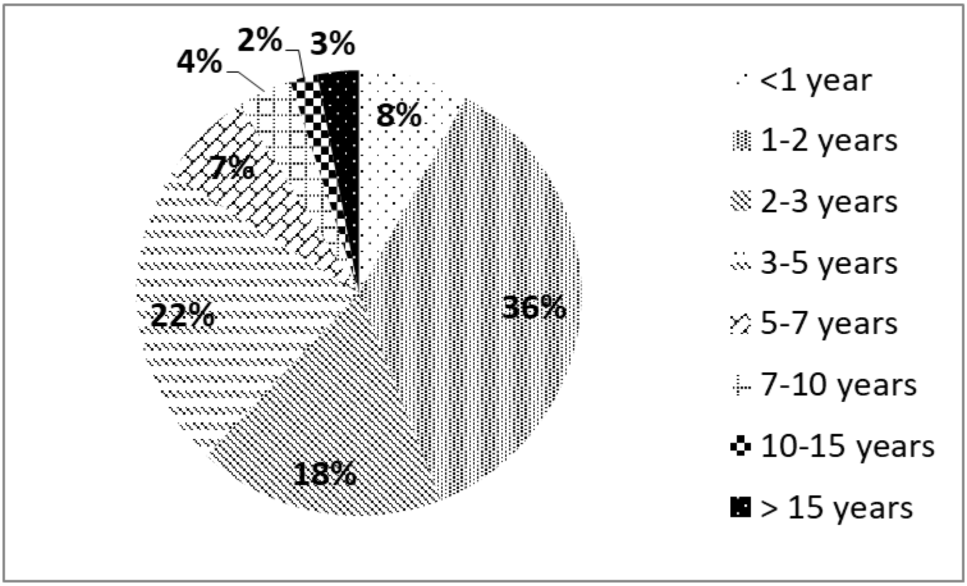


Figure 5: Distribution of Diesel Generator Sets by Age/Purchase Year in the Kathmandu Valley in FY 2012/13

(Source: World Bank (2014a))

3.1.4. Emission Factors

An emission factor (EF) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere from an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per tonne of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution (US EPA, 1995).

EFs are compiled from a wide range of sources. For energy combustion related emissions, uncontrolled EFs mostly are based on IPCC (1996), AP-42 of US EPA (1995) and several published papers. For BC and OC emissions, which are highly technology-based, some values are extracted from Bond et al., (2004). The EFs for SO_2 emission consider the varying fuel quality with respect to local ash and sulfur contents as well as retention of ash and sulfur in the combustion devices. Table 2 and Table 3 presents the emission factors used in this study for estimating emissions from the power generation and captive power generation sectors respectively.

Table 2: Emission Factors for the Power Generation Sector, kg/TJ

Air Pollutants	Emission factors (kg/TJ)	
	Gas/Diesel Oil	Heavy Fuel Oil
NO_X[a]	632	249
CO[b]	15	15
NMVOC[b]	5	5
PM_{10}*[c]	0.33	0.9
$PM_{2.5}$*[c]	0.24	0.66
NH_3	-	0.101
BC[d]	6.22, 5.7-8.3[e]	1.29, 6.2-8.9[e]
OC[d]	0.04, 6.2[f]	0.484, 6.7[f]
GHGs		
CO_2[b]	74,100	77,400
CH_4[b]	3	3

*Note: *in g/kg*

Source: [a]Kato and Akimoto (1992); [b]IPCC Guideline (1997 and 2006); [c]Reddy and Venkataraman (2002); [d]Bond et al. (2004); [e]Streets et al. (2001); [f]Streets et al. (2003)

Table 3: Emission Factors for Captive Power Generation

Air Pollutants	Emission factors (Kg/TJ)		
	For newer engines < 15 yrs old		For old engines >15 yrs
	<447 kW	>447 kW	Old engine of all size
CO	1127.8	888.9	0.0
NO_X - uncontrolled	5222.2	3888.9	0.0
NO_X - controlled	0.0	2194.4	0.0
PM_{10}	372.2	91.7	1250.0
SO_2	50.0	50.0	0.0
VOC	416.7	119.4	0.0
BC	223.3	55.0	500.0
OC	111.7	27.5	562.5
GHG			
CO_2	195555.6	195277.8	0.0

Source: World Bank (2014a) citing U.S. EPA (1996), Shah et al. (2007) and CPCB (2011)

Table 4: Annual Emissions from Grid Connected Power Generation in FY 2008/09, tonne

Air Pollutants	Emissions	
	Low emission case (tonne/year)	High emission case (tonne/year)
SO_2	17.2[a]	31.9[b]
NO_X	79.4[c]	79.4[c]
CO	1.9[d]	1.9[d]
NMVOC	0.6[d]	0.6[d]
NH_3	-	-
PM_{10}	1.0[e]	1.0[e]
$PM_{2.5}$	0.7[e]	0.7[e]
BC	0.7[f]	1.0[f]
OC	0.003[g]	0.8[h]
GHGs		
CH_4	0.4[c]	0.4[c]
CO_2	9307.3[d]	9307.3[d]
N_2O	0.1[d]	0.1[d]

Note: [a]with sulphur content of diesel oil taken as 0.54% (based on JICA (1997)); [b]with sulphur content of diesel oil taken as 1% (based on http://www.iocl.com/Products/LightDieseloil.aspx);

Sources: [c]Kato and Akimoto (1992); [d]IPCC (1997 and 2006); [e]Reddy and Venkataraman (2002); [f]Streets et al. (2001); [g]Bond et al. (2004); [h]Streets et al. (2003)

3.1.5. Estimated Emissions

The emissions from the grid connected power generation sector in FY 2008/09 are presented in Table 4 for two different cases (i.e., Low and High Emission Cases): The "Low emission case" here represents the emissions considering the lower range values of the emission factors, while"High emission case" represents the emissions considering the higher range values of the emission factors. It is estimated that there were around 9307 tonnes of CO_2 emissions from the power generation sector in FY 2008/09. The SO_2 emissions from the power sector are estimated to be around 17.2 tonnes under the low emission case and 31.9 tonnes under the high emission case.

Around 79.4 tonnes of NO_X are estimated to be emitted from grid connected thermal power generation in Nepal in both the cases. BC emissions from this sector are estimated to lie within the range of 0.7 tonnes to 1.0 tonnes, while OC emissions are estimated to be in the range of 0.003 tonne to 0.8 tonne under low and high emission cases.

Table 5 shows the estimated emissions from captive power generation in Nepal.

Table 5: Annual Emissions from Captive Power Generation in FY 2008/09, tonne

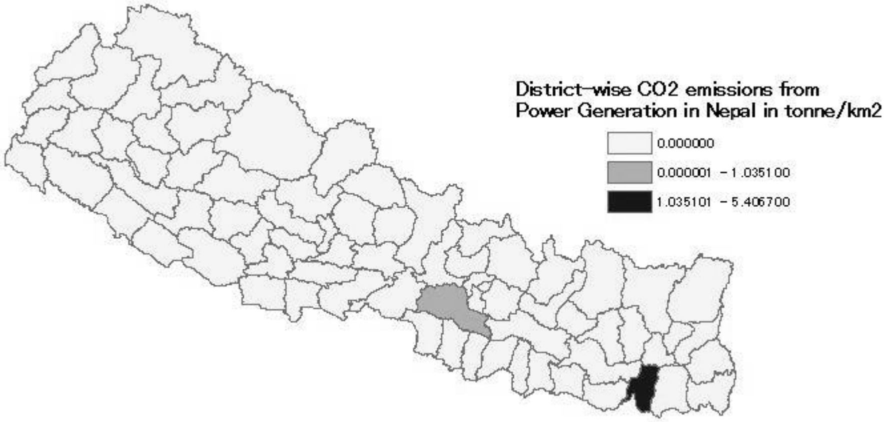
Air Pollutants	Emissions
NO_X	1825.8
CO	394.3
NMVOC	145.7
PM_{10}	130.1
BC	78.1
OC	39.1
GHG	
CO_2	68368.9

3.1.6. Temporal and Spatial Variations

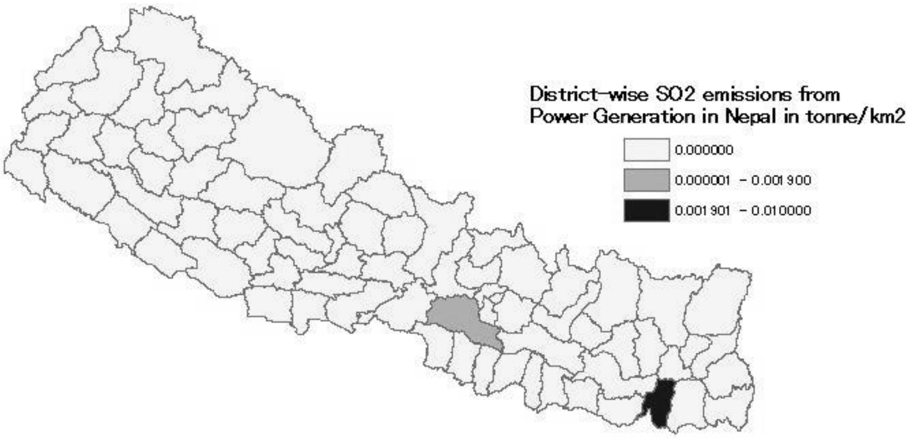
Under low emission case, around 12.6 and 4.6 tonne of SO_2 emissions are estimated to be generated from the thermal power plants located at Duhabi in Sunsari and Hetauda in Makwanpur respectively. The Duhabi power plant has been estimated to account for 73% of the total SO_2 emissions from thermal power plants while the Hetauda power plant accounts for the remaining 27%. Table 6 presents the distribution of total emissions by pollutant type among the Sunsari and Makwanpur district. Figure 6 shows the spatial variation of total CO_2 and SO_2 emissions from the power generation sector in Nepal. The spatial variations of all other emissions by pollutant type (i.e. NO_X, CO, NMVOC, CH_4, N_2O, BC and OC) from the power generation sector are presented in Annex 3.

Table 6: District-wise Annual Emissions from Power Generation in FY 2008/09, tonne

District	Annual Emissions								
	Air Pollutants						GHGs		
	SO_2	NO_X	CO	NMVOC	BC	OC	CH_4	CO_2	N_2O
Sunsari	12.57	57.96	1.37	0.46	0.53	0.002	0.28	6796.16	0.06
Makwanpur	4.65	21.42	0.51	0.17	0.19	0.001	0.10	2511.10	0.02



a) CO_2 Emission Density



b) SO_2 Emission Density

Figure 6: Spatial Variation of CO_2 and SO_2 Emission Densities from the Power Generation Sector in FY 2008/09

3.2. Manufacturing and Construction

3.2.1. Overview

The manufacturing (industrial) sector[4] in Nepal has been divided into two categories, i.e. modern and traditional industries. The Census of Manufacturing Establishments (CME 2006/07) as well as the Survey of Small Manufacturing Establishments (SSME 2008/09) does not differentiate modern industries from the traditional ones. Therefore, the classification of industries into small and large establishments is considered more appropriate than as modern and traditional industries. From the perspective of energy use, the industrial sector has been disaggregated into the following eight sub-sectors, (i) food, beverage and tobacco; (ii) textiles, wearing apparels and leather; (iii) wood and wood products; (iv) paper and paper products, printing and publishing; (v) chemicals, rubber and plastic products; (vi) non-metallic mineral products; (vii) iron and steel; and (viii) other manufacturing.

According to Department of Industry (DOI), there are altogether 4,552 industries[5] registered in Nepal (DOI, 2011), while as of FY 2008/09, there were altogether 3,958 industries (including large, medium and small) registered, of which 1,977 are manufacturing based while the remaining 1,981 are agro, construction, energy, minerals, tourism and service based industries (DOI, 2009). Among the 3,958 registered industries, 348 are categorized as large industries, 988 as medium industries and 2,622 as small-scale industries. As of FY 2008/09, altogether 32,326 small manufacturing establishments (SMEs) were under operation in the country (CBS, 2009c). Of the total SMEs, around 14,456 were operating in the CDR, 8,701 in the EDR, 5,074 in the WDR, 2,677 in the MWDR, and 1,418 in the FWDR. The distribution of manufacturing establishments across the districts is highly uneven. About 48.2% of the total industrial establishments in the country were located in nine districts (i.e., Kathmandu, Morang, Jhapa, Lalitpur, Sunsari, Parsa, Rupandehi, Chitwan and Rautahat); while the rest 66 districts together housed only 51.8% of the total industrial enterprises (CBS, 2009c).

The manufacturing sector is relatively small in Nepal and accounted for 6.8% of the national GDP in 2008/09. The sector's share in the national GDP was decreasing from 7.3% in 2007/08 to 6.5% in FY 2010/11 (MOF, 2011b). Coal, electricity and fuelwood are the three dominant fuels used in this sector. The demand for energy in the industry sector was increasing; it increased from 12.76 TJ in FY 2004/05 to 13.37 TJ in FY 2008/09.

The total fuel consumed by the industry sector in FY 2008/09 was 13.4 million GJ i.e. a share of about 3.3% in the total national energy consumption. The main end uses of energy in the industry sector are motive power, process heating, boiling and lighting. Figure 7 shows the structure of the industry sector energy consumption by fuel type in FY 2008/09. Coal is the major source of energy in the industrial sector; it is mainly used for heating purpose in boiler and kilns. Biomass resources such as agricultural residues and fuelwood, account for more than 15% of the industrial energy consumption and are used for heating and are sometimes used along with coal.

[4] *The term "industry sector" hereafter basically refers to the manufacturing sector.*

[5] *An "industry" here means a production entity or establishment.*

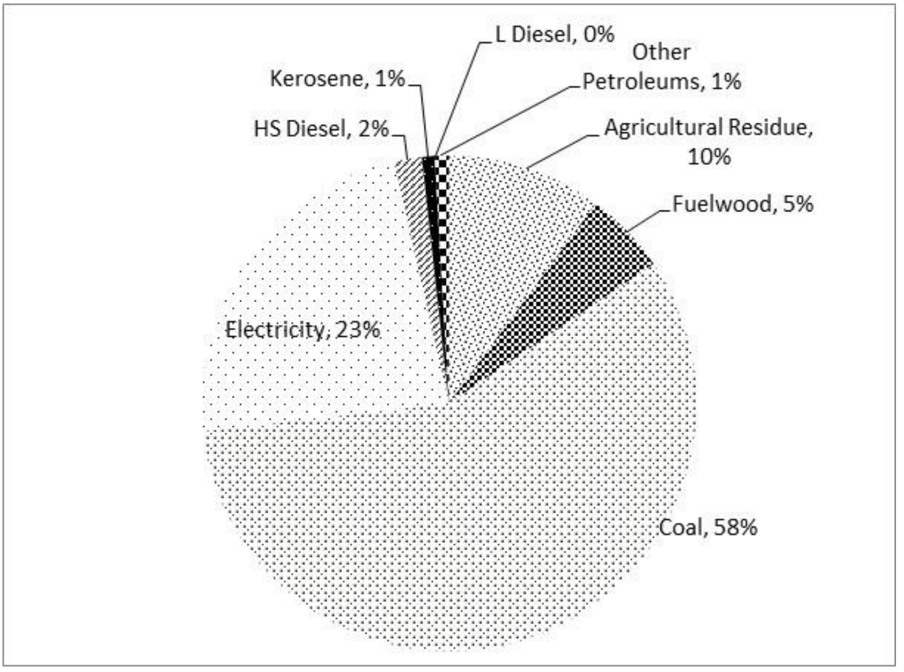


Figure 7: Industrial Energy Consumption by Fuel type in FY 2008/09, %

Note: HS Diesel = High Speed Diesel; L Diesel = Light Diesel

(Source: WECS (2010))

Brick manufacturing falls under the small/cottage industry category despite the large investment in this industry (GEFONT, 2007). With the expansion of urban area, brick industry is also growing; however, the brick production operation is mostly seasonal. Brick kilns generally operate in winter and dry season, when the air pollution is also at its peak. Construction works in urban areas are increasing at a fast pace due to migration of people from rural to urban areas, where concrete and bricks are mainly used in buildings. Brick kilns in Nepal are basically situated in interiors of sub-urban areas close to urban areas. There were more than 500 brick factories in Nepal in 2007 (GEFONT, 2007). It is estimated that about 4 billion bricks were produced in Nepal in 2007 and the demand for building materials was growing at the rate of about 11% per year[6]. In 2009, Nepal produced around 4.8 billion bricks. According to the Census of Manufacturing Establishments FY 2006/07, around 436 brick kilns were registered in Nepal with the total production capacity of 872 million bricks (CBS, 2008b). According to "All Nepal Brick Kiln Entrepreneurs Association", about 700 brick kilns existed in Nepal with the estimated total annual production capacity of about 1,423 million bricks. As already stated, coal and fuelwood are the two major fuels used in the brick industries.

[6] *www.swiss-cooperation.admin.ch/**nepal**/en/Home/.../resource_en_162523.pdf*

Three different types of brick kilns exist in Nepal, namely, single chimney, double chimney and no chimney brick kilns. In technical terms, four major types of brick kilns exist in Nepal. They include (i) Clamp; (ii) Moving Chimney Brick Kiln Technology (MCBKT); (iii) Fixed Chimney Brick Kiln Technology (FCBTK); and (iv) Vertical Shaft Brick Kiln (VSBK). Of the total 700 brick kilns in Nepal, there were 42 of Clamp type, 399 of MCBKT type, 233 of FCBTK type and 26 of VSBK type (Amatya, 2012). There were 120 brick kilns within Kathmandu valley. Almost all brick kilns in the Kathmandu valley are with single permanent chimneys, whereas in the Terai districts there are both temporary and permanent chimney types of brick kilns.[7] Around 80,000 tonnes of coal were consumed annually by the brick kilns in the Kathmandu valley. These brick kilns are estimated to emit around 200,000 tonnes of CO_2 emissions annually in the valley (Amatya, 2012). Information on brick kiln emissions are, however, quite limited and do not yet include BC/OC measurements (Chaisson, 2008). Brick making in Nepal is still dominated by the Bull's Trench Kiln (BTK) type moving chimney brick kiln technology.

One of the main problems associated with the moving chimney BTK is the excessive local pollution as well as their high greenhouse gas emissions. As government has banned the use of MCBTK in the Kathmandu valley, brick entrepreneurs are making their shift towards Fixed Chimney BTK that emit less air pollutants compared to the MCBTKs but still use almost the same excessive amount of coal per brick. In May 2002, the Government of Nepal announced the discontinuation of production licenses for Bull's trench kilns (BTK) with movable chimneys. This decision along with environmental concerns from neighboring communities has placed brick makers under strong pressure to find a viable alternative to the BTK[8]. Although Vertical Shaft Brick Kiln technology is common in many countries, it was introduced in Nepal in the year 2003. Even being an efficient technology, this technology has not yet been used widely due to its high initial investment and lower returns compared to BTK.

3.2.2. Emission Estimation Methodology

Following EMEP/CORINAIR (2006 and 2007), the annual anthropogenic emissions from the manufacturing and the construction sector are estimated as annual rates of emission-related activities multiplied by respective emission factors as described in the general emission inventory equation given as:

$$Em_{j,m,k} = A_{m,k} \times EF_{j,m,k,l} \quad (3)$$

where,

$Em_{j,m,k}$ denotes the amount of emissions of pollutant type j from fuel type m and manufacturing industry type k; $A_{m,k}$ is the activity level in terms of fuel type m used in the manufacturing industry type k; and $EF_{j,m,k,l}$ is the emission factor specific to pollutant type j, fuel type m, manufacturing industry type k, and abatement technology l, if any. This method is generally used when detailed data are not available.

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[7] *In temporary chimney type of brick kilns, there are two medium height chimneys, whose location is changed as per the fire work sites. Brick kilns with permanent chimneys are generally large in size and chimneys are fixed in one place.*

[8] http://cleanairinitiative.org/portal/node/1531

For the calculations of SO_2 emissions which are likely to be more dependent on fuel quality, Equation 4 has been used. Emission factor (EF) values are compiled considering varying fuel quality with respect to local ash and sulfur content as well as retention of ash and sulfur in boilers during combustion. EF for SO_2 emissions from the energy sector is estimated using the following relation:

$$EF_{SO2} = 2 \times CS_{fuel} \times (1-\alpha_s) \times \frac{1}{H_u} \times 10^6 \times (1-\eta_{cd}) \quad (4)$$

where,

EF_{SO2} is the emission factor for SO_2, CS_{fuel} represents sulfur content in fuel, α_s denotes sulfur retention in ash, H_u is the lower heating value of fuel, and η_{cd} is the reduction efficiency of the control device.

3.2.3. Data on Activity Levels

Manufacturing industries covered in the present emission inventory are: iron and steel, non-ferrous metal, non-metallic, chemicals, pulp and paper, food, beverages and tobacco, textiles and others. Other industries include leather, rubber, glass and glass products, furniture, footwears, jute, carpets and rugs and other manufacturing industries and are covered under others sector. Due to unavailability of necessary data, the construction sector could not be covered for emission estimation. The main activity data used for emission estimation is fuel consumption by each category of manufacturing industry. They are based on various sources such as WECS (1997, 1998 and 2010), DOI (2009) and CBS (2008b and 2009b). The fuel consumption data for sub-sectors are presented in Table 7. The sub-sectoral fuel consumption data presented in the table are estimated based on the fuel shares of modern and traditional industries given in the "Study for industrial energy survey report" (WECS, 1998). The high-speed diesel consumption data shown in the table includes the diesel consumption in captive power generation as well. As the emissions produced from diesel used in captive power generation in the manufacturing industries have already been covered in section 3.1, the emission estimation of such activity is excluded in this chapter in order to avoid double counting. It has been estimated that out of the total diesel consumption (shown in Table 7) in manufacturing industries like non-ferrous metals, pulp and paper, food, beverages and tobacco, textiles and other manufacturing industries around 0.9, 2.5, 8.4, 0.1 and 2.6 TJ of diesel has been assumed to be consumed for boiler applications and other industrial activities respectively.

3.2.4. Emission Factors

In order to estimate emissions from the manufacturing industries, EFs of trace gases and GHGs are mainly based on IPCC (1997) and AP-42 USEPA (1995). To the extent available, Asia specific values are taken from Kato and Akimoto (1992) and Streets et al., (2001). EFs of BC and OC are based on Reddy and Venkataraman (2002). Emission factor for SO_2 is calculated based on fuel quality. Table 8 presents the emission factors considered in this study for estimating emissions from the manufacturing industries.

3.2.5. Estimated Emissions

Total emissions of air pollutants and GHGs from fuel combustion in manufacturing industries in FY 2008/09 are presented for the Low and High Emission Cases in Table 9 and 10 respectively; these are estimated using low and high values of emission factors respectively.

Around 1017 thousand tonnes of CO_2 emissions are estimated to be emitted from the industrial sector during the year 2008/09 under the low emission factor case. About 20.0% of the CO_2 emissions are produced from the other manufacturing industries like carpets and rugs, jute manufactures, leather and leather products, footwear manufacturing, saw mills and other wooden products, furnitures/fixtures, rubber, plastic products, glass and glass products, electric appliance, and jewelry and related articulates industries.

Food, beverage and tobacco industries occupied a share of about 33.0% in the total CO_2 emissions from the industrial sector, followed by brick (19.4%), pulp and paper (12.2%), textiles (5.5%), non-metallic mineral (4.4%), chemicals (4.0%), non-ferrous metals (1.4%) and iron and steel (0.07%).

About 68.9% of PM_{10} and 57.5% of $PM_{2.5}$ were emitted from the pulp and paper industry. Brick industries emitted 0.02% of PM_{10}, 0.01% of $PM_{2.5}$ and 24.1% of BC. Of the total BC emissions from the industrial sector, other manufacturing industries accounted for 23.1%, whereas the food, beverages and tobacco industries accounted for 37.4%.

As can be seen in Tables 9 and 10, the estimated emissions vary widely with the values of the emission factors considered. With different values of sulfur contents of the fuels considered (see the footnotes in Tables 9 and 10), the SO_2 emissions from the iron and steel industries are found to be in the range of 5.2 tonnes to 12.3 tonnes under the Low and High cases respectively.

Table 7: Fuel Consumption in the Manufacturing Industries in FY 2008/09, TJ

Fuel Types	Fuel Consumption								
	Iron and steel	Non-ferrous metal	Non-metallic (mineral)	Chemicals	Pulp and paper	Brick	Food, Beverage and Tobacco	Textiles	Others
Fuelwood	0.0	3.6	301.4	284.2	0.0	NA	125.9	4.8	1.1
Agricultural Residue	0.0	2.7	40.0	8.7	1225.8	NA	53.7	17.6	1.8
Coal	7.4	131.8	78.4	87.9	0.0	2081.0	3251.5	568.0	1510.4
Kerosene	0.0	3.1	0.0	0.0	1.5	0.0	34.7	0.0	70.2
HS Diesel	0.0	14.6	0.0	0.0	41.7	0.0	140.2	1.0	43.5
L Diesel	0.0	0.01	0.0	0.0	0.03	0.0	0.1	0.0	0.04
Other Petroleums	0.0	7.4	0.0	0.0	21.3	0.0	71.6	0.5	22.2
Electricity	227.4	78.1	27.5	20.8	252.4	0.0	1475.2	636.5	388.7
Total	**237.5**	**290.1**	**476.4**	**434.0**	**1542.6**	**2081.0**	**6353.7**	**1438.0**	**2595.7**

Note: NA = Not Available

Source: Estimated based on WECS (1998 and 2010); Amatya (2012)

Table 8: Emission Factors for Fuel Combustion in Manufacturing, kg/TJ

Air Pollutants	Emission factors					
	Coal	L. Diesel	Kerosene	HS Diesel	Fuelwood	Agricultural Residue
NO_X[a]	300	222[b]	167[b]	222[b]	100	100
CO[a]	150	15	15	15	2000	4000
NMVOC[a]	20	5	5	5	50	50
PM_{10}	438[d], 51.8-167.3[c,i]	3.3	10.8, 3.3, 20	3.3	666-146	666-146
$PM_{2.5}$	7.8-55.2[c,i], 54.2[e], 131.5-26.3[d], 486[h]	0.83, 4.37	1.9, 10, 0.82	0.83, 4.37	240, 566-126, 12, 120	240, 566-126, 12, 120
NH_3[j]	-	0.007	-	0.007	-	-
BC[c]	0.37[e], 1.3-0.13[d], 73, 3.7[g], 45.9-0.76	3.9	0.06, 5.5, 0.67-3.12	3.9, 1.84-9	60[d], 56.6-6.3, 1.2, 9.6, 36.6	60, 56.6-6.3, 1.2, 9.6, 0.86
OC[c]	0.16[e], 404, 1.2[g], 34.45, 2.14	0	1.7, 0.67, 0.89	32.3	340-25.2, 1.2[f], 14.4[f], 213	340-25.2, 1.2[f], 14.4[f], 0.13
GHGs						
CO_2[a]	96100, 94600	74100	71900	74100	112000	100000
CH_4[a]	10	3	3	3	30	30
N_2O[a]	1.5	0.6	0.6	0.6	4	4

Source: [a]IPCC (2006); [b]Kato and Akimoto (1992); [c]Bond et al. (2004); [d]Streets et al. (2001); [e]Reddy and Venkataraman (2002); [f]Kupiainen and Klimont (2007); [g]Ge et al. (2001); [h]values are applicable for brick kiln industry; [i]Values are converted from g/kg to kg/t by using net calorific values for each type of fuel; [j]EMEP/CORINAIR (2002)

Table 9: Annual Emissions of Air Pollutants and GHGs from the Manufacturing Sector in FY 2008/09 in Low Case, tonne

Air Pollutants	Emissions of air pollutants and GHGs from manufacturing sectors (tonnes/year)								
	Iron and steel	Non-ferrous metal	Non-metallic (mineral)	Chemicals	Pulp and paper	Brick	Food, Beverage and Tobacco	Textiles	Others
SO_2[a]	5.2	93.0	67.3	71.9	57.8	1459.2	2280.8	398.3	1466.6
NO_x[b]	2.2	42.0	57.7	55.7	126.5	6.2	1011.4	172.7	636.3
CO[b]	1.1	38.2	774.7	616.3	4903.4	3.1	956	165.2	321.0
NMVOC[b]	0.1	3.0	18.6	16.4	61.4	0.4	74.6	12.5	42.0
NH_3[e]	0.0	0.002	0.001	0.001	0.01	0.02	0.04	0.01	0.03
BC[c]	1.1	6.2	14.7	14.4	1.1	99.4	154.1	26.3	95.2
OC[c]	0.01	5.3	67.0	63.7	0.2	74.6	139.0	20.6	71.5
PM_{10}[d]	15.3	312.0	3105.8	14.8	14248.5	3.5	2269.3	342.1	379
$PM_{2.5}$[d]	16.3	14.7	2674.5	4244.6	12296.6	1.5	1718.8	253.4	174.6
GHGs									
CO_2[b]	700.0	13984.1	45178.4	41017.4	124430.0	196863.3	335426.1	56071.5	202849.2
CH_4[b]	0.1	1.5	11.0	9.7	36.8	20.8	38.2	6.4	21.1
N_2O[b]	0.01	0.2	1.5	1.3	4.9	3.1	5.7	0.9	3.2

Note: [a]Sulfur content of coal, kerosene, diesel oil, fuelwood and agricultural residue considered to be 1.27%, 0.09%, 0.54%, 0.04% and 0.04% respectively

Source: [b]EFs based on IPCC (2006), [c]EFs based on Ge et al. (2001); [d]EFs based on Bond et al. (2004); [e]EMEP/CORINAIR (2002); [f]EFs based on Streets et al. (2001); [g]EFs based on Reddy and Venkataraman (2002)

Table 10: Annual Emissions of Air Pollutants and GHGs from the Manufacturing Sector in FY 2008/09 in High Case, tonne

Air Pollutants	Emissions of air pollutants and GHGs from industries (tonne/year)								
	Iron and steel	Non-ferrous metal	Non-metallic (mineral)	Chemicals	Pulp and paper	Brick	Food, Beverage and Tobacco	Textiles	Others
SO_2[a]	12.3	219.2	142.2	155.9	58.4	3447.0	5386.6	940.8	3452.6
NO_x	2.2	42.0	57.7	55.6	126.5	6.2	1011.5	1.7	505.4
CO[b]	1.1	38.2	774.7	616.3	4903.4	3.1	956.1	0.9	785.6
NMVOC[b]	0.1	3.0	18.6	16.4	61.4	0.4	74.6	0.1	41.5
NH_3[e]	0.0	0.002	0.001	0.001	0.0	0.02	0.04	0.01	0.03
BC[c]	0.4	0.2	11.1	10.5	1.1	0.0	0.0	0.0	6.1
OC[c]	0.001	1.1	64.5	60.8	0.2	0.0	0.0	0.0	31.5
PM_{10}[d]	49.3	561.5	3254.3	181.2	14248.5	3.5	5.5	1.0	5113.5
$PM_{2.5}$[d]	2.3	46.2	2693.3	4265.6	12296.6	1.5	2.3	0.4	2194.0
GHGs									
CO_2[b]	700.0	13984.1	45180.9	41012.7	124430.0	196863.3	333918.7	53739.8	179602.6
CH_4[b]	0.1	1.5	11.0	9.7	36.8	20.8	38.2	5.7	21.9
N_2O[b]	0.01	0.2	1.5	1.3	4.9	3.1	5.7	0.9	3.2

Note: [a]Sulfur content of coal, kerosene, diesel oil, fuelwood and agricultural residue is considered to be 3%, 0.16%, 0.25%, 0.04% and 0.04% respectively.

Source: [b]EFs based on IPCC (2006), [c]EFs based on Ge et al. (2001); [d]EFs based on Bond et al. (2004); [e]EMEP/CORINAIR (2002); [f]EFs based on Streets et al. (2001); [g]EFs based on Reddy and Venkataraman (2002)

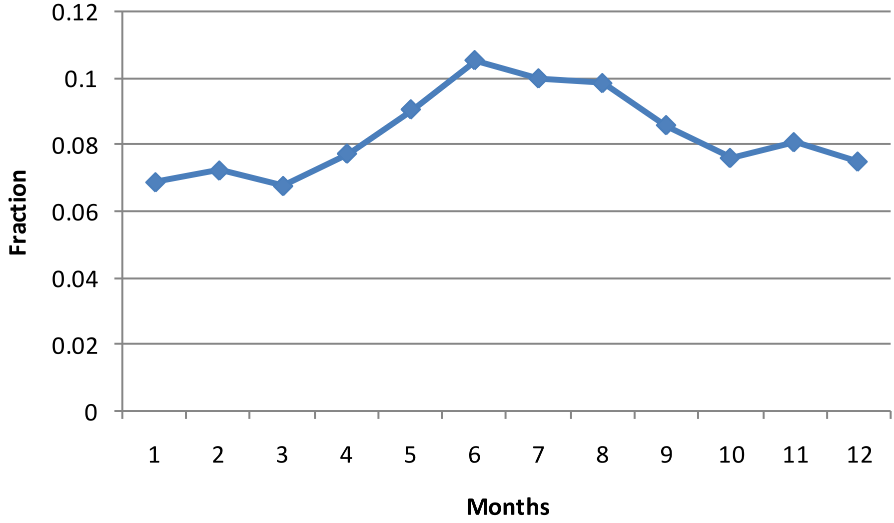

Figure 8: Temporal Variation Pattern of Emissions from Industrial Sector in FY 2008/09

3.2.6. Temporal and Spatial Variations

The disaggregation of monthly emissions can be ideally done by using monthly fuel consumption or the production data. However, in the absence of monthly fuel consumption and production data, monthly industrial electricity consumption data have been used as a proxy to estimate the monthly pattern of all the industrial emissions except that for brick industries. Figure 8 shows the monthly variation of emissions from the industrial sector in FY 2008/09 using the monthly industrial electricity pattern. The monthly industrial electricity sales data were obtained from the Nepal Electricity Authority (NEA)[9]. Figure 8 shows that there were increasing monthly emissions during the months of April to June and a decreasing emission thereafter. For spatial variation of emissions, the industrial value addition according to district has been considered. Since the district wise industrial value added was not available for FY 2008/09, the value addition for this year has been estimated using the shares of district in total GDP in FY 2008/09 to be the same as that in the FY 2006/07. The district-wise value addition information in the FY 2006/07 has been considered from the Census of Manufacturing Establishments 2006/07 (CBS, 2008b). Table 11 shows the district-wise emissions by pollutant type from the industrial sector under the Low Case.

Figure 9 shows the spatial variations of SO_2 and CO_2 emissions from the industrial sector in FY 2008/09 for the "Low Case" while the spatial variations for other pollutant types are presented in Annex 4. Among the districts, the Bara district is estimated to have the highest share (25.57%) in the total industrial sector emissions of the country in FY 2008/09; it is followed by Nawalparasi (9.63%), Kathmandu (9.56%), Morang (8.44%), Dhanusa (8.17%), Parsa (7.38%), Makawanpur (6.06%) and Sunsari (5.25%) districts. The remaining 19.9% of the total industrial sector emissions are estimated to come from rest of the districts.

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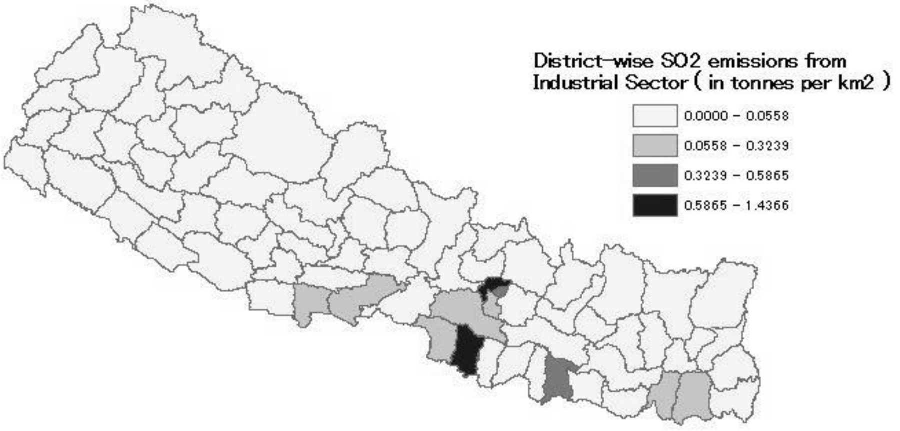
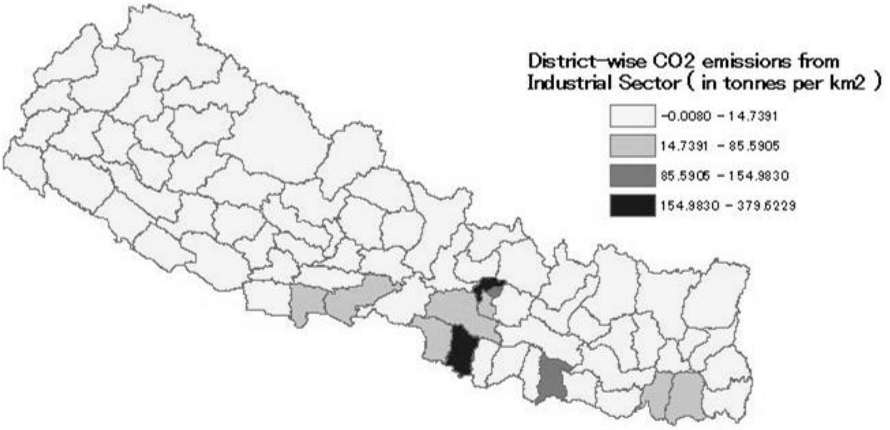
[9] The monthly industrial sector electricity consumption data for the year 2008/09 was obtained from the "Distribution and Consumer Service" Department of Nepal Electricity Authority.



a) SO_2 Emission Density



b) CO_2 Emission Density

Figure 9: District-wise Densities of SO_2 and CO_2 Emission Densities from Industrial Sector in FY 2008/09

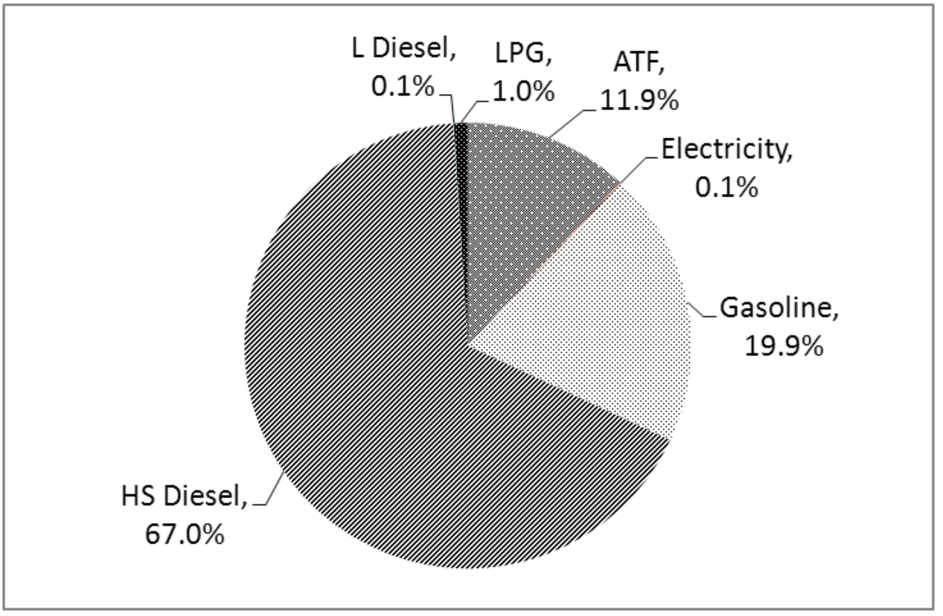
Table 11: Estimated District-wise of Annual Emissions Air Pollutants and GHGs from the Industrial Sector, tonne/year

Districts	Air Pollutants									GHGs		
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Sankhuwasabha	0.64	0.23	0.85	0.02	0.00	2.25	2.33	0.04	0.05	0.02	110.72	0.00
Solukhumbu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Taplejung	0.65	0.23	0.85	0.03	0.00	2.27	2.34	0.05	0.05	0.02	111.34	0.00
Bhojpur	0.28	0.10	0.37	0.01	0.00	0.98	1.01	0.02	0.02	0.01	48.11	0.00
Dhankuta	2.92	1.05	3.85	0.11	0.00	10.25	10.59	0.20	0.22	0.07	503.38	0.01
Ilam	5.81	2.08	7.66	0.23	0.00	20.36	21.06	0.41	0.43	0.14	1000.50	0.02
Khotang	0.31	0.11	0.41	0.01	0.00	1.10	1.14	0.02	0.02	0.01	54.08	0.00
Okhaldhunga	0.54	0.19	0.71	0.02	0.00	1.88	1.95	0.04	0.04	0.01	92.55	0.00
Panchthar	1.08	0.39	1.43	0.04	0.00	3.80	3.93	0.08	0.08	0.03	186.75	0.00
Terhathum	1.16	0.41	1.53	0.04	0.00	4.06	4.20	0.08	0.09	0.03	199.35	0.00
Udaypur	76.32	27.30	100.63	2.96	0.00	267.65	276.77	5.34	5.72	1.88	13149.70	0.27
Jhapa	89.06	31.86	117.42	3.46	0.00	312.32	322.96	6.23	6.67	2.20	15344.38	0.31
Morang	497.75	178.07	656.26	19.32	0.01	1745.50	1804.95	34.80	37.28	12.28	85757.04	1.76
Saptari	20.60	7.37	27.16	0.80	0.00	72.25	74.71	1.44	1.54	0.51	3549.42	0.07
Siraha	13.47	4.82	17.76	0.52	0.00	47.25	48.85	0.94	1.01	0.33	2321.17	0.05
Sunsari	310.00	110.90	408.72	12.03	0.01	1087.10	1124.12	21.67	23.22	7.65	53409.42	1.09
Dolakha	0.93	0.33	1.23	0.04	0.00	3.27	3.38	0.07	0.07	0.02	160.42	0.00
Rasuwa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sindhupalchowk	2.86	1.02	3.77	0.11	0.00	10.03	10.37	0.20	0.21	0.07	492.86	0.01
Bhaktapur	69.39	24.82	91.49	2.69	0.00	243.34	251.63	4.85	5.20	1.71	11955.37	0.24
Dhading	6.97	2.49	9.18	0.27	0.00	24.43	25.26	0.49	0.52	0.17	1200.20	0.02
Kathmandu	564.19	201.83	743.86	21.90	0.01	1978.49	2045.87	39.44	42.26	13.92	97203.50	1.99
Kavre	32.07	11.47	42.28	1.24	0.00	112.45	116.28	2.24	2.40	0.79	5524.81	0.11
Lalitpur	120.69	43.18	159.12	4.68	0.00	423.23	437.64	8.44	9.04	2.98	20793.26	0.43

Makawanpur	357.71	127.97	471.63	13.88	0.01	1254.42	1297.14	25.01	26.79	8.83	61629.93	1.26
Nuwakot	0.55	0.20	0.72	0.02	0.00	1.92	1.98	0.04	0.04	0.01	94.23	0.00
Ramechhap	0.93	0.33	1.22	0.04	0.00	3.25	3.36	0.06	0.07	0.02	159.67	0.00
Sindhuli	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bara	1508.53	539.66	1988.92	58.55	0.03	5290.06	5470.24	105.47	112.99	37.23	259902.23	5.32
Chitwan	76.17	27.25	100.43	2.96	0.00	267.11	276.21	5.33	5.71	1.88	13123.31	0.27
Dhanusa	482.24	172.52	635.81	18.72	0.01	1691.10	1748.69	33.72	36.12	11.90	83083.98	1.70
Mahaottari	31.61	11.31	41.67	1.23	0.00	110.83	114.61	2.21	2.37	0.78	5445.21	0.11
Parsa	435.71	155.87	574.46	16.91	0.01	1527.94	1579.98	30.46	32.63	10.75	75068.15	1.54
Rautahat	14.43	5.16	19.03	0.56	0.00	50.62	52.34	1.01	1.08	0.36	2486.78	0.05
Sarlahi	27.57	9.86	36.35	1.07	0.00	96.67	99.97	1.93	2.06	0.68	4749.55	0.10
Manang	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mustang	0.55	0.20	0.73	0.02	0.00	1.93	2.00	0.04	0.04	0.01	94.83	0.00
Argakhanchi	0.64	0.23	0.84	0.02	0.00	2.25	2.32	0.04	0.05	0.02	110.30	0.00
Baglung	0.67	0.24	0.88	0.03	0.00	2.35	2.43	0.05	0.05	0.02	115.31	0.00
Gorkha	13.90	4.97	18.33	0.54	0.00	48.75	50.41	0.97	1.04	0.34	2395.17	0.05
Gulmi	1.41	0.50	1.86	0.05	0.00	4.95	5.11	0.10	0.11	0.03	242.97	0.00
Kaski	71.40	25.54	94.13	2.77	0.00	250.37	258.90	4.99	5.35	1.76	12300.81	0.25
Lamjung	0.50	0.18	0.66	0.02	0.00	1.76	1.82	0.04	0.04	0.01	86.35	0.00
Myagdi	1.12	0.40	1.47	0.04	0.00	3.92	4.05	0.08	0.08	0.03	192.63	0.00
Palpa	3.97	1.42	5.23	0.15	0.00	13.91	14.38	0.28	0.30	0.10	683.31	0.01
Parbat	1.15	0.41	1.52	0.04	0.00	4.04	4.18	0.08	0.09	0.03	198.58	0.00
Syangja	1.30	0.47	1.72	0.05	0.00	4.56	4.72	0.09	0.10	0.03	224.22	0.00
Tanahu	6.95	2.49	9.17	0.27	0.00	24.38	25.22	0.49	0.52	0.17	1198.02	0.02
Kapilbastu	77.19	27.61	101.77	3.00	0.00	270.68	279.90	5.40	5.78	1.90	13298.51	0.27
Nawalparasi	568.36	203.32	749.35	22.06	0.01	1993.10	2060.98	39.74	42.57	14.03	97921.41	2.00
Rupandehi	252.23	90.23	332.55	9.79	0.00	884.50	914.63	17.63	18.89	6.22	43455.92	0.89

Dolpa	-0.02	-0.01	-0.03	0.00	0.00	-0.09	-0.09	0.00	0.00	0.00	-4.29	0.00
Humla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jumla	0.45	0.16	0.59	0.02	0.00	1.57	1.62	0.03	0.03	0.01	77.12	0.00
Mugu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kalikot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dailekh	0.10	0.03	0.13	0.00	0.00	0.34	0.35	0.01	0.01	0.00	16.64	0.00
Jajarkot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pyuthan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rolpa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rukum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salyan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surkhet	1.94	0.69	2.56	0.08	0.00	6.81	7.04	0.14	0.15	0.05	334.48	0.01
Dang	12.53	4.48	16.52	0.49	0.00	43.94	45.44	0.88	0.94	0.31	2158.90	0.04
Banke	87.64	31.35	115.55	3.40	0.00	307.32	317.79	6.13	6.56	2.16	15098.95	0.31
Bardia	3.01	1.08	3.97	0.12	0.00	10.57	10.93	0.21	0.23	0.07	519.07	0.01
Bajhang	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bajura	0.60	0.21	0.79	0.02	0.00	2.09	2.17	0.04	0.04	0.01	102.89	0.00
Darchula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accham	0.21	0.08	0.28	0.01	0.00	0.75	0.78	0.01	0.02	0.01	36.83	0.00
Baitadi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dadeldhura	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Doti	0.49	0.18	0.65	0.02	0.00	1.72	1.78	0.03	0.04	0.01	84.74	0.00
Kailali	28.10	10.05	37.05	1.09	0.00	98.55	101.91	1.96	2.10	0.69	4841.95	0.10
Kanchanpur	10.58	3.79	13.95	0.41	0.00	37.11	38.37	0.74	0.79	0.26	1823.01	0.04
Total	**5900.1**	**2110.7**	**7779.0**	**229.0**	**0.1**	**20690.3**	**21395.0**	**412.5**	**441.9**	**145.6**	**1016520.0**	**20.8**

3.3. Transport Sector



Note: HS Diesel = High Speed Diesel; L Diesel = Light Diesel; ATF = Air Turbine Fuel; LPG = Liquefied Petroleum Gas

Figure 10: Transport Sector Energy Consumption by Fuel Type in FY 2008/09, %

(Source: WECS (2010))

3.3.1. Overview

As a landlocked and predominantly mountainous country, the transport system in Nepal relies heavily on road and air travel with high domination of road-based transport. There is no existing rail transportation system in operating condition in Nepal.[10] Transport was the second largest energy consuming sector in Nepal in FY 2008/09. In FY 2008/09 the sector consumed around 20.9 million GJ of fuel. High speed diesel (HS diesel) was the main fuel consumed in this sector and accounted for about 67.0% of the total transport sector energy consumption (see Figure 10), Gasoline accounted for 19.9% of the total energy consumption in the sector while the shares of air turbine fuel and LPG were 11.9% and 1.0% respectively. Electricity and light diesel had a share of 0.1% each. Road transport consumes around 86.5% of the total sectoral energy consumption whereas the aviation sub-sector consumes about

[10]*The country has the total physical railway line of 57 km. Nepal Railways Company (NRC), a government agency owns the 53-kilometer narrow-gauge rail line, which is composed of two sections - 32-kilometer section between Jaynagar in India to Janakpur in Nepal, and a 21-kilometer portion from Janakpur to Bijalpura. Janakpur to Bijalpura network is not operational at present. The Indian Railways manages the six-kilometer railway line (of which four-kilometers fall in Nepal) that connects Inland Clearance Deport (ICD) in Birgunj to Raxaul, India*

(Source: http://go.worldbank.org/I99TRS72B0).

13.4% (WECS, 2010). Energy consumption in the transportation sector has been rising at a CAGR of 5.5% during 2000/01-2008/09. The growth in the use of petroleum products in this sector is directly linked with the increase in the number of vehicles during recent years. The number of registered vehicles in Nepal in 2008 by type of vehicles in different zones are presented in the Annex 5.

Bagmati zone has the highest number of vehicle registration in the country (see Annex 5). There were 47 airports in the country in FY 2008/09, out of which 32 were in operation (CAAN, 2009). However as of FY 2010, there were altogether 55 airports in the country including, one international airport, 5 regional hub airports, 43 other domestic airports and 5 airports under construction. However, of these, air services were provided by only 34 airports (CAAN, 2010).

3.3.2. Emission Estimation Method

3.3.2.1. Road Transport

For the road transport sector, the average distance traveled per vehicle has been used for emission estimation and this information was obtained from WECS (1997 and 2000). Number of registered vehicles and their categories were obtained from the Department of Transport Management (DoTM), Nepal. The method proposed in EMEP/CORINAIR (2006) is used to estimate the emissions from the road transport sector, i.e.,

$$Em_{i,j,k} = N_j \times M_{j,k} \times e_{i,j,k} \tag{5}$$

where,

i,j,k = *Pollutant type i of vehicle class j and road type k (urban or rural)*

$Em_{i,j,k}$ = *Emissions of the pollutant type i by vehicle of class j driven on road of type k*

N_j = *Number of vehicles of class j in circulation in the reference year*

$M_{j,k}$ = *Mileage per vehicle of class j driven on roads of type k*

$e_{i,j,k}$ = *Average fleet representative baseline emission factor for the pollutant i, relevant for the vehicle class j, operated on roads of type k*

3.3.2.2. Air Traffic

For air traffic, two activities are considered for the emission inventory, i.e., landing and take-off (LTO) and cruise. The key data related to this sector are: number of LTO per airport and total aviation fuel sold. The LTO data was obtained from the Civil Aviation Authority of Nepal (CAAN, 2010) while the data on aviation fuel sold in the FY 2008/09 was obtained from the Nepal Oil Corporation Limited[11] (NOC, 2011). The estimation of emissions from air traffic is carried in two parts. The first part includes the estimation of fuel consumption for LTO activities while the other part includes the estimation of fuel consumption for cruise activities. For the estimation of fuel consumption in LTO activities, the total number of LTOs per aircraft type and the fuel consumption per LTO has been used (see Equation 6). The data on fuel consumption per LTO is based on EMEP/CORINAIR (2006).

$$TFC_{LTO_{jn}} = \sum LTO_{ijn} \times UFC_i \tag{6}$$

[11] *The aviation fuel sales data were obtained directly from personal contact from Nepal Oil Corporation Limited.*

where,

TFC_{LTOjn} = Total fuel consumption for LTO activities per aviation type j in year n

UFC_i = Fuel consumption per LTO per aircraft type i

From the total amount of aviation fuel sold, the fuel sold for domestic and international aviation are estimated using the following relation,

$$FS_{jn} = \left[\frac{\sum LTO_{jn}}{\sum LTO_{tn}} \right] \times TFS_n \tag{7}$$

where,

FS_{jn} = Total fuel sold for aviation type j in year n

LTO_{jn} = Total LTO per aviation type j in year n

LTO_{tn} = Total LTO in year n (including both domestic and international aviation)

TFS_n = Total aviation fuel sold in year n

The fuels consumed in cruise activities are then estimated using the following relation:

$$FC_{CR_{jn}} = \left[\frac{\sum LTO_{ijn}}{\sum LTO_{jn}} \right] \times FS_{jn} - FC_{LTO_{jn}} \tag{8}$$

where,

FC_{CRjn} = Total fuel consumed for cruise activity for aviation type j in year n

LTO_{ijn} = Total number of LTO per aircraft type i for aviation type j in year n

LTO_{jn} = Total number of LTO for aviation type j in year n (j refers to either domestic or international aviation)

LTO_{ijn} = Total number of LTOs per aircraft type i, per aviation type j in year n

FS_{jn} = Total fuel sold for aviation type j in year n

FC_{LTOjn} = Fuel consumed for LTO activity for aviation type j in year n

The total emission estimation from the aircraft traffic includes emission estimation from the LTO and cruise activities. The emission from LTO activities are calculated based on the following relation:

$$ELTO_{ijn} = LTO_{ijn} \times EF_i \tag{9}$$

where,

$ELTO_{ijn}$ = Emission from LTO activity from aircraft type i and aviation type j in year n

LTO_{ijn} = LTO of aircraft type i and aviation type j in year n

EF_i = Emission factor of aircraft type i

The emission from the cruise activity is estimated based on the following relation:

$$ECR_{ijn} = fc_{ijn} \times EF_i \tag{10}$$

where,

ECR_{ijn} = Emission from cruise activity of aircraft type i and aviation type j in year n

fc_{ijn} = Aviation fuel consumed per aircraft type i and aviation type j in year n

EF_i = Emission factor of aircraft type i

3.3.3. Data on Activity Levels

3.3.3.1. Road Transport

The existing vehicle fleet was 1,235,579 in FY 2011/12, which is almost two times of that in the FY 2008 (i.e. 710,914). The compound average growth rate of the vehicle population during 2011- 2008 was 20%. The vehicle fleet in Nepal is characterized by the high share of two wheelers; their share was growing from 67% in 2004 to 81% in 2008 and to 89% in 2011. Moreover, there is a significant share of old and poorly maintained vehicles. In Nepal, more than 50% of the registered vehicles are found to ply in the roads of Kathmandu valley. The increasing demand for fuel in the transport sector is directly associated with the increasing demand of vehicle stock. Figure 11 shows the increasing pattern of vehicle fuel consumption during 2001-2011.

Vehicular emission is one of the growing problems in the country. Besides the use of old and poorly maintained vehicles, poorly maintained road conditions and fuel adulteration are the causes for the growing emissions from the transport sector since the poor road infrastructure and growing number of vehicles lead to higher fuel consumption. Roads in Nepal are of three types, i.e., paved and blacktopped, graveled and earthen. Of the total road length of 21,455 km in the FY 2010/11, 44% were fair weathered, 32% were blacktopped, and 23% were graveled (MOF, 2011b). The increase in the number of vehicles has not been matched by expansion and upgradation of road infrastructures, leading to increased traffic congestion.

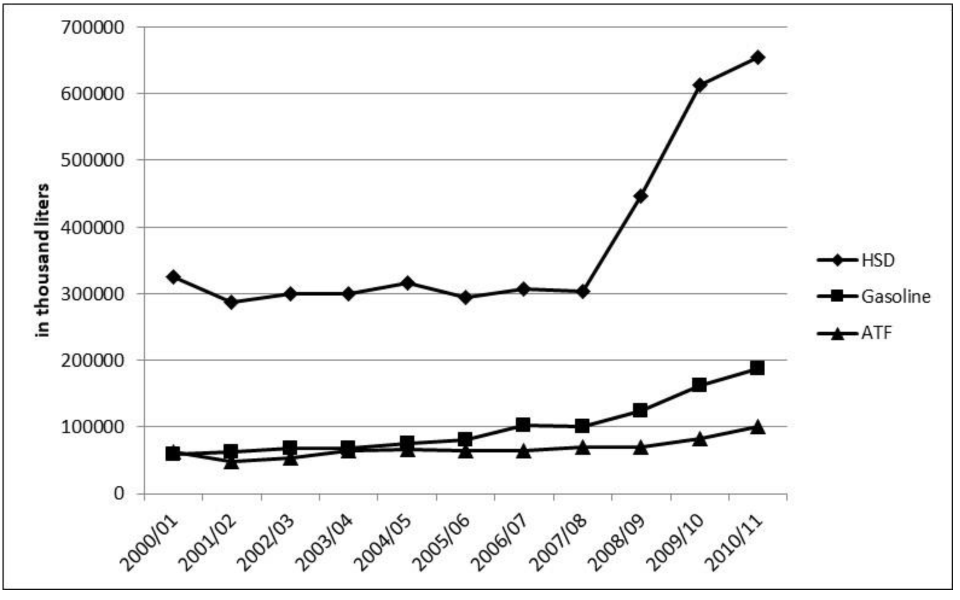


Figure 11: Fuel Sales for Fiscal Years 2000/01-2010/11

(Source: NOC (2011))

The estimation of emissions from the road transport is based on the average distance traveled per vehicle and number of registered vehicles. The sources of data on average mileage per vehicle are WECS (1997 and 2000) while the data on number of registered vehicles by zone in FY 2008/09 are obtained from personal communication from the Department of Transport Management (DoTM), Nepal. Due to the lack of average vehicle mileage data for FY 2008/09, 1999/2000 data as given in WECS (2000) have been used. Vehicle composition by fuel type was assigned based on WECS (1997 and 2000) and Dhakal (2006). Based on these references, it has been assumed that 83.9% of the registered vehicles in Nepal use gasoline; 15.8% use diesel; 0.2% use LPG and 0.1% use electricity.

Although there are some diesel cars in the country, it is assumed that all the registered cars and two-wheelers use gasoline while all the registered heavy duty vehicles (includes bus, minibus, crane, dozer, excavator and truck) use diesel. Two-wheelers occupy the largest share (71.1%) in the total number of registered vehicles in Nepal in FY 2008/09, followed by cars (12.1%), heavy duty vehicles (8.4%), light duty vehicles12 (7.4%) and 3-wheelers (0.9%). Table 12 presents the number of vehicles in circulation, average distance traveled per vehicle and the unit fuel consumption data considered in this study. Emission factors (EFs) for the estimation of emission from this sector are mostly borrowed from EMEP/CORINAIR (2006), IPCC (1996), CPCB (2000), Paw-amart (2004), Bond et al. (2004), and Reddy and Venkataraman (2002).

[12] *Light duty vehicles include jeep, van, pick-up and micro bus.*

Table 12: Number of Vehicles in Circulation, Average Distance Traveled per Vehicle and Fuel Economy in FY 2008/09

Fuel	Vehicle Class	Number of Vehicles in Circulation[a]	Average Distance Traveled per Vehicle (km/yr)[b]	Fuel economy (km/liter)[c]
Gasoline	Gasoline cars	97590	23624	9.49
	Light-duty vehicles	844		
	Jeep/van	844	23624	9.49
	Two wheelers	573020		
	2-stroke	126064	10491	38.40
	4-stroke	446956	10491	53.80
	Three wheelers	4604	12756	5.39
Diesel	Light-duty vehicles	58538		
	Jeep/van	1692	31929	8.71
	Pick-up	4706	31929	8.71
	Micro-bus	1430	37125	8.00
	Tractors	44767	17281	5.08
	Others	5943	17281	5.08
	Heavy-duty vehicles	67619		
	Bus	19685	47998	6.09
	Mini-bus	7497	47998	6.09
	Crane/dozer/excavator/truck	40437	47998	6.09
	Three-wheelers	970	27173	9.39
LPG	Light-duty vehicles	633		
	Microbus	633	37125	8.00
	Three wheelers	857	35502	14.70
Total		**805614**		

Source: [a]Data Collected from Department of Transport Management, [b,c]WECS (2000) and Dhakal (2006)

Table 13: Frequency of Landing and Takeoff Activity and Aviation Fuel Consumption in 2008

Flight Type	Frequency of LTO[a]	Fuel Consumption per LTO (kg/LTO)[b]	Total Annual Aviation Fuel Sold in 2008[d], in kt
Domestic	223275	200	65967.8
International	14276	1300[c]	4217.9
Total	237551		70185.7

Source: [a]CAAN (2010); [b]ICAO (2011); [c]IPCC (2000); [d]Estimated based on the data obtained from Nepal Oil Corporation Limited.

3.3.3.2. Air Traffic

There were 47 airports in Nepal in FY 2008/09, out of which 32 were in operation. The country has only one international airport which is situated in Kathmandu. The LTO data were collected for all the domestic airports in operation and for the only international airport. The emission from air transportation has been categorized into domestic and international. Due to lack of disaggregated data on fuel consumption for domestic and international flights, the total aviation fuel sold in 2008 has been disaggregated into domestic and international using the factor of fuel consumption per LTO (in kg/LTO). Fuel consumption per LTO acts as a factor to distribute the total fuel consumption into domestic and international. The fuel consumption data thus obtained have been utilized to calculate the emissions from both domestic as well as international flights. For domestic flights, the average fleet types in operation in Nepal are twinotters, Beechcraft, and ATR (Aerei da Trasporta Regionale or Avions de Transport Regional). However, the average domestic fleet type is assumed to be ATR in this study. For international flights, the average fleet type is assumed to be Boeing 757. The activity data related to aviation in 2008 in Nepal are presented in Table 13 while the estimated total emissions are presented in Table 16. The airport wise data on arrival and departure of flights are presented in Annex 6.

3.3.4. Emission Factors

For both the road and air transport sectors emission factors are mostly based on EMEP/CORINAIR (2006). Note, however, that Japanese and Indian emission factors provided by Kannari et al., (2007) and Reddy and Venkataraman (2002) are used for road transportation wherever available. For air traffic, the EFs given in EMEP/CORINAIR (2006), IPCC (2000) and Bond et al., (2004) are used. Table 14 and Table 15 present the emission factors used in this study for road and air transport respectively for estimating emissions from the transport sector. In the absence of specific emission factors by the type of domestic fleet used in Nepal, an average emission factors for domestic aircraft based on ICAO (2011) and IPCC (2000) has been considered in this study.

Table 14: Emission Factors for Road Transport Vehicles, g/km

Fuel Type	Category	Emission Factor										
		Air Pollutants								GHGs		
		CO[a]	NO_X[a]	NMVOC[a]	NH_3[a]	PM_{10}[a]	$PM_{2.5}$[a]	BC[a]	OC[a]	CO_2*[a]	N_2O*[a]	CH_4*[a]
Gasoline	Passenger Cars (PC)	46.00, 9.8[b]	2.20, 1.8[b]	5.30, 1.7[b]	0.002	0.06[b]	0.06[b], 0.073[g], 0.059[h], 0.59[i]	0.025[g], 0.0200[b], 0.005[h], 0.05[i], 0.07[o*]	0.026[g], 0.021[b], 0.04h, 0.4i, 0.6o*	3180	0.14f	1.7, 1.5[f]
	Light Duty Vehicles	36.80	2.94	6.09	-	0.11	0.11	0.07[o*]	0.6o*	-	-	-
	Motorcycles (2-stroke)	22.00	0.08	16.00, 3.9[b]	0.001	0.05	0.05, 0.23[b]	0.01[b], 1.4[p*]	0.18b, 27p*	38.8	0.14f	1.24, 1.5[f]
	Motorcycles (4-stroke)	20.00, 3[b], 1.6[c]	0.30, 0.31[b], 0.17[c]	3.90, 0.8[b]	0.002	0.03	0.032, 0.07[b]	0.0035[b]	0.05b	36.65	0.14f	1.24, 1.5[f]
	3-Wheelers (2-stroke)	24.00, 14[b]	0.09, 0.05[b]	16.00, 8.3[b]	0.002	0.6	0.6, 0.35[b]	0.017[b]	0.3b	3180	0.14f	1.24, 1.5[f]
Diesel	3-Wheelers	2.25	13.00[d]	-	0.001	1.54[c]	1.54[c]	0.8[n]	0.24n	3140	0.17f	0.08
	Light Duty Vehicles	1.58, 6.9[b]	1.43, 2.49[b]	0.42, 0.34[b]	0.001	0.25	0.8[b], 0.324[j], 0.26[k], 0.15[c], 0.73l	0.13k, 0.4g, 0.16j, 0.51n, 0.5l, 2.75q*	0.067k, 0.15j, 0.24n, 0.17l, 0.85q*	3140	0.17f	0.08, 0.17[f]
	Heavy Duty Vehicles	8.98, 5.5[b], 4.96[e]	10.40, 6.54[e]	1.95, 1.78[b], 1.88[e]	0.003	1.00	2.25[b], 3.3[k], 1.34[c], 1.3[m]	2.6k, 2g, 0.74n, 0.54m, 5.5r*	0.3k, 1n, 0.47m, 1.7r*	3140	0.17f	0.25, 0.17[f]
LPG	Light Duty Vehicles	8.00[a, b]	2.10	3.50[a,b]	-	-	0.06[b]	-	-	3030	0.009	2.9[f]
	3-Wheelers	2.48	0.65	-	-	-	-	-	-	-	-	-

Source: [a]EMEP/CORINAIR (2006); [b]CPCB (2000). Applicable to Indian cars 1995-2005 model. BC/PM ratio used is 34 % while OC/PM ratio used is 36% for gasoline vehicles (Gillies and Gertler, 2000). For 2-stroke motorcycle and 2-stroke 3-wheelers, BC/PM ratio used is 5% while OC/PM ratio is 79% (Sakai et al., 1999 and Kojima et al., 2000). Values are recommended for other Asian countries; [c]Paw-amart (2004). Values are applicable for LD and HD for Bangkok vehicles, Thailand with fewer car samples; [d]Shrestha and Malla (1996); [e]Chen et al. (2007); [f]IPCC (2006); [g]Williams et al. (1989); [h]Hildemann et al. (1991); [i]Schauer et al. (2002); [j]Norbeck et al. (1998); [k]Kim Oanh et al. (2009); [l]Caddle et al. (1999); [m]Watson et al. (1998); [n]BC and OC EFs are derived from $PM_{2.5}$ values (CPCB, 2000) by using BC/PM ratio of 53% and OC/PM ratio of 16% for gasoline passenger cars (taken from Williams et al., 1989). For diesel LDV cars BC/PM ratio is 64% and OC/PM ratio is 30% while for diesel HDV cars BC/PM ratio is 33% and OC/PM ratio is 45% (Williams et al., 1989); oReddy and Venkataraman, 2002a. Assumed PM_{10} value is similar to PM with $PM_{2.5}$/PM ratios similar to Durbin et al., (1999). BC/PM ratio used is 52% and OC/PM ratio is 30% (taken from Williams et al., 1989). For gasoline PC, BC/PM ratio is 8.1% and OC/PM ratio is 65.5% (taken from Hildeman, 1991); [p]Faiz et al., 1996. Average emission from 167 Thai motorcycles, BC is assumed to be 5% of the particulate matter, and that the remainder is OM; [q]Muhlbaier and Williams, 1982 and Muhlbaier and Cadle, 1989. Uncontrolled emission; [r]Subramanian et al., 2009. BC/PM ratio used is 60%, and OC/PM ratio is 21%; unit in g/kg.*

Table 15: Emission Factors for Air Traffic

Fleet Categories	Emission Factors from Air Traffic										
	Air Pollutants								GHGs		
	SO_2	CO	NO_X	NMVOC	PM_{10}	$PM_{2.5}$	BC*,d	OC*,d	CO_2	CH_4	N_2O
Domestic											
LTO (in kg/LTO)- Average Fleet[a]	0.2	2.33	1.82	12.7[b]	-	-	-	-	620	1.4[b]	0.03[b]
Cruise (in kg/tonne) - Average Fleet[a]	0.2	2.33	1.82	12.7[b]	-	-	-	-	620	0	0.03
International											
LTO (in kg/LTO)- Average Fleet (B757)[b]	1.3	10.6	21.6	0.8	0.52	0.48	30#	100#	4110	0.1	0.1
Cruise (in kg/tonne) - Average Fleet (B757)[c,+]	1	1.1	12.8	0.5	0.01	0.2	-	-	3150	0	0.1

*Note: # unit in kg/kilotonnes; *unit in g/kg; +for fleet type B767; Source: [a]ICAO (2011); [b]IPCC (2000); [c]EMEP/CORINAIR (2006); [d]Bond et al. (2004)*

3.3.5. Estimated Emissions

Table 16 and Table 17 show the total estimated emissions from the road and air transport sectors respectively in Nepal in FY 2008/09. In Table 16, "Low Case" and "High Case" refer to the cases using low and high emission factors respectively. Energy use in the transport sector is increasing at a faster pace than in other sectors. The increase in energy use in the transport sector is a clear indication of the increase in the carbon emissions because all the energy requirements of this sector are in the form of petroleum products.

Table 16: Annual Emissions from the Road Transport Sector in FY 2008/09, tonne

Type of GHG/air pollutant	Total Emissions	
	Low Case	High Case
Air Pollutants		
SO_2	4747[a]	6593[b]
NO_X	29106[d]	38022[c]
CO	97358[d]	258873[c]
NMVOC	19025[d]	58944[c]
NH_3	27[c]	27[c]
PM_{10}	3663[c,d,e]	3663[c,d,e]
$PM_{2.5}$	3663[c,d,e]	7593[d,e,f]
BC	79[c]	2686[g,h,i,j]
OC	215	1637[g,h,i,j]
GHGs		
CH_4	2169[c]	2169[c]
CO_2	2679416[c]	2679416[c]
N_2O	45[c]	45[c]

Note: [a]using sulfur content of gasoline, diesel and LPG as 0.015%, 0.396% and 0.00054% respectively (based on IPCC (1996) and Kato and Akimoto (1992)); [b]using sulfur content of gasoline, diesel and LPG as 0.046%, 0.54% and 0.00054% respectively (based on http://www.rrcap.unep.org/male/baseline/Baseline/Nepal/NEPCH3.htm and Kato and Akimoto (1992));[c]Using EFs based on EMEP/CORINAIR (2006); [d]Using EFs based on CPCB (2000); [e]Using EFs based on Paw-amart (2004); [f]Using EFs based on Williams et al. (1989); [g]Reddy and Venkataraman, 2002a. Assumed PM_{10} value is similar to PM with $PM_{2.5}$/PM ratios similar to Durbin et al., (1999). BC/PM ratio used is 52% and OC/PM ratio is 30% (taken from Williams et al., 1989). For gasoline PC, BC/PM ratio is 8.1% and OC/PM ratio is 65.5% (taken from Hildeman, 1991); [h]Faiz et al. (1996). Average emission from 167 Thai motorcycles, BC is assumed to be 5% of the particulate matter, and that the remainder is OM; [i]Muhlbaier and Williams (1982) and Muhlbaier and Cadle (1989). Uncontrolled emission; [j]Subramanian et al. (2009). BC/PM ratio used is 60%, and OC/PM ratio is 21%;[k] IPCC (2006)

Road transport is the largest energy consuming sector in Nepal. For the road based transportation, CO_2 emission was estimated to be around 2679.4 thousand tonne. The total SO_2 emission from the road transport is found to vary from 4747 to 6593 tonnes (refer to Table 16). The total SO_2 emissions from the air-based transportation is estimated to be around 44674 tonnes in the year 2008/09, while the CO_2 figure is estimated to be 197159 tonnes in the same year (see Table 17).

3.3.6. Temporal and Spatial Variations

For spatial distribution of emissions from the road transport sector, the total vehicle population per district has been used as a proxy factor. Since district wise data on vehicle population were not available, the spatial distribution has been estimated based on the total vehicle population registered in the fourteen zones and total population of the 75 districts of Nepal. The total vehicle population in each district has been estimated based on the total population share of the district. For temporal distribution of emissions, national level monthly sales data of gasoline has been considered (see Figure 12).

The district-wise emissions by pollutant type under the high emission case from the road transport sector are presented in Table 18. It has been estimated that around 17.9% of the total road transport based emissions comes from the Kathmandu district, while 5.6% and 3.7% of the emissions comes from Lalitpur and Bhaktapur districts respectively. Figure 13 shows the spatial variation pattern of total CO_2 and SO_2 emissions from the road based transport. The spatial variation patterns of other emissions by pollutant type from the road transport are presented in Annex 7.

Table 17: Annual Emissions from Air Transportation in FY 2008/09, tonne

Air Pollutants	Emissions
SO_2	44674
NO_X	715
CO	672
NMVOC	2848
NH_3	-
PM_{10}	7
$PM_{2.5}$	0.01
BC	127
OC	422
GHGs	
CH_4	314
CO_2	197159
N_2O	32

Figure 14 shows the monthly pattern of emissions from the road-based transport sector. The temporal variation of emissions from the road transport sector follows the same pattern as the consumption of gasoline shown in Figure 12.

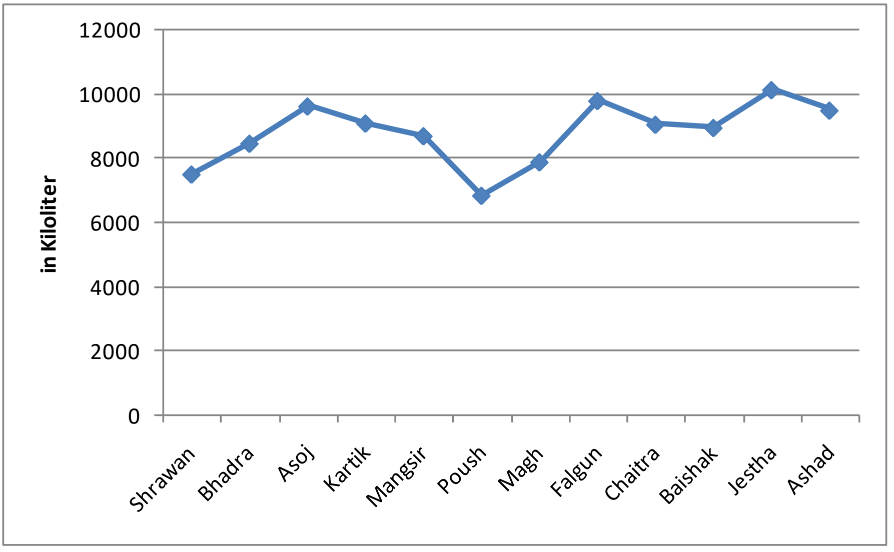
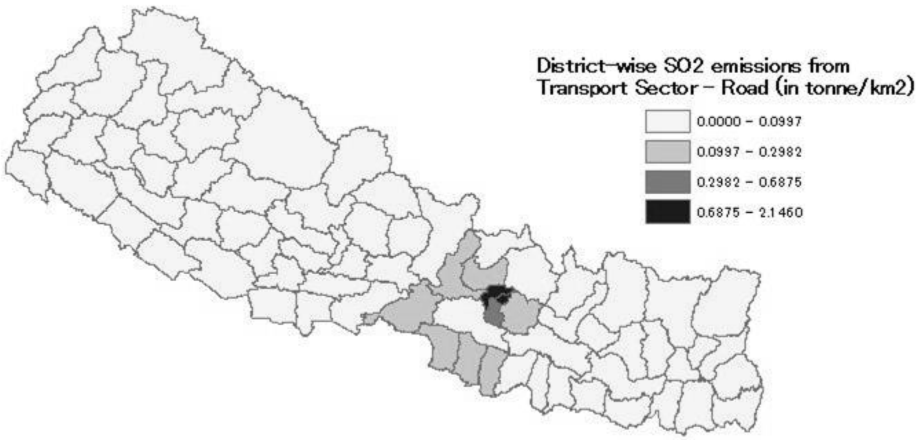


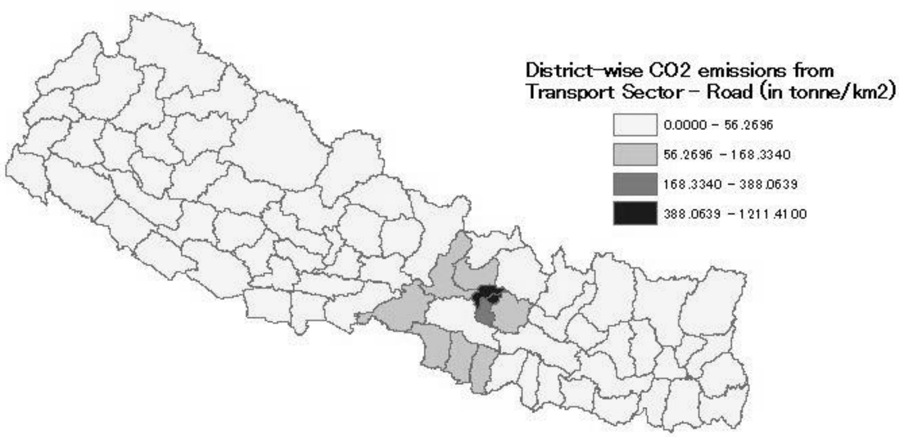
Figure 12: Monthly Pattern of Gasoline Sales in Nepal in 2008[13]

(Source: Nepal Oil Corporation Limited)

[13] *Note: Month 1 = July = Ashad-Shrawan; Month 2 = August = Shrawan-Bhadra; Month 3 = September = Bhadra-Asoj; Month 4 = October = Asoj-Kartik; Month 5 = November = Kartik-Mangsir; Month 6 = December = Mangsir-Poush;Month 7 = January = Poush-Magh; Month 8 = February = Magh-Falgun; Month 9 = March = Falgun-Chaitra; Month 10 = April = Chaitra-Baisakh; Month 11 = May = Baishak-Jestha; Month 12 = June = Jestha-Ashad.*



a) SO_2 Emission Density



b) CO_2 Emission Density

Figure 13: Spatial Variation of Densities of SO_2 and CO_2 Emissions from the Road Transport Sector, tonne/km^2

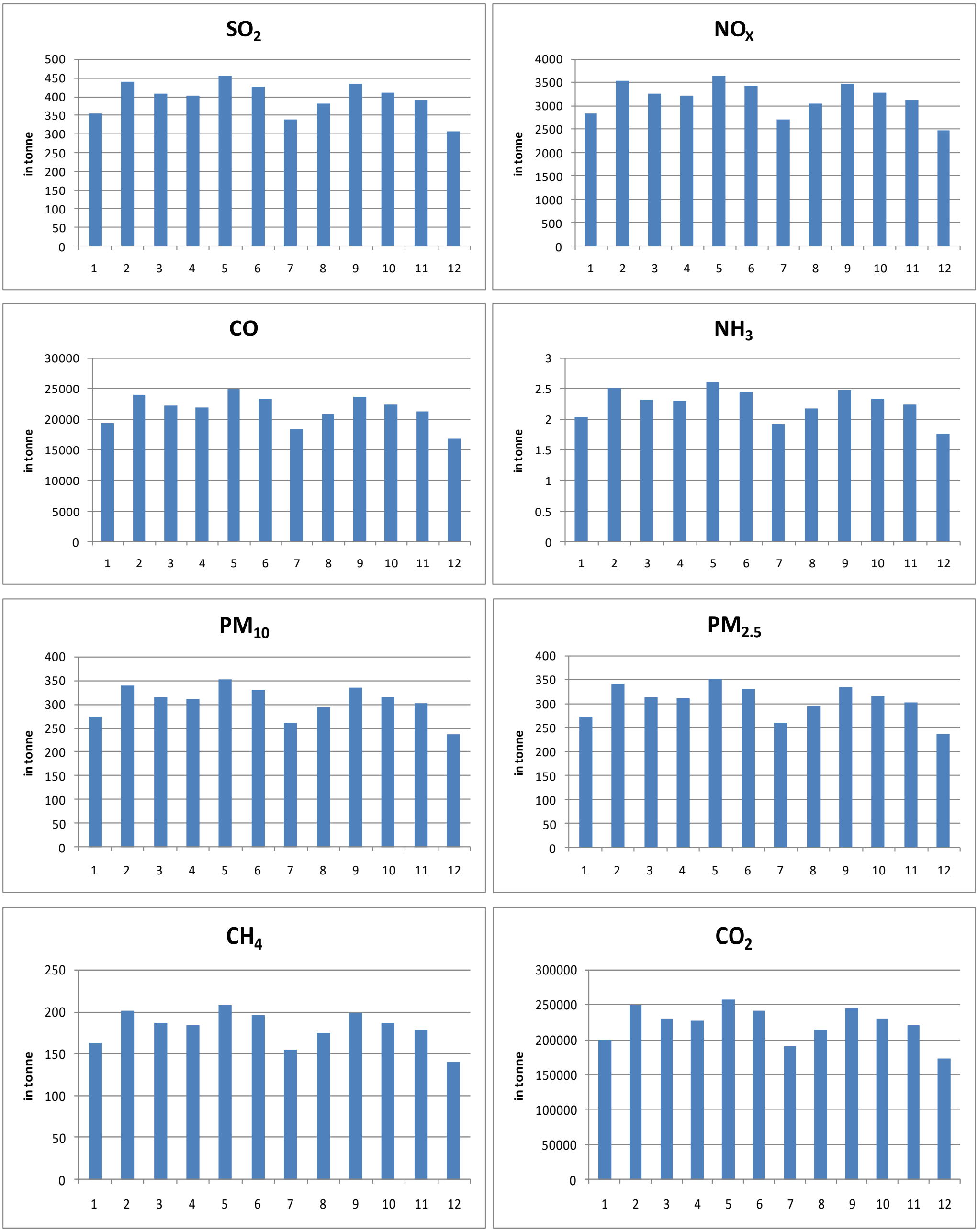


Figure 14: Temporal Variation of Emissions of Air Pollutants and GHGs from the Road Transport Sector, tonne

Table 18: District-wise Emissions of Air Pollutants and GHGs from Road Transportation Sector in FY 2008/09, tonne

Districts	Emissions											
	Air Pollutants									GHGs		
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Sankhuwasabha	13.51	108.20	736.67	167.74	0.08	10.42	10.42	0.22	0.61	6.17	7624.72	0.13
Solukhumbu	0.57	4.59	31.26	7.12	0.00	0.44	0.44	0.01	0.03	0.26	323.51	0.01
Taplejung	11.66	93.42	636.05	144.83	0.07	9.00	9.00	0.19	0.53	5.33	6583.30	0.11
Bhojpur	17.22	137.98	939.41	213.90	0.10	13.29	13.29	0.29	0.78	7.87	9723.15	0.16
Dhankuta	14.12	113.14	770.33	175.40	0.08	10.90	10.90	0.23	0.64	6.46	7973.19	0.13
Ilam	24.49	196.14	1335.42	304.07	0.14	18.89	18.89	0.41	1.11	11.19	13822.00	0.23
Khotang	1.23	9.86	67.16	15.29	0.01	0.95	0.95	0.02	0.06	0.56	695.13	0.01
Okhaldhunga	0.83	6.68	45.48	10.36	0.00	0.64	0.64	0.01	0.04	0.38	470.77	0.01
Panchthar	17.49	140.14	954.12	217.25	0.10	13.50	13.50	0.29	0.79	8.00	9875.39	0.17
Terhathum	9.60	76.87	523.39	119.17	0.05	7.41	7.41	0.16	0.44	4.39	5417.23	0.09
Udaypur	1.53	12.26	83.50	19.01	0.01	1.18	1.18	0.03	0.07	0.70	864.28	0.01
Jhapa	54.81	439.05	2989.25	680.64	0.31	42.29	42.29	0.91	2.49	25.05	30939.61	0.52
Morang	71.54	573.07	3901.76	888.41	0.41	55.21	55.21	1.19	3.25	32.70	40384.37	0.68
Saptari	3.04	24.31	165.53	37.69	0.02	2.34	2.34	0.05	0.14	1.39	1713.26	0.03
Siraha	3.03	24.29	165.41	37.66	0.02	2.34	2.34	0.05	0.14	1.39	1712.05	0.03
Sunsari	53.08	425.19	2894.93	659.17	0.30	40.96	40.96	0.88	2.41	24.26	29963.47	0.50
Dolakha	0.98	7.85	53.44	12.17	0.01	0.76	0.76	0.02	0.04	0.45	553.08	0.01
Rasuwa	35.05	280.76	1911.52	435.25	0.20	27.05	27.05	0.58	1.59	16.02	19784.84	0.33

Districts	Emissions											
	Air Pollutants									GHGs		
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Sindhupalchowk	230.14	1843.54	12551.70	2857.97	1.31	177.59	177.59	3.82	10.45	105.18	129914.02	2.18
Bhaktapur	176.66	1415.11	9634.79	2193.80	1.01	136.32	136.32	2.93	8.02	80.74	99723.02	1.67
Dhading	265.35	2125.60	14472.12	3295.24	1.51	204.76	204.76	4.40	12.05	121.27	149790.86	2.51
Kathmandu	847.67	6790.23	46231.26	10526.68	4.84	654.12	654.12	14.05	38.48	387.40	478507.79	8.02
Kavre	302.19	2420.68	16481.20	3752.70	1.72	233.19	233.19	5.01	13.72	138.11	170585.49	2.86
Lalitpur	264.67	2120.12	14434.81	3286.75	1.51	204.24	204.24	4.39	12.02	120.96	149404.73	2.51
Makawanpur	241.83	1937.13	13188.97	3003.08	1.38	186.61	186.61	4.01	10.98	110.52	136509.96	2.29
Nuwakot	226.04	1810.64	12327.74	2806.98	1.29	174.42	174.42	3.75	10.26	103.30	127595.89	2.14
Ramechhap	1.18	9.48	64.52	14.69	0.01	0.91	0.91	0.02	0.05	0.54	667.82	0.01
Sindhuli	1.54	12.37	84.22	19.18	0.01	1.19	1.19	0.03	0.07	0.71	871.72	0.01
Bara	344.40	2758.81	18783.35	4276.90	1.97	265.76	265.76	5.71	15.64	157.40	194413.44	3.26
Chitwan	290.76	2329.12	15857.78	3610.76	1.66	224.37	224.37	4.82	13.20	132.88	164132.95	2.75
Dhanusa	3.74	29.95	203.94	46.44	0.02	2.89	2.89	0.06	0.17	1.71	2110.80	0.04
Mahaottari	3.08	24.69	168.13	38.28	0.02	2.38	2.38	0.05	0.14	1.41	1740.17	0.03
Parsa	306.26	2453.31	16703.37	3803.29	1.75	236.33	236.33	5.08	13.90	139.97	172885.01	2.90
Rautahat	335.78	2689.72	18312.94	4169.78	1.92	259.11	259.11	5.57	15.24	153.46	189544.55	3.18
Sarlahi	3.54	28.36	193.10	43.97	0.02	2.73	2.73	0.06	0.16	1.62	1998.67	0.03
Manang	1.27	10.14	69.06	15.73	0.01	0.98	0.98	0.02	0.06	0.58	714.82	0.01
Mustang	0.60	4.84	32.97	7.51	0.00	0.47	0.47	0.01	0.03	0.28	341.28	0.01
Argakhanchi	26.01	208.32	1418.33	322.95	0.15	20.07	20.07	0.43	1.18	11.89	14680.13	0.25

Districts	Emissions											
	Air Pollutants									GHGs		
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Baglung	10.85	86.94	591.93	134.78	0.06	8.38	8.38	0.18	0.49	4.96	6126.63	0.10
Gorkha	38.06	304.86	2075.66	472.62	0.22	29.37	29.37	0.63	1.73	17.39	21483.77	0.36
Gulmi	37.02	296.55	2019.05	459.73	0.21	28.57	28.57	0.61	1.68	16.92	20897.83	0.35
Kaski	50.26	402.62	2741.25	624.17	0.29	38.79	38.79	0.83	2.28	22.97	28372.75	0.48
Lamjung	23.40	187.43	1276.15	290.57	0.13	18.06	18.06	0.39	1.06	10.69	13208.53	0.22
Myagdi	4.62	37.00	251.90	57.36	0.03	3.56	3.56	0.08	0.21	2.11	2607.21	0.04
Palpa	33.51	268.46	1827.83	416.19	0.19	25.86	25.86	0.56	1.52	15.32	18918.60	0.32
Parbat	6.37	51.02	347.37	79.10	0.04	4.91	4.91	0.11	0.29	2.91	3595.42	0.06
Syangja	41.91	335.74	2285.91	520.49	0.24	32.34	32.34	0.69	1.90	19.16	23659.92	0.40
Tanahu	41.64	333.54	2270.91	517.08	0.24	32.13	32.13	0.69	1.89	19.03	23504.61	0.39
Kapilbastu	60.15	481.81	3280.37	746.93	0.34	46.41	46.41	1.00	2.73	27.49	33952.85	0.57
Nawalparasi	70.24	562.67	3830.94	872.29	0.40	54.20	54.20	1.16	3.19	32.10	39651.44	0.66
Rupandehi	88.41	708.17	4821.56	1097.85	0.50	68.22	68.22	1.47	4.01	40.40	49904.66	0.84
Dolpa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Humla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jumla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mugu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kalikot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dailekh	4.13	33.12	225.51	51.35	0.02	3.19	3.19	0.07	0.19	1.89	2334.07	0.04
Jajarkot	2.48	19.84	135.05	30.75	0.01	1.91	1.91	0.04	0.11	1.13	1397.82	0.02
Pyuthan	0.52	4.19	28.53	6.50	0.00	0.40	0.40	0.01	0.02	0.24	295.33	0.00

Districts	Emissions											
	Air Pollutants									GHGs		
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Rolpa	0.52	4.14	28.20	6.42	0.00	0.40	0.40	0.01	0.02	0.24	291.89	0.00
Rukum	0.46	3.72	25.30	5.76	0.00	0.36	0.36	0.01	0.02	0.21	261.91	0.00
Salyan	0.15	1.20	8.14	1.85	0.00	0.12	0.12	0.00	0.01	0.07	84.29	0.00
Surkhet	4.95	39.69	270.24	61.53	0.03	3.82	3.82	0.08	0.22	2.26	2797.04	0.05
Dang	1.14	9.12	62.09	14.14	0.01	0.88	0.88	0.02	0.05	0.52	642.67	0.01
Banke	7.08	56.75	386.36	87.97	0.04	5.47	5.47	0.12	0.32	3.24	3999.00	0.07
Bardia	7.03	56.28	383.17	87.25	0.04	5.42	5.42	0.12	0.32	3.21	3965.92	0.07
Bajhang	0.22	1.77	12.07	2.75	0.00	0.17	0.17	0.00	0.01	0.10	124.88	0.00
Bajura	0.13	1.07	7.27	1.66	0.00	0.10	0.10	0.00	0.01	0.06	75.23	0.00
Darchula	0.48	3.85	26.25	5.98	0.00	0.37	0.37	0.01	0.02	0.22	271.65	0.00
Accham	0.31	2.45	16.71	3.80	0.00	0.24	0.24	0.01	0.01	0.14	172.92	0.00
Baitadi	0.92	7.41	50.43	11.48	0.01	0.71	0.71	0.02	0.04	0.42	521.98	0.01
Dadeldhura	0.50	3.99	27.14	6.18	0.00	0.38	0.38	0.01	0.02	0.23	280.93	0.00
Doti	0.27	2.20	14.96	3.41	0.00	0.21	0.21	0.00	0.01	0.13	154.81	0.00
Kailali	0.82	6.54	44.55	10.14	0.00	0.63	0.63	0.01	0.04	0.37	461.07	0.01
Kanchanpur	1.49	11.94	81.30	18.51	0.01	1.15	1.15	0.02	0.07	0.68	841.47	0.01
Total	4746.57	38022.05	258873.01	58944.38	27.09	3662.77	3662.77	78.69	215.48	2169.26	2679415.54	44.92

For the air transport, the number of flight movements in each airport in 2008 has been used as a proxy factor for spatial distribution of emissions (see Annex 6). For the estimation of the temporal variation of emissions, the monthly aircraft movement data has been used (see Figure 15).

Since the data on monthly aircraft movement were not available for every operating airport, the monthly aircraft movement information of the Tribhuvan International Airport (TIA) has been used for estimating temporal variations of the emissions. Figure 15 shows aircraft movements were higher during the months of September – November with the highest being in the month of October; as such, the emissions are also estimated to be the highest in that month.

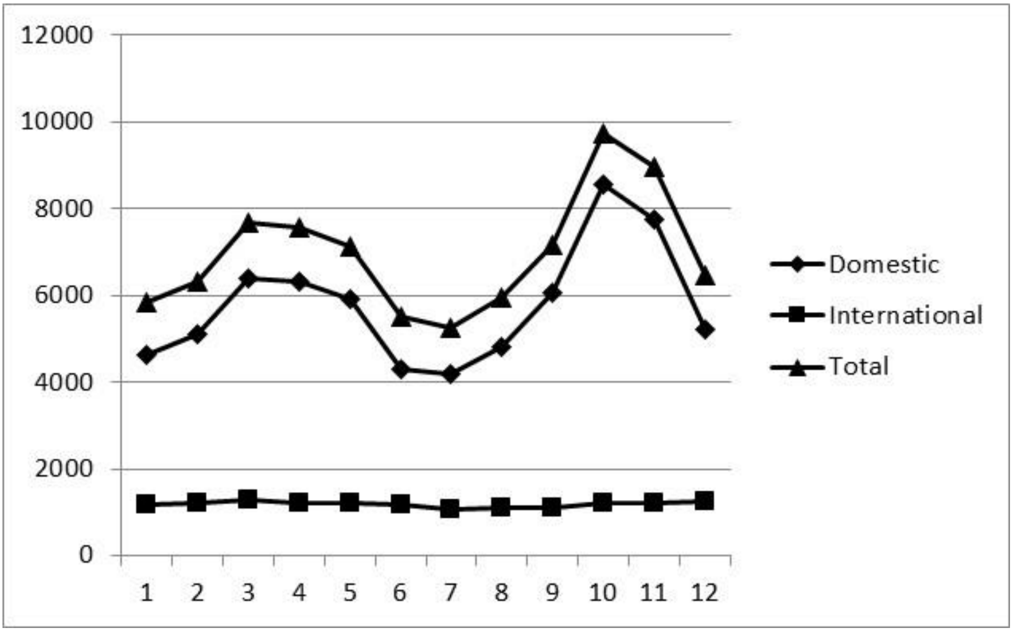


Figure 15: Aircraft Monthly Movement Data at the TIA in 2008[14]

(Source: CAAN (2010))

Figure 16 shows the monthly aviation fuel consumption data for the year 2008. The monthly fuel consumption pattern shows a high level of fuel consumption in the month 9 i.e. September. Figure 17 shows the pattern of spatial distribution of CO_2 and SO_2 emissions from the air transport. The spatial distribution of other types of emissions from the air transport are presented in Annex 8. Table 19 presents the estimated district wise emissions by pollutant type from the air transport sector in Nepal. The Kathmandu district occupies the largest share (35.2%) in the total air transport related emissions among the districts of Nepal; this is followed by Jhapa (16.5%), Dhanusa (8.9%), Kaski (8.3%), Morang (5.2%), Solukhumbu (5.1%), Banke (4.1%), and Surkhet (3.6%). The remaining 13.1% of the air transport emissions comes from the rest of the districts of Nepal.

[14] *Note: 1 = January; 2 = February; 3 = March; 4 = April; 5 = May; 6 = June; 7 = July; 8 = August; 9 = September; 10 = October; 11 = November; 12 = December.*

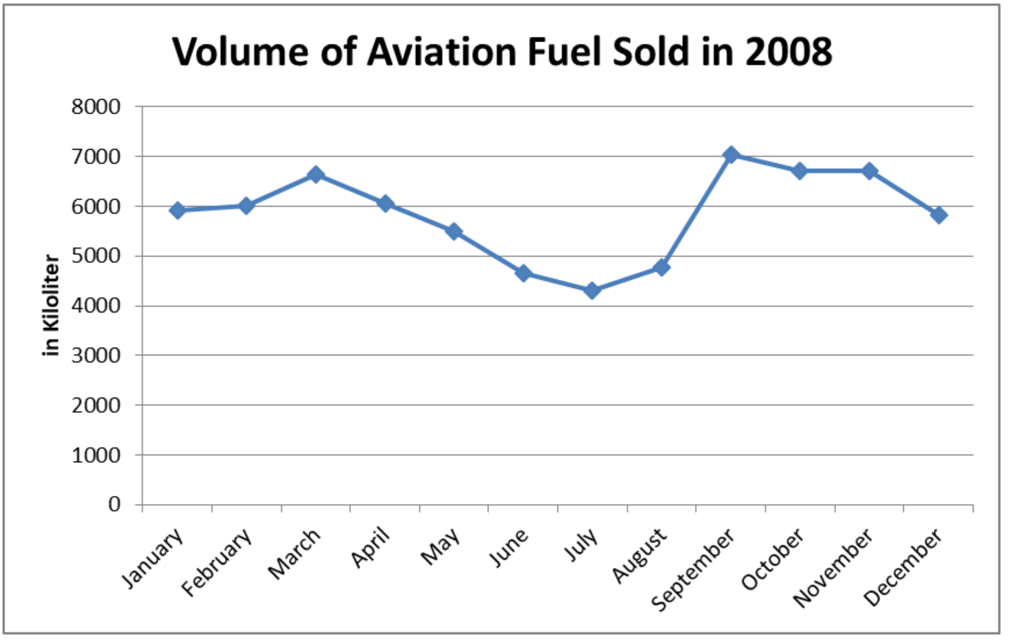
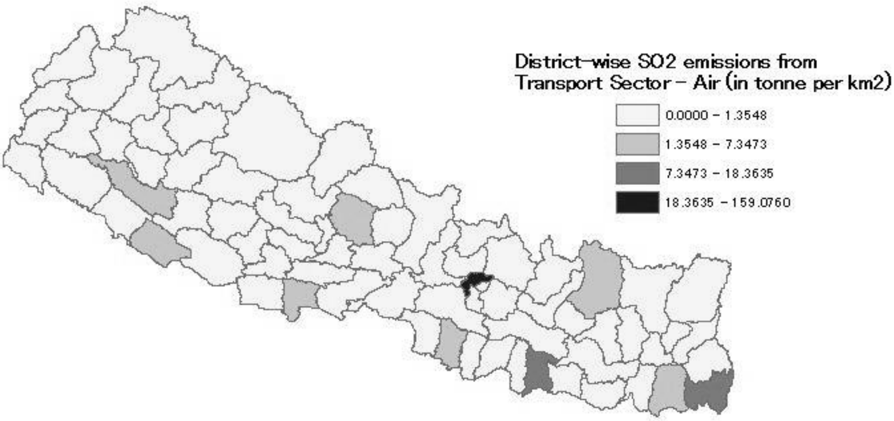


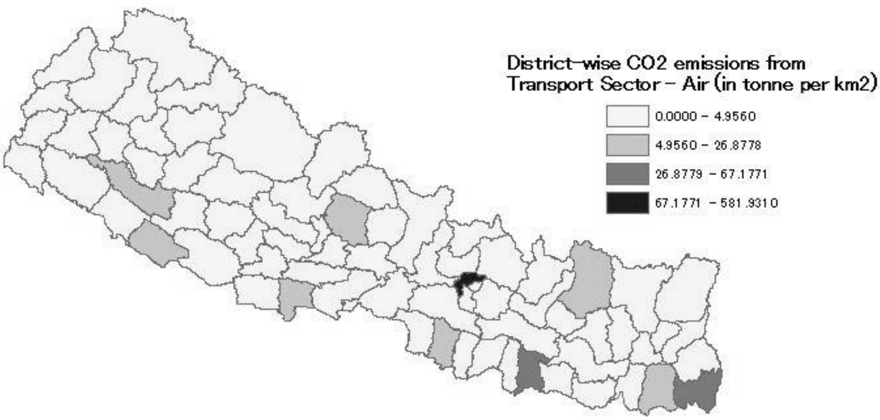
Figure 16: Temporal Pattern of Aviation Fuel Sales in 2008[15]

(Source: Nepal Oil Corporation Limited)

[15]*Note: Month 1 = December = Mangsir-Poush; Month 2 = January = Poush-Magh; Month 3 = February = Magh-Falgun; Month 4 = March = Falgun-Chaitra; Month 5 = April = Chaitra-Baisakh; Month 6 = May = Baisakh-Jestha; Month 7 = June = Jestha-Ashad; Month 8= July = Ashad-Shrawan; Month 9 = August = Shrawan-Bhadra; Month 10 = September = Bhadra-Asoj; Month 11= October = Asoj-Kartik; Month 12 = November = Kartik-Mangsir.*



a) SO_2 Emissions Density



b) CO_2 Emissions Density

Figure 17: Spatial Variations of SO_2 and CO_2 Emission Densities from Air Traffic

Table 19: Estimated District-wise Emissions of Air Pollutants and GHGs from the Air Transport Sector in FY 2008/09, tonne

	Emissions										
	Air Pollutants								GHGs		
Districts	SO_2	NO_X	CO	NMVOC	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Sankhuwasabha	411.49	6.59	6.19	26.20	0.06	0.00	1.17	3.89	2.95	1816.03	0.30
Solukhumbu	2284.18	36.56	34.36	145.59	0.36	0.00	6.49	21.58	15.99	10080.74	1.64
Taplejung	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bhojpur	177.13	2.83	2.66	11.32	0.03	0.00	0.50	1.67	1.26	781.74	0.13
Dhankuta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Khotang	341.13	5.46	5.13	21.77	0.05	0.00	0.97	3.22	2.38	1505.51	0.24
Okhaldhunga	143.67	2.30	2.16	9.14	0.02	0.00	0.41	1.36	0.98	634.06	0.10
Panchthar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terhathum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Udaypur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jhapa	7375.72	118.05	110.95	470.22	1.16	0.00	20.97	69.67	51.89	32551.15	5.28
Morang	2309.78	36.97	34.74	147.26	0.36	0.00	6.57	21.82	16.27	10193.71	1.65
Saptari	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Siraha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sunsari	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dolakha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rasuwa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Emissions										
	Air Pollutants								GHGs		
Sindhupalchowk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bhaktapur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dhading	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kathmandu	15714.70	251.51	236.39	1001.83	2.46	0.00	44.67	148.44	110.51	69353.44	11.25
Kavre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lalitpur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Makawanpur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nuwakot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ramechhap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sindhuli	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bara	838.75	13.42	12.62	53.49	0.13	0.00	2.38	7.92	5.89	3701.66	0.60
Chitwan	751.51	12.03	11.31	47.90	0.12	0.00	2.14	7.10	5.33	3316.61	0.54
Dhanusa	3969.60	63.53	59.71	253.07	0.62	0.00	11.28	37.50	27.91	17518.96	2.84
Mahaottari	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parsa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rautahat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sarlahi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manang	62.45	1.00	0.94	3.99	0.01	0.00	0.18	0.59	0.42	275.63	0.05
Mustang	649.92	10.40	9.78	41.44	0.10	0.00	1.85	6.14	4.63	2868.27	0.47
Argakhanchi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Emissions										
	Air Pollutants								GHGs		
Baglung	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gorkha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gulmi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kaski	3706.29	59.32	55.75	236.31	0.58	0.00	10.54	35.01	26.08	16356.90	2.65
Lamjung	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Myagdi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palpa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parbat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Syangja	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tanahu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kapilbastu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nawalparasi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rupandehi	787.60	12.60	11.85	50.22	0.12	0.00	2.24	7.44	5.47	3475.91	0.56
Dolpa	354.31	5.67	5.33	22.57	0.06	0.00	1.01	3.35	2.52	1563.67	0.26
Humla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jumla	684.54	10.96	10.30	43.62	0.11	0.00	1.95	6.47	4.77	3021.07	0.49
Mugu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kalikot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dailekh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jajarkot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Emissions										
	Air Pollutants								GHGs		
Pyuthan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rolpa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rukum	113.96	1.83	1.71	7.26	0.02	0.00	0.32	1.08	0.84	502.95	0.08
Salyan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surkhet	1625.24	26.01	24.45	103.64	0.25	0.00	4.62	15.35	11.36	7172.64	1.16
Dang	33.10	0.53	0.50	2.10	0.01	0.00	0.09	0.31	0.28	146.09	0.03
Banke	1827.39	29.25	27.49	116.48	0.29	0.00	5.20	17.26	12.90	8064.79	1.31
Bardia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bajhang	46.64	0.75	0.70	2.98	0.01	0.00	0.13	0.44	0.28	205.83	0.03
Bajura	145.19	2.32	2.18	9.29	0.02	0.00	0.41	1.37	0.98	640.77	0.10
Darchula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accham	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Baitadi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dadeldhura	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Doti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kailali	319.69	5.12	4.81	20.39	0.05	0.00	0.91	3.02	2.24	1410.87	0.23
Kanchanpur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	44673.99	715.00	672.00	2848.07	7.00	0.01	127.00	422.00	314.14	197159.00	32.00

3.4. Residential Sector

3.4.1. Overview

Biomass resources, namely fuelwood, agricultural residues and animal waste are the predominant sources of energy used in this sector, while the role of modern energy sources (electricity, LPG, kerosene, biogas and coal) is very small.Figure 18 presents the share of various fuels in the total residential sector energy consumption. Fuelwood has the largest share (i.e., 86.5%) in the sector's total energy consumption in 2008, followed by animal waste (6.5%), agricultural residues (3.7%), electricity (1.0%), LPG (0.9%), biogas (0.7%) and kerosene (0.6%). The shares of other energy resources like solar and coal are not significant in the total residential energy consumption. Energy is used in the sector mainly for cooking, heating, lighting and animal feed preparation. Since the main drivers behind the residential energy consumption are the total population (number of households) and the economic condition of households, the sectoral energy consumption pattern shows differences across the rural and urban areas of Nepal. Cooking accounts for the largest share (about 52%) of the total energy consumption by urban households and is followed by electric appliances (14%), lighting (13%), heating and cooling (10%), animal feeding (8%), and agricultural processing (3%) (WECS, 2010).

According to CBS (2009a), overall 68.4% of households in Nepal use fuelwood as their main source of cooking fuel, followed by LPG (12.3%), animal waste (10.7%), agricultural residue (4.3%), biogas (2.4%), kerosene (1.4%) and others (0.5%). The distribution of households by main fuel used for cooking according to the ecological belt and the development regions of Nepal are given in Annex 9. Among the three ecological belts of Nepal, the share of fuelwood used for cooking is highest in the mountain region (87.9%), followed by hill (76.2%) and terai (58.3%) regions. More than 75% of the rural households use fuelwood for cooking while only 35.8% of the urban households use fuelwood for cooking. Fuelwood is the major source of cooking energy for the rural households while LPG is the main source of fuel used for cooking for the urban households (CBS, 2009a).

The share of fuelwood in the total residential energy consumption in urban areas is around 29%, which is comparatively less than that of the rural residential sector. The shares of fuelwood and electricity in the urban residential sector of Nepal are almost the same (i.e. 29%), while the shares of LPG, kerosene, animal waste and biogas are 25%, 9%, 6% and 2% respectively. There has been a heavily decreasing trend of kerosene use in the residential sector in recent years, whereas the consumption of LPG has been growing at a high rate of 11.3% during the FY 1995/96 to 2008/09 (WECS, 2010).

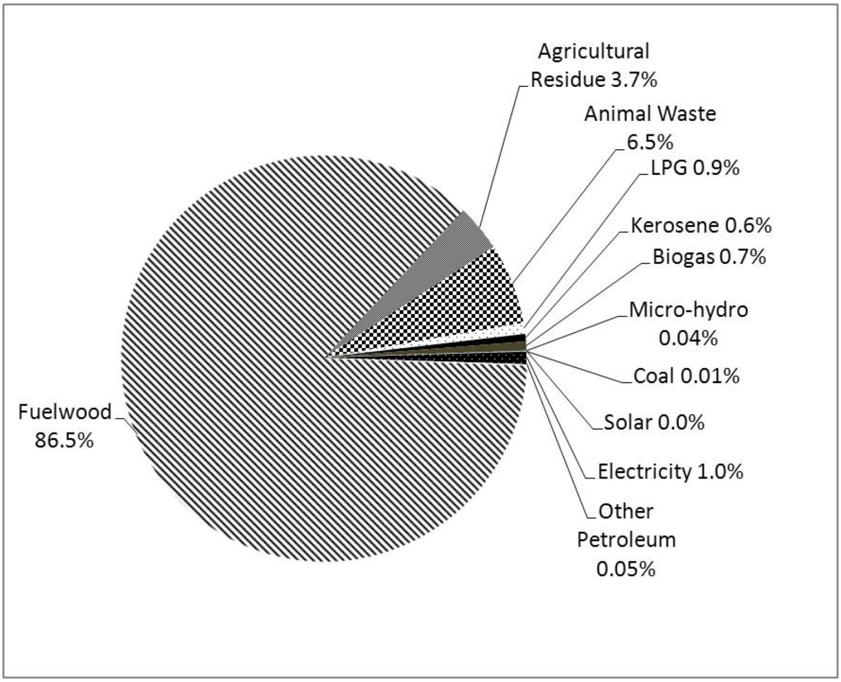


Figure 18: Residential Sector Energy Consumption by Fuel Type in FY 2008/09

(Source: WECS (2010))

Around 56% of households in Nepal had access to electricity and use it for lighting according to the "Nepal Labour Force Survey 2008" (CBS, 2009a), while the rest 44.0% of the households were dependent on gas, oil, kerosene and other fuels for lighting. Almost all (i.e. around 99.7%) of the households in Kathmandu Valley have access to electricity supply (CBS, 2009a). Among the development regions, the households in the Western development region have higher access to electricity (63.0%), followed by Central (62.2%), Eastern (58.2%), Far-western (43.7%), and Mid-western (34.4%) development regions. About 65.6% of the households still lack access to electricity supply and depend upon other forms of energy for lighting in the Mid-western development region; the corresponding figures in other regions are: 56.4% in Far-western-, 41.7% in Eastern, 37.8% in Central- and 36.5% in Western- development regions (see Annex 10).

3.4.2. Emission Estimation Method

The emissions from the residential sector are calculated by using the simple emission inventory equation proposed by EMEP/CORINAIR (see Equation 11). This method is generally used when detailed data are not available. The main data requirement of this method is consumption of different types of fuels in the sector.

The annual anthropogenic emissions from the sector are estimated as annual rates of emission-related activities multiplied by respective emission factors as expressed in the general emission inventory equation:

$$Em_{j,m,k} = A_{m,k} \times EF_{j,m,k} \tag{11}$$

where,

$Em_{j,m,k}$ denotes emission of pollutant type j, from fuel type m and end use k; $A_{m,k}$ is activity rate of fuel type m and enduse k, and $EF_{j,m,k}$ is emission factor specific to pollutant type j, fuel type m, and enduse type k in the residential sector.

3.4.3. Data on Activity Levels

Cooking and lighting are the two main activities in the residential sector. Besides, energy is also used for space heating, space cooling, water boiling, pumping, animal feed preparation and other electrical appliances. The data on fuel consumption in the sector are presented in Table 20. Figure 19 shows the share of different enduses in the total residential energy consumption in 2008/09.

3.4.4. Emission Factors

Table 21 presents the emission factors used in the estimation of emissions rom the residential sector. The emission factors for PM, CO_2, CO, CH_4, NO_X, SO_2 and N_2O for household stoves are based on available studies in the context of Asian countries (Zhang et al., 2000; Oanh et al., 1999; Bhattacharya et al., 2002; Venkataraman and Rao, 2001) as compiled in the ABC Emission Inventory Manual. The emission factors for BC and OC are based on Bond et al. (2004).

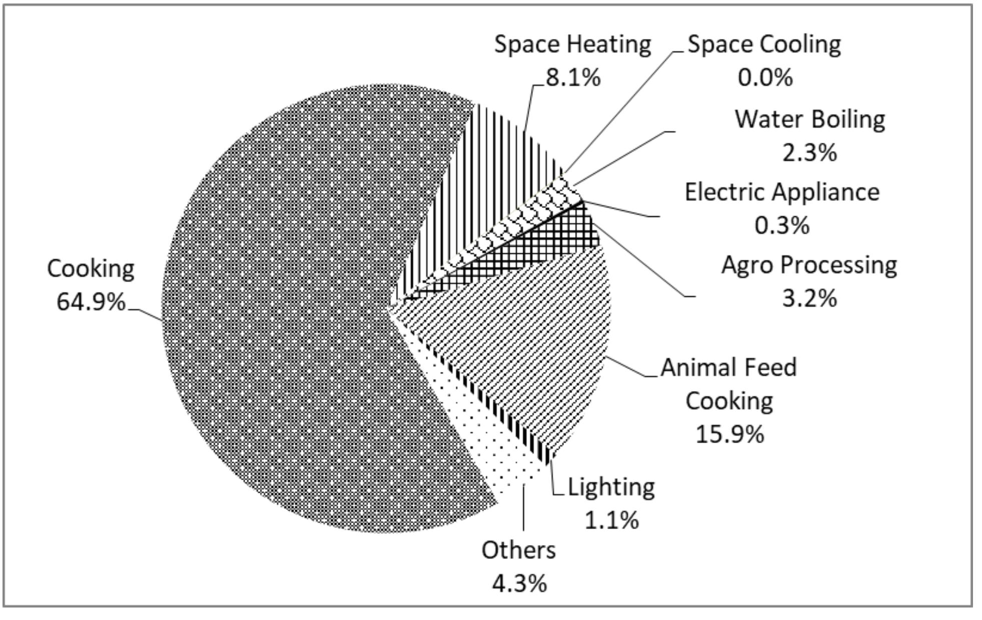


Figure 19: Structure of Total Residential Energy Consumption by Enduse Category, %

(Source: WECS (1997 and 2010))

Table 20: Fuel Consumption in the Residential Sector by Enduse Category in FY 2008/09, thousand GJ

Enduse Category	Fuel Types								
	Fuelwood	Agricultural Residue	Animal Waste	LPG	Kerosene	Biogas	Coal	Electricity	Total
Cooking	201277	7506	16798	2650	764	1944	30	230	231199
Lighting	-	-	-	-	1090	649	-	2088	3828
Water Boiling	7062	457	187	300	149	-	-	20	8176
Space Heating	23879	2276	2592	-	19	-	-	83	28848
Animal Feed Cooking	51908	2647	2069	4	8	-	-	3	56638
Agro Processing	10536	293	679	-	1	-	5	-	11512
Others	13942	156	693	247	97	-	-	34	15170
Total	**308604**	**13335**	**23017**	**3201**	**2127**	**2593**	**35**	**3534**	**356447**

Source: WECS (1997 and 2010)

Table 21: Emission Factors for the Residential Sector, g/kg

Fuel type	Air Pollutants							GHGs		
	NO_x[a]	CO[a]	SO_2[a]	PM_{10}[a]	$PM_{2.5}$[b]	BC[c]	OC[c]	CO_2[d]	CH_4[d]	N_2O
Residential Cooking										
Fuelwood	1.2, 0.05-0.2	69.2, 19-136	0.008	3.82, 2-5	3.1	0.3-1.4	1.7-7.8	1520, 1560-1620	5.06, 6-10	0.06[g]
Agricultural Residue	0.7	86.3, 75[g]	0.216, 6[g]	8.05, 5[i], 10[g]	-	0.12-0.17[l]	3.3	1130	4.56, 3.8-69	0.06[g], 0.16[d]
Animal waste	0.7-7, 3.85[e]	26-83, 54.5[e]	6[e]	4.1-20	-	0.53	1.8	1060[e]	3.9[g], 3.7[d]	0.053[g], 0.36[d]
Coal	0.914	71.3, 300[f]	2.67	1.3, 7[i]	1.17	0.76-5.4	0.4-4.3	2280	2.92, 6.7-66	-
Kerosene	1.1	7.39	0.025	0.13, 1.9[j]	0.12	0.9, 0.16[j]	0.09, 0.16[j]	3130	0.025	0.05-0.08
LPG/Gas	1.76	3.72	0.33	0.26, 0.33[j]	0.25	0.2, 0.01[j]	0.05, 0.03[j]	2980	0.14	0.03-0.16
Residential Space Heating										
Fuelwood	1.3	126.3[h]	0.2[h]	17.3[h], 12[c], 6.7[k]	-	1.8, 1.3[m]	7.2, 5.27[n]	1700[h]	-	0.15[d]

Source: [a]Zhang et al. (2000); [b]Assume a $PM_{2.5}$/PM ratio of 0.9 for coal, 0.964 for kerosene and LPG (Reddy and Venkataraman (2002a)) and 0.8 for wood and charcoal (Reddy and Venkataraman (2002b); [c]Bond et al. (2004); [d]IPCC Guideline (1996 and 2006); [e]Values are compiled by Bhattacharya et al. (2002) from various EF works in India and Nepal for improved biomass cooking stove; [f]EFs are determined by using a carbon balance approach for 56 types of fuel/stove combinations in China and India; [g]Ventakaraman and Rao (2001). Values are applicable for traditional cooking stoves; [h]USEPA (1996); [i]Oanh et al. (1999) (for charcoal only). For others refer to Oanh et al, (2005). EFs are derived from hood monitoring of 12 selected cooking stoves in Asia, using wood, rice husk briquettes and anthracite coal as fuel; [j]Values have been estimated and used by Reddy and Venkataraman (2002a) from various sources. For domestic coal, BC and OC fractions of PM for domestic coal combustion were 15% and 64%, respectively (Mumford et al., 1987); [k]Purvis et al. (2000). Fireplaces using wet/seasoned oak; [l]Venkataraman et al. (2005); [m]Muhlbaier and Williams (1982). Residential fireplace using softwood; [n]Fine et al. (2002). In $PM_{2.5}$, fireplace combustion, hardwoods with thermal methods with an optical correction based on reflectance or transmittance of light (TO).

3.4.5. Estimated Emissions

Table 22 presents the estimated emissions from the residential sector in FY 2008/09 for two different cases, i.e., a Low Emission Case (a case considering lower ranges of emission factors) and a High Emission Case (a case considering higher ranges of emission factors). Since cooking is the largest energy consuming enduse in the sector, it has the largest share in the total emissions (around 66.9%); it is followed by cooking/preparation of animal feed (17.1%), space heating (9.3%), agro-processing (3.5%), water boiling (2.6%) and lighting (0.6%).

Table 22: Annual Emissions of Air Pollutants and GHGs from the Residential Sector in FY 2008/09, tonne

Type of Air Pollutant/GHG	Emissions	
	Low Case	High Case
Air Pollutants		
SO_2[a]	9364	13129[b]
NO_X[a]	14925	27795[c]
CO[a]	1670604	2513100[b, c, d]
NMVOC	-	-
NH_3	15501	15501
PM_{10}[a]	90725[e]	140321[f]
$PM_{2.5}$[g]	58081	58081
BC[e]	26848	26848
OC[e]	65594	138621
GHGs		
CH_4[h]	98140	220190[b]
CO_2[a, c]	30207529	31409183
N_2O	1313[b]	1827[h]

Note: [a]EFs based on Zhang et al. (2000); [b]EFs based on Ventakaraman and Rao (2001). Values are applicable for traditional cooking stoves; [c]Values compiled by Bhattacharya et al. (2002) from various EF works in India and Nepal for improved biomass cooking stove are used; [d]EFs based on a carbon balance approach for 56 types of fuel/stove combinations in China and India are used; [e]Bond et al. (2004);[f]EFs estimated and used by Reddy and Venkataraman (2002a) from various sources has been used;[g]Assumed a $PM_{2.5}$/PM ratio of 0.9 for coal, 0.964 for kerosene and LPG and 0.8 for wood and charcoal (based on Reddy and Venkataraman (2002);[i]IPCC Guideline (1996 and 2006).

3.4.6. Temporal and Spatial Variations

In order to get the temporal pattern of the residential sector emissions, monthly kerosene sales data obtained from the Nepal Oil Corporation has been used. Figure 20 shows the monthly kerosene sales pattern in Nepal for the year 2008/09. The figure shows two peaks, one minor peak around the month of March and a major spike around the month of September. The higher levels of kerosene consumption in these months result in higher amounts of residential emissions during these months.

Figure 21 shows the temporal pattern of emissions from the residential sector in FY 2008/09 in Low Emission Case.

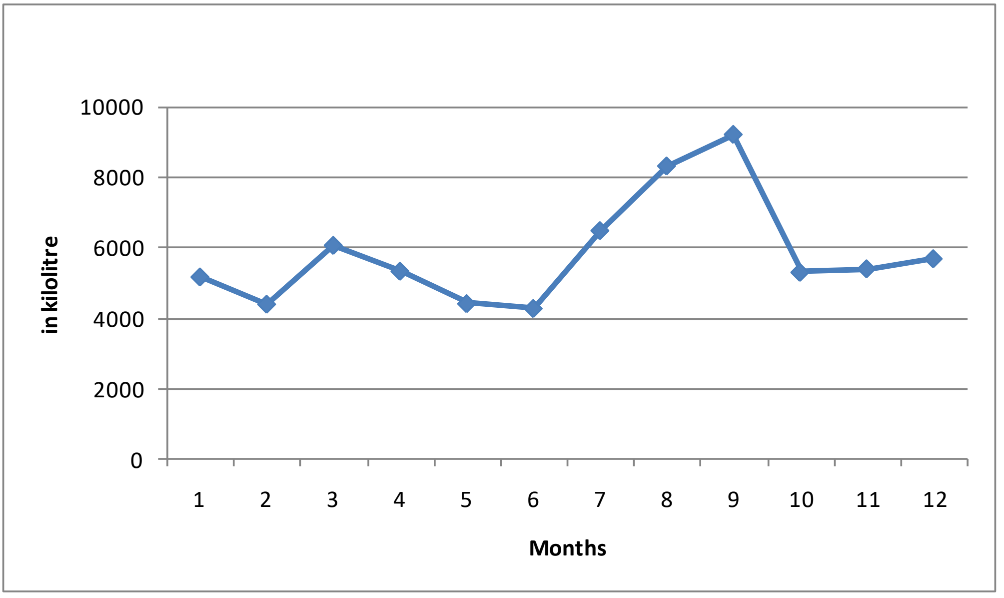


Figure 20: Monthly Pattern of Kerosene Sold in Nepal in FY 2008/09[16]

[16] *Based on data obtained from Nepal Oil Corporation.*

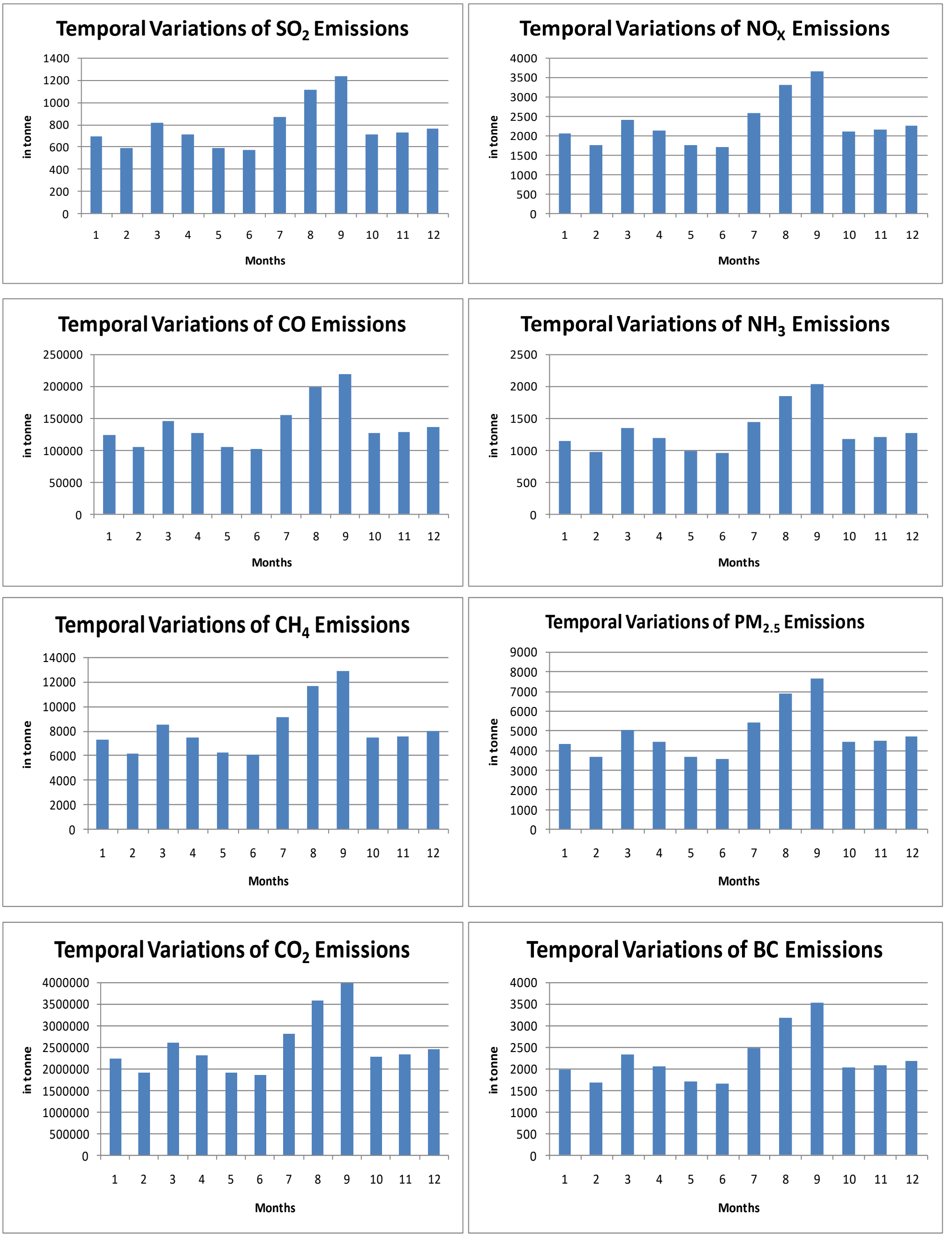
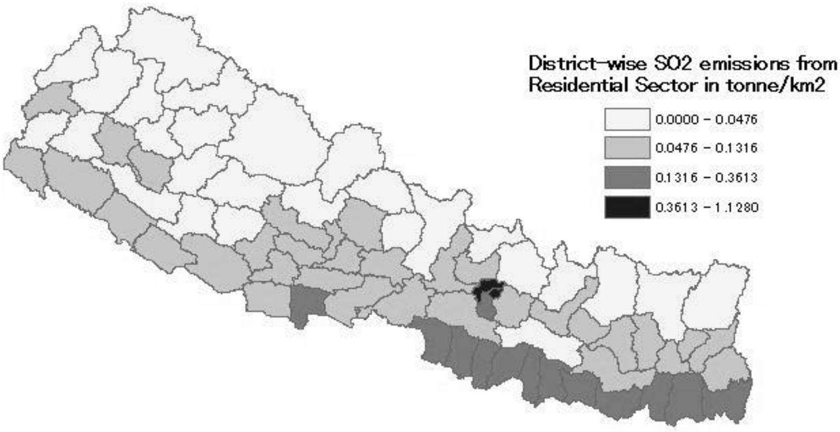
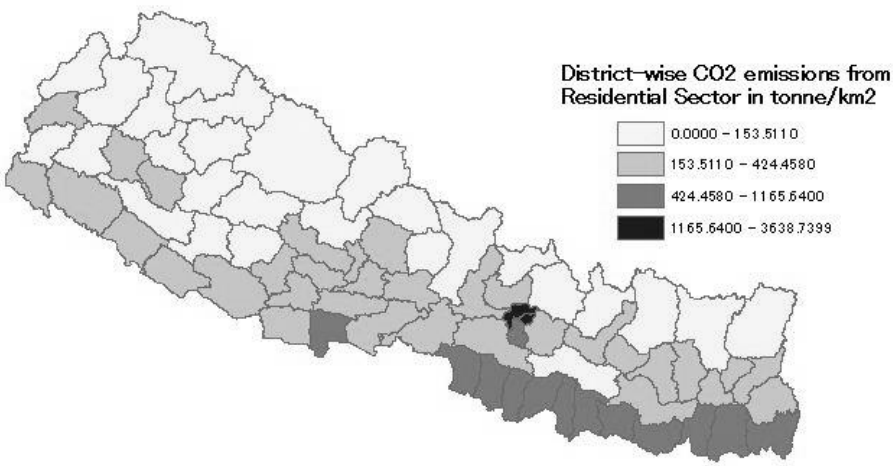


Figure 21: Monthly Patterns of Air Pollutants and GHGs Emissions from the Residential Sector in FY 2008/09 (Low Emission Case)



a) SO_2 Emission Density



b) CO_2 Emission Density

Figure 22: Spatial Variation of SO_2 and CO_2 Emission Densities from the Residential Sector

For the spatial distribution of emissions, district-wise population of FY 2008/09 has been considered as a basis. The district-wise population has been further disaggregated into the district-wise rural and urban population using the urban population share in 2011 based on the urban population of 58 municipalities of Nepal (CBS, 2012). Figure 22 shows the spatial distribution of SO_2 and CO_2 emissions from the residential sector. It is clear from Figure 22[17] that the total emissions from the residential sector originates from the Central and Eastern development regions of the country where most of the population resides. It is found that eight districts together (i.e., Kathmandu (4.8%), Morang (3.7%), Rupandehi (3.1%), Dhanusa (3.0%), Sunsari (2.8%), Sarlahi (2.8%), Jhapa (2.8%) and Kailali (2.7%) districts) accounted for about 25.7% of the total national emission from the residential sector in FY 2008/09, while the rest 67 districts accounted for the remaining emissions.

Figure 23 and Figure 24 present the spatial variation of total CO_2 and SO_2 emissions (in terms of emission density) from the urban and rural residential sectors respectively under the Low Emission Case. The spatial distributions of other emissions from the urban and rural residential sectors are presented in the Annexes 11 and 12 respectively.

The estimated district-wise emissions by pollutant type from the urban and rural residential sectors under the Low Emission Case are presented in Table 23 and 24.

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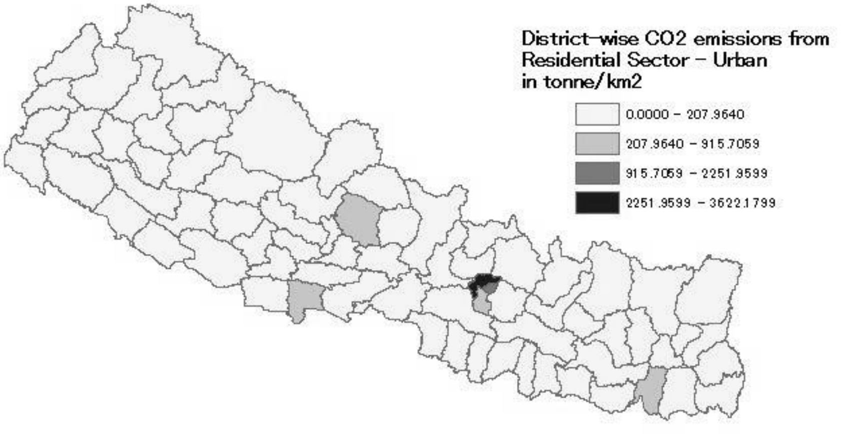
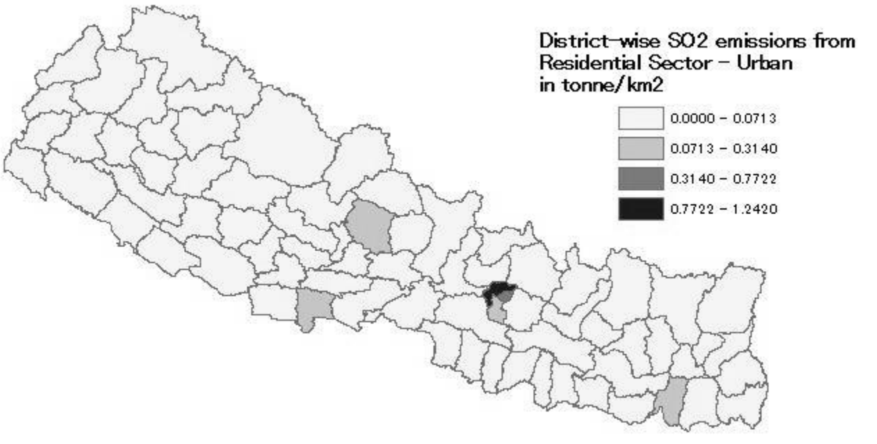
[17] *This is under the Low Emission Factor Case.*

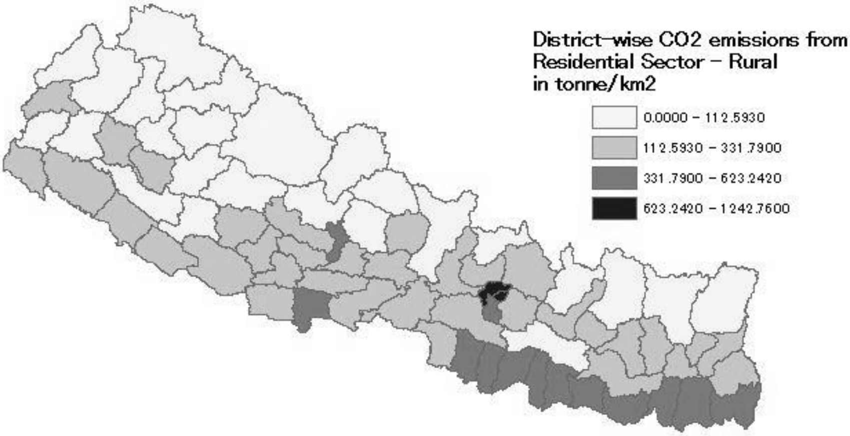


a) CO_2 Emission Density

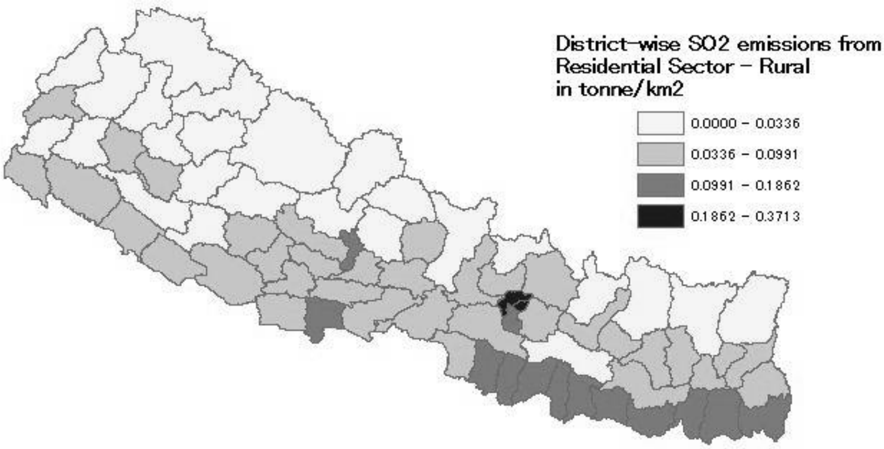


b) SO_2 Emission Density

Figure 23: Spatial Variation of CO_2 and SO_2 Emission Densities from the Residential Sector-Urban



a) CO_2 Emission Density



b) SO_2 Emission Density

Figure 24: Spatial Variation of CO_2 and SO_2 Emission Densities from the Residential Sector-Rural

Table 23: Estimated District-wise Emissions from the Urban Residential Sector of Nepal, tonne

Districts	Emissions from Urban Residential Sector										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Sankhuwasabha	19.76	53.01	2994.54	29.49	156.53	98.06	51.25	126.21	178.76	57613.83	2.38
Solukhumbu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Taplejung	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bhojpur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dhankuta	21.35	57.30	3236.58	31.87	169.19	105.99	55.39	136.41	193.21	62270.56	2.57
Ilam	13.99	37.53	2120.12	20.88	110.83	69.43	36.29	89.36	126.56	40790.21	1.68
Khotang	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Okhaldhunga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panchthar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terhathum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Udaypur	47.81	128.28	7246.16	71.35	378.78	237.29	124.02	305.41	432.57	139413.28	5.76
Jhapa	87.67	235.24	13288.22	130.84	694.62	435.15	227.42	560.07	793.26	255660.09	10.56
Morang	132.28	354.97	20051.02	197.43	1048.13	656.61	343.17	845.10	1196.98	385773.73	15.93
Saptari	25.21	67.64	3820.93	37.62	199.73	125.12	65.39	161.04	228.10	73513.11	3.04
Siraha	41.47	111.27	6285.40	61.89	328.56	205.83	107.57	264.91	375.22	120928.67	4.99
Sunsari	136.67	366.74	20716.03	203.98	1082.89	678.39	354.55	873.13	1236.68	398568.32	16.46
Dolakha	16.26	43.63	2464.75	24.27	128.84	80.71	42.18	103.88	147.14	47420.78	1.96
Rasuwa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sindhupalchowk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bhaktapur	91.89	246.58	13928.75	137.15	728.10	456.13	238.39	587.06	831.50	267983.66	11.07

Districts	Emissions from Urban Residential Sector										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Dhading	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kathmandu	490.62	1316.51	74365.44	732.24	3887.31	2435.26	1272.74	3134.32	4439.37	1430761.91	59.09
Kavre	51.84	139.10	7857.08	77.37	410.71	257.30	134.47	331.16	469.04	151167.06	6.24
Lalitpur	120.89	324.39	18324.02	180.43	957.85	600.06	313.61	772.31	1093.88	352546.93	14.56
Makawanpur	59.10	158.58	8957.74	88.20	468.25	293.34	153.31	377.55	534.75	172343.46	7.12
Nuwakot	21.48	57.63	3255.12	32.05	170.16	106.60	55.71	137.20	194.32	62627.24	2.59
Ramechhap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sindhuli	28.44	76.32	4310.99	42.45	225.35	141.17	73.78	181.70	257.35	82941.81	3.43
Bara	25.92	69.54	3928.31	38.68	205.35	128.64	67.23	165.57	234.51	75579.20	3.12
Chitwan	116.91	313.71	17720.43	174.49	926.30	580.29	303.28	746.87	1057.85	340934.08	14.08
Dhanusa	64.71	173.63	9808.01	96.58	512.70	321.18	167.86	413.38	585.51	188702.31	7.79
Mahaottari	16.14	43.31	2446.33	24.09	127.88	80.11	41.87	103.11	146.04	47066.48	1.94
Parsa	85.02	228.13	12886.40	126.89	673.61	421.99	220.55	543.13	769.28	247929.34	10.24
Rautahat	20.75	55.67	3144.85	30.97	164.39	102.98	53.82	132.55	187.74	60505.59	2.50
Sarlahi	15.34	41.17	2325.82	22.90	121.58	76.16	39.81	98.03	138.84	44747.82	1.85
Manang	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mustang	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Argakhanchi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Baglung	22.76	61.07	3449.81	33.97	180.33	112.97	59.04	145.40	205.94	66373.08	2.74
Gorkha	26.60	71.38	4032.01	39.70	210.77	132.04	69.01	169.94	240.70	77574.38	3.20
Gulmi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kaski	185.42	497.54	28104.60	276.73	1469.12	920.35	481.00	1184.54	1677.75	540721.46	22.33

Districts	Emissions from Urban Residential Sector										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Lamjung	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Myagdi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palpa	23.68	63.53	3588.83	35.34	187.60	117.52	61.42	151.26	214.24	69047.72	2.85
Parbat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Syangja	45.04	120.85	6826.58	67.22	356.85	223.55	116.84	287.72	407.52	131340.73	5.42
Tanahu	31.43	84.33	4763.51	46.90	249.00	155.99	81.53	200.77	284.37	91648.05	3.79
Kapilbastu	19.24	51.62	2915.68	28.71	152.41	95.48	49.90	122.89	174.06	56096.48	2.32
Nawalparasi	18.73	50.25	2838.51	27.95	148.38	92.95	48.58	119.64	169.45	54611.91	2.26
Rupandehi	110.35	296.12	16726.71	164.70	874.36	547.75	286.27	704.99	998.53	321815.41	13.29
Dolpa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Humla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jumla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mugu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kalikot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dailekh	13.98	37.52	2119.42	20.87	110.79	69.41	36.27	89.33	126.52	40776.90	1.68
Jajarkot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pyuthan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rolpa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rukum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salyan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surkhet	29.64	79.53	4492.41	44.23	234.83	147.11	76.89	189.34	268.18	86432.26	3.57
Dang	72.55	194.68	10996.58	108.28	574.83	360.11	188.20	463.48	656.46	211569.98	8.74

Districts	Emissions from Urban Residential Sector										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Banke	42.82	114.89	6489.71	63.90	339.24	212.52	111.07	273.53	387.41	124859.48	5.16
Bardia	37.94	101.80	5750.25	56.62	300.58	188.30	98.41	242.36	343.27	110632.53	4.57
Bajhang	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bajura	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Darchula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accham	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Baitadi	12.03	32.29	1823.73	17.96	95.33	59.72	31.21	76.87	108.87	35087.80	1.45
Dadeldhura	14.59	39.16	2211.82	21.78	115.62	72.43	37.85	93.22	132.04	42554.64	1.76
Doti	19.16	51.40	2903.45	28.59	151.77	95.08	49.69	122.37	173.33	55861.20	2.31
Kailali	94.60	253.85	14339.15	141.19	749.55	469.57	245.41	604.36	856.00	275879.57	11.39
Kanchanpur	66.01	177.13	10005.30	98.52	523.01	327.64	171.24	421.70	597.28	192497.99	7.95
Total	**2638.05**	**7078.83**	**399861.10**	**3937.25**	**20901.99**	**13094.31**	**6843.52**	**16853.16**	**23870.38**	**7693171.00**	**317.74**

Table 24: Estimated District-wise Emissions of Air Pollutants and GHGs from the Rural Residential Sector of Nepal, tonne

Districts	Emissions from Rural Residential Sector										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Sankhuwasabha	46.48	143.17	8782.42	79.92	482.56	310.91	138.26	336.86	513.30	155602.31	6.88
Solukhumbu	37.79	116.39	7139.43	64.97	392.29	252.75	112.39	273.84	417.27	126492.76	5.59
Taplejung	47.27	145.59	8930.29	81.27	490.69	316.15	140.58	342.53	521.94	158222.26	6.99
Bhojpur	71.24	219.43	13459.82	122.48	739.57	476.50	211.89	516.27	786.67	238473.97	10.54
Dhankuta	48.28	148.70	9121.54	83.01	501.20	322.92	143.59	349.87	533.12	161610.70	7.14
Ilam	92.60	285.21	17494.72	159.20	961.28	619.35	275.41	671.03	1022.49	309962.25	13.70
Khotang	81.20	250.09	15340.51	139.60	842.91	543.08	241.50	588.40	896.59	271795.11	12.01
Okhaldhunga	54.99	169.37	10389.13	94.54	570.85	367.79	163.55	398.49	607.20	184069.14	8.14
Panchthar	70.90	218.39	13396.04	121.90	736.07	474.24	210.89	513.82	782.94	237343.96	10.49
Terhathum	39.69	122.25	7499.11	68.24	412.05	265.48	118.05	287.64	438.29	132865.21	5.87
Udaypur	78.25	241.02	14784.26	134.54	812.34	523.39	232.74	567.07	864.08	261939.78	11.58
Jhapa	180.51	555.98	34104.30	310.35	1873.92	1207.36	536.88	1308.11	1993.25	604242.02	26.71
Morang	233.08	717.89	44035.79	400.73	2419.62	1558.95	693.23	1689.04	2573.71	780203.05	34.49
Saptari	188.15	579.51	35547.25	323.48	1953.20	1258.44	559.60	1363.46	2077.59	629807.48	27.84
Siraha	180.29	555.29	34061.83	309.96	1871.58	1205.85	536.21	1306.48	1990.77	603489.62	26.68
Sunsari	154.64	476.30	29216.44	265.87	1605.34	1034.32	459.94	1120.63	1707.58	517641.50	22.88
Dolakha	54.01	166.35	10203.80	92.85	560.66	361.23	160.63	391.38	596.37	180785.56	7.99
Rasuwa	15.70	48.35	2965.60	26.99	162.95	104.99	46.69	113.75	173.33	52543.02	2.32
Sindhupalchowk	103.07	317.46	19473.17	177.21	1069.98	689.39	306.55	746.92	1138.13	345015.40	15.25
Bhaktapur	35.48	109.28	6703.09	61.00	368.31	237.30	105.52	257.10	391.77	118761.81	5.25
Dhading	118.84	366.03	22452.56	204.32	1233.69	794.86	353.46	861.19	1312.26	397802.75	17.59
Kathmandu	146.65	451.69	27706.65	252.13	1522.39	980.87	436.17	1062.72	1619.34	490891.98	21.70
Kavre	110.72	341.03	20918.79	190.36	1149.42	740.56	329.31	802.36	1222.62	370628.12	16.38
Lalitpur	61.12	188.27	11548.38	105.09	634.54	408.83	181.80	442.95	674.95	204608.15	9.04
Makawanpur	109.71	337.90	20726.87	188.61	1138.87	733.77	326.29	795.00	1211.40	367227.75	16.23
Nuwakot	91.03	280.38	17198.94	156.51	945.02	608.87	270.75	659.69	1005.21	304721.73	13.47
Ramechhap	74.54	229.58	14082.36	128.15	773.78	498.54	221.69	540.15	823.06	249503.88	11.03

Districts	Emissions from Rural Residential Sector										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Sindhuli	83.79	258.07	15830.14	144.05	869.81	560.42	249.20	607.18	925.21	280470.16	12.40
Bara	183.90	566.42	34744.65	316.18	1909.10	1230.03	546.96	1332.67	2030.68	615587.52	27.21
Chitwan	110.13	339.21	20807.11	189.34	1143.28	736.61	327.55	798.08	1216.09	368649.47	16.30
Dhanusa	204.86	630.98	38704.99	352.22	2126.71	1370.23	609.31	1484.58	2262.14	685754.63	30.31
Mahaottari	186.56	574.61	35247.01	320.75	1936.70	1247.81	554.87	1351.94	2060.04	624488.02	27.61
Parsa	134.11	413.06	25337.26	230.57	1392.20	896.99	398.87	971.84	1480.86	448912.22	19.84
Rautahat	181.44	558.85	34280.02	311.95	1883.57	1213.58	539.65	1314.85	2003.52	607355.41	26.85
Sarlahi	215.79	664.64	40769.42	371.00	2240.14	1443.31	641.81	1563.76	2382.80	722331.16	31.93
Manang	3.36	10.36	635.61	5.78	34.92	22.50	10.01	24.38	37.15	11261.32	0.50
Mustang	5.26	16.19	993.22	9.04	54.57	35.16	15.64	38.10	58.05	17597.35	0.78
Argakhanchi	73.13	225.23	13816.04	125.73	759.14	489.11	217.50	529.93	807.49	244785.34	10.82
Baglung	83.57	257.38	15788.15	143.67	867.51	558.93	248.54	605.57	922.75	279726.19	12.37
Gorkha	88.48	272.52	16716.27	152.12	918.50	591.79	263.15	641.17	977.00	296170.14	13.09
Gulmi	104.10	320.63	19667.76	178.98	1080.68	696.28	309.62	754.38	1149.50	348462.98	15.40
Kaski	45.48	140.08	8592.82	78.19	472.15	304.20	135.27	329.59	502.21	152243.11	6.73
Lamjung	62.16	191.47	11744.74	106.88	645.33	415.79	184.89	450.48	686.43	208087.09	9.20
Myagdi	40.16	123.70	7587.68	69.05	416.92	268.62	119.45	291.03	443.47	134434.54	5.94
Palpa	83.00	255.63	15680.74	142.69	861.60	555.13	246.85	601.45	916.47	277823.08	12.28
Parbat	55.38	170.58	10463.65	95.22	574.94	370.43	164.72	401.35	611.56	185389.44	8.20
Syangja	89.96	277.09	16997.11	154.67	933.93	601.73	267.57	651.94	993.41	301145.92	13.31
Tanahu	95.70	294.75	18080.18	164.53	993.44	640.07	284.62	693.49	1056.71	320335.14	14.16
Kapilbastu	160.00	492.80	30228.51	275.08	1660.95	1070.15	475.87	1159.45	1766.73	535572.92	23.68
Nawalparasi	188.63	580.97	35637.35	324.30	1958.15	1261.63	561.02	1366.91	2082.85	631403.83	27.91
Rupandehi	196.19	604.27	37066.38	337.30	2036.67	1312.22	583.51	1421.72	2166.38	656722.72	29.03
Dolpa	7.75	23.85	1463.28	13.32	80.40	51.80	23.04	56.13	85.52	25925.58	1.15
Humla	14.25	43.88	2691.39	24.49	147.88	95.28	42.37	103.23	157.30	47684.69	2.11
Jumla	24.29	74.82	4589.59	41.77	252.18	162.48	72.25	176.04	268.24	81315.94	3.59
Mugu	11.04	34.01	2086.09	18.98	114.62	73.85	32.84	80.01	121.92	36960.19	1.63
Kalikot	4.04	12.44	763.10	6.94	41.93	27.02	12.01	29.27	44.60	13520.16	0.60

Districts	Emissions from Rural Residential Sector										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Dailekh	72.39	222.95	13676.00	124.45	751.45	484.16	215.29	524.56	799.30	242304.11	10.71
Jajarkot	47.33	145.77	8941.56	81.37	491.31	316.55	140.76	342.96	522.60	158421.95	7.00
Pyuthan	74.56	229.66	14087.40	128.20	774.05	498.72	221.77	540.34	823.35	249593.16	11.03
Rolpa	73.69	226.98	13922.98	126.70	765.02	492.90	219.18	534.03	813.74	246680.04	10.90
Rukum	66.13	203.67	12493.18	113.69	686.46	442.28	196.67	479.19	730.17	221347.66	9.78
Salyan	21.28	65.54	4020.55	36.59	220.92	142.33	63.29	154.21	234.98	71233.96	3.15
Surkhet	80.63	248.33	15232.88	138.62	836.99	539.27	239.80	584.27	890.30	269888.11	11.93
Dang	127.80	393.64	24146.09	219.73	1326.75	854.82	380.12	926.15	1411.24	427807.84	18.91
Banke	115.06	354.40	21739.29	197.83	1194.50	769.61	342.23	833.84	1270.57	385165.41	17.03
Bardia	116.26	358.09	21965.44	199.89	1206.93	777.62	345.79	842.51	1283.79	389172.06	17.20
Bajhang	58.61	180.53	11073.60	100.77	608.46	392.03	174.32	424.74	647.21	196196.17	8.67
Bajura	35.31	108.76	6671.37	60.71	366.57	236.18	105.02	255.89	389.91	118199.77	5.23
Darchula	42.81	131.86	8088.17	73.60	444.42	286.34	127.33	310.23	472.72	143301.93	6.33
Accham	81.16	249.98	15333.88	139.54	842.54	542.85	241.39	588.15	896.20	271677.65	12.01
Baitadi	76.55	235.77	14462.10	131.60	794.64	511.99	227.67	554.71	845.25	256231.87	11.33
Dadeldhura	37.34	115.02	7055.15	64.20	387.66	249.77	111.06	270.61	412.34	124999.47	5.53
Doti	63.57	195.79	12009.59	109.29	659.89	425.16	189.06	460.64	701.91	212779.66	9.41
Kailali	171.48	528.17	32398.58	294.83	1780.19	1146.97	510.03	1242.69	1893.56	574021.05	25.37
Kanchanpur	101.26	311.90	19131.88	174.10	1051.23	677.30	301.18	733.83	1118.18	338968.61	14.98
Total	**6725.95**	**20716.17**	**1270743.00**	**11563.75**	**69823.01**	**44986.69**	**20004.48**	**48740.84**	**74269.62**	**22514358.00**	**995.26**

3.5. Commercial Sector

3.5.1. Overview

Around 5.2 million GJ of energy was consumed in the commercial sector of Nepal in FY 2008/09; the sector accounted for around 1.3% in the total energy consumption of Nepal. LPG accounted for the largest share (44.7%) in the total energy consumption in this sector; it was followed by fuelwood (36.0%), electricity (11.0%) and kerosene (5.9%). Figure 25 shows the share of various fuels consumed in the commercial sector in FY 2008/09. The main enduses of commercial sector are quite similar to the residential sector such as cooking, lighting, space heating, space cooling, water boiling, electric appliances etc. Cooking is the largest enduse and accounts for about 68.4% of the total energy consumption in this sector; it is followed by lighting (19.3%), electric appliances (6.7%), space heating and cooling (5.3%) and water boiling (0.3%) (WECS, 2010).

3.5.2. Emission Estimation Method

The method used for the estimation of emissions from the commercial sector in this study is similar to the one used for the residential sector discussed earlier. Fuel consumption by type of enduse is the main activity data required in this sector. The total emission of a specific pollutant from the use of a specific fuel is calculated as:

$$Em_{j,m,k} = A_{m,k} \times EF_{j,m,k} \quad (12)$$

where,

$Em_{j,m,k}$ is emissions from pollutant type j, fuel type m and enduse k; $A_{m,k}$ is the activity rate of fuel type m and enduse k; and $EF_{j,m,k}$ is the emission factor specific to pollutant type j, fuel type m, and enduse type k of the commercial sector.

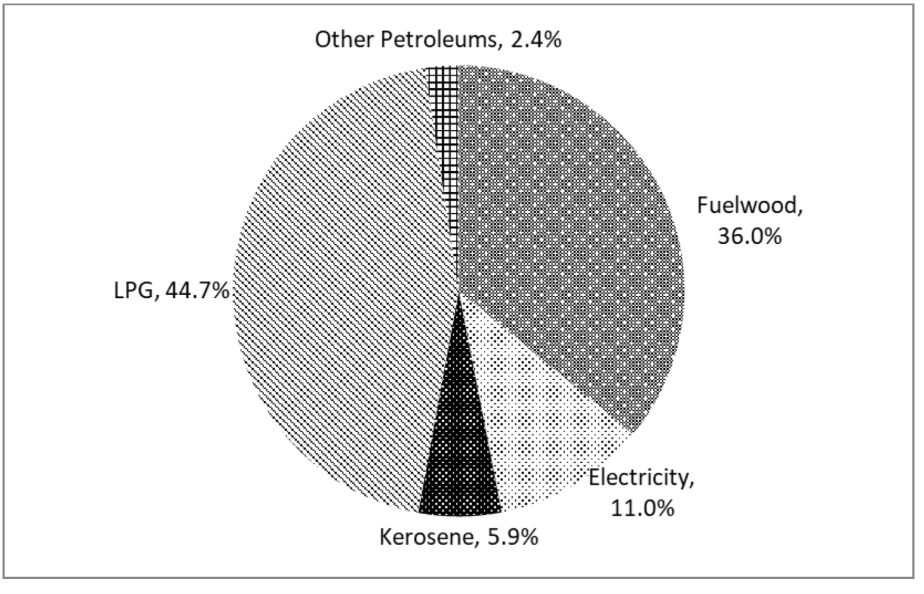


Figure 25: Commercial Sector Energy Consumption by Fuel Type in 2008/09, %

(Source: WECS (2010))

3.5.3. Data on Activity Levels

The required activity data is the rate of annual fuel consumption for each of the enduses, i.e., cooking, space heating, water boiling, lighting etc. The fuel consumption data of the commercial sector for FY 2008/09 has been obtained from the "Energy Synopsis Report 2010" (WECS, 2010). Since the disaggregated fuel consumption data in the form of enduse category for FY 2008/09 were not available, the enduse data has been estimated based on the enduse shares given in the Water and Energy Commission Secretariat study for the year 1996 (WECS, 1997). The fuel consumption data in the commercial sector by enduse category for the FY 2008/09 are presented in Table 25. Around 76.9% of the total commercial fuels were estimated used for cooking, followed by lighting (10.8%), space heating (8.8%), water boiling (1.6%), space cooling (1.2%), electric appliance (0.7%), and others (0.1%). Around 98% of fuelwood was used for cooking in the commercial sector, while the remaining 2% were used for water boiling and space heating purposes. Apart from fuelwood, kerosene, LPG and electricity are also used as cooking fuels in Nepal in this sector. Based on WECS (1997), all of the LPG consumption in this sector was assumed to be used for cooking while around 83% of kerosene was assumed to be utilized for cooking purposes. Other petroleum products used for providing lighting and electric appliances services as reported in WECS (2010) are considered to have been used for captive power generation in the commercial sector; this has been discussed under emissions from Energy Industry in Section 3.1.

3.5.4. Emission Factors

For commercial activities, the emission factors of all the pollutants and GHGs are considered to be the same as that used for the residential sector (see Table 21).

3.5.5. Estimated Emissions

Table 26 shows two cases of emission estimates, i.e., the emissions using lower range values of emission factors (i.e., Low Emission Case) and those using the higher range values (i.e., High Emission Case) of emission factors. Emissions from the commercial sector mainly arise due to the use of fuelwood and petroleum products (e.g., LPG and kerosene) for cooking. Commercial cooking are the important contributors to CO and CO_2 emissions (see Table 26). Around 95.7% of total emissions from the commercial sector come from cooking; it is followed by lighting (2.3%), water boiling (1.1%) and space heating (0.9%).

Table 25: Fuel Consumption in the Commercial Sector by Enduse Category in FY 2008/09, thousand GJ

Fuel type/ Enduse	Cooking	Space Heating	Space Cooling	Water Boiling	Electrical Appliance	Lighting	Others	Total
Fuelwood	1805	2	0	36	0	0	0	1842
Agricultural Residue	0	0	0	0	0	0	0	0
Animal Waste	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	0
Kerosene	253	40	0	8	0	2	0	304
LPG	2290	0	0	0	0	0	0	2290
Other Petroleums	0	0	0	0	6	117	0	123
Electricity	47	152	46	3	20	292	3	563
Total	**4395**	**194**	**46**	**47**	**26**	**411**	**3**	**5122**

Source: WECS (1998 and 2010)

Table 26: Annual Emissions of Air Pollutants and GHGs from the Commercial Sector, tonne

Air Pollutants	Emissions	
	Low Case	High Case
SO_2[a]	16	16
NO_X[a]	221	111
CO[a]	7835	15174[b,c,d]
NMVOC	-	-
NH_3	142	142
PM_{10}[a]	434[e]	578[f]
$PM_{2.5}$[g]	192	192
BC[e]	51	169
OC[e]	190	860
GHGs		
CH_4[h]	563	1096
CO_2[a,c]	326081	336855
N_2O	8[b]	15[h]

Note: [a]EFs based on Zhang et al. (2000); [b]EFs based on Ventakaraman and Rao (2001). Values are applicable for traditional cooking stoves; [c]Values compiled by Bhattacharya et al. (2002) from various EF works in India and Nepal for improved biomass cooking stove are used; [d]EFs based on a carbon balance approach for 56 types of fuel/stove combinations in China and India are used; [e]Bond et al. (2004); [f]EFs estimated and used by Reddy and Venkataraman (2002a) from various sources has been used; [g]Assumed a $PM_{2.5}$/PM ratio of 0.9 for coal, 0.964 for kerosene and LPG and 0.8 for wood and charcoal (based on Reddy and Venkataraman (2002); [h]IPCC Guideline (1996 and 2006)

3.5.6. Temporal and Spatial Variations

The monthly variation of the emissions in the commercial sector has been estimated using the monthly kerosene consumption pattern obtained from the Nepal Oil Corporation (as shown in Figure 20) as a proxy. To obtain the monthly emissions, the monthly fractional factor[18] is multiplied by the annual average emission. Figure 26 shows the monthly pattern of emissions from the commercial sector. The temporal variation of emissions shows an increase in the sectoral emissions during the months of July – September. As the commercial sector is rapidly growing, the sectoral emissions are also increasing.

In order to estimate spatial distribution of emissions, data on district level fuel consumption are needed. However, due to lack of district level commercial fuel consumption data, the district level population has been used as the proxy for this purpose. Figure 27 shows the district wise distribution of emissions from the commercial sector.

[18] The monthly fractional factor is obtained as the ratio of monthly fuel consumption to the total yearly fuel consumption.

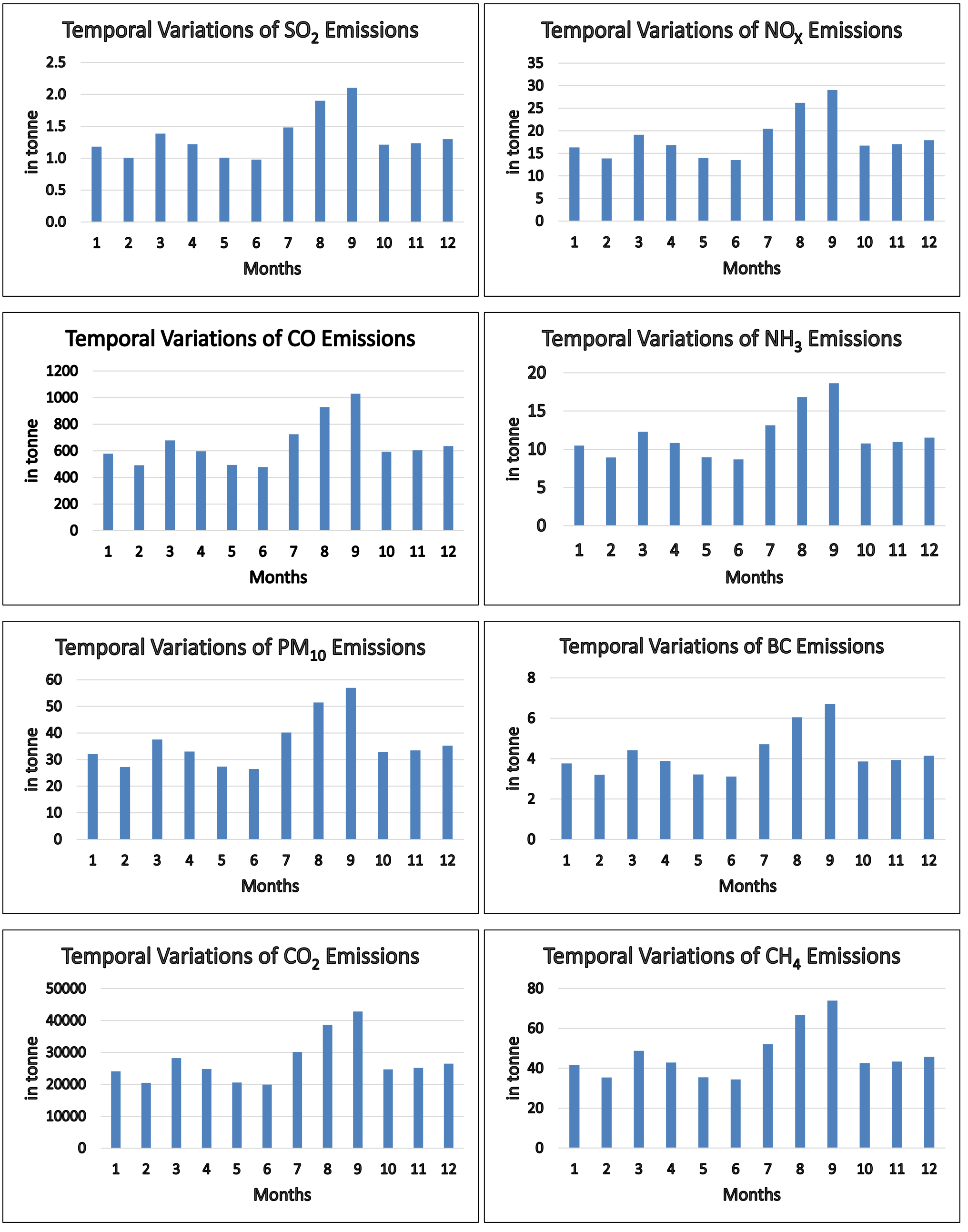
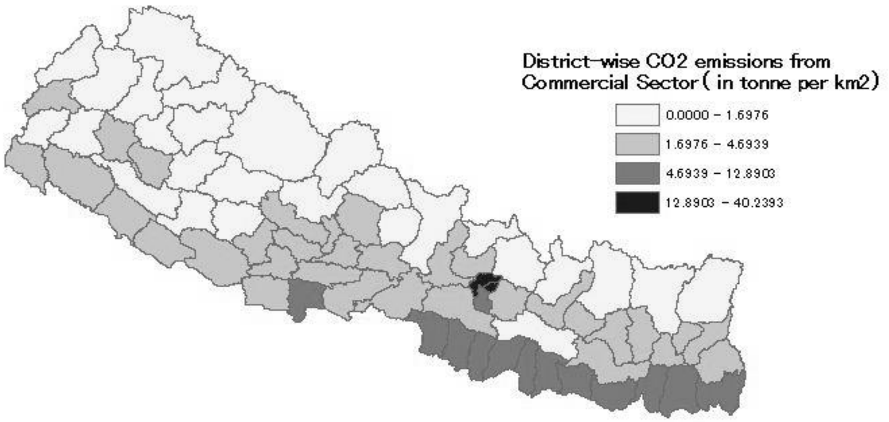
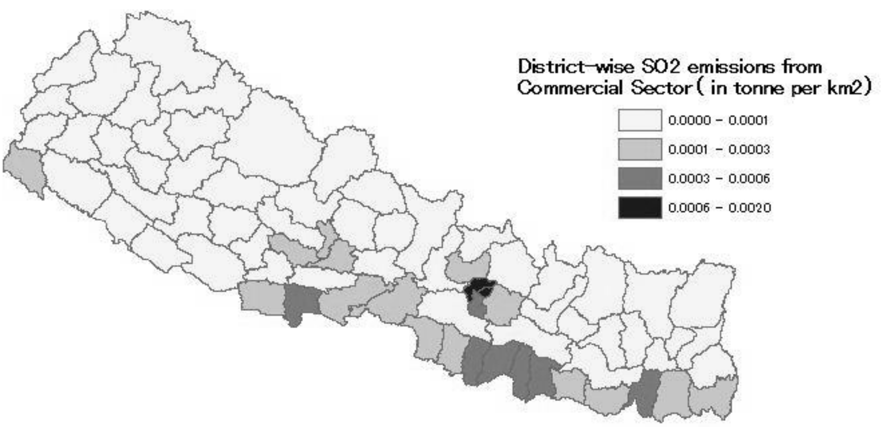


Figure 26: Temporal Pattern of Emissions of Air Pollutants and GHGs from the Commercial Sector, tonne (Low Emission Case)

The estimated district-wise emissions by pollutant type from the commercial sector are presented in Table 27. Among the districts, Kathmandu is the main center with clustered commercial buildings and institutions, and occupies a share of 4.8% of the total commercial emissions. Since district level population data has been used as a proxy factor to distribute the commercial sector's total emissions among the districts, it may not give the accurate picture of commercialization. The district wise variations of densities of other emissions from the commercial sector are presented in the Annex 13.



a) CO_2 Emission Density



b) SO_2 Emission Density

Figure 27: Spatial Distribution of CO_2 and SO_2 Emission Densities of the Commercial Sector

Table 27: District-wise Commercial Sector Emissions in FY 2008/09, tonne

Districts	Estimates of Emissions of Air Pollutants and GHGs from Commercial Sectors										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Sankhuwasabha	0.11	1.55	54.86	0.99	3.04	1.34	1.18	1.33	3.94	2283.20	0.06
Solukhumbu	0.08	1.05	37.11	0.67	2.06	0.91	0.80	0.90	2.67	1544.38	0.04
Taplejung	0.09	1.31	46.42	0.84	2.57	1.14	1.00	1.13	3.34	1931.77	0.05
Bhojpur	0.14	1.97	69.96	1.27	3.88	1.71	1.51	1.70	5.03	2911.58	0.07
Dhankuta	0.12	1.62	57.37	1.04	3.18	1.41	1.24	1.39	4.12	2387.55	0.06
Ilam	0.20	2.75	97.45	1.77	5.40	2.39	2.10	2.36	7.00	4055.85	0.10
Khotang	0.16	2.25	79.73	1.45	4.42	1.95	1.72	1.93	5.73	3318.40	0.08
Okhaldhunga	0.11	1.52	54.00	0.98	2.99	1.32	1.16	1.31	3.88	2247.34	0.06
Panchthar	0.14	1.96	69.63	1.26	3.86	1.71	1.50	1.69	5.00	2897.78	0.07
Terhathum	0.08	1.10	38.98	0.71	2.16	0.96	0.84	0.95	2.80	1622.18	0.04
Udaypur	0.20	2.80	99.14	1.80	5.49	2.43	2.14	2.40	7.12	4125.88	0.10
Jhapa	0.45	6.15	218.14	3.95	12.08	5.35	4.71	5.29	15.68	9078.75	0.22
Morang	0.59	8.20	290.57	5.27	16.10	7.12	6.27	7.05	20.88	12093.01	0.30
Saptari	0.40	5.54	196.52	3.56	10.89	4.82	4.24	4.77	14.12	8178.68	0.20
Siraha	0.40	5.54	196.38	3.56	10.88	4.81	4.24	4.76	14.11	8172.92	0.20
Sunsari	0.44	6.08	215.59	3.91	11.94	5.28	4.65	5.23	15.49	8972.50	0.22
Dolakha	0.12	1.71	60.62	1.10	3.36	1.49	1.31	1.47	4.36	2522.84	0.06
Rasuwa	0.03	0.43	15.41	0.28	0.85	0.38	0.33	0.37	1.11	641.51	0.02
Sindhupalchowk	0.21	2.85	101.21	1.83	5.61	2.48	2.18	2.45	7.27	4212.36	0.10

Districts	Estimates of Emissions of Air Pollutants and GHGs from Commercial Sectors										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Bhaktapur	0.16	2.19	77.69	1.41	4.30	1.90	1.68	1.88	5.58	3233.44	0.08
Dhading	0.24	3.29	116.70	2.12	6.46	2.86	2.52	2.83	8.39	4856.85	0.12
Kathmandu	0.76	10.52	372.80	6.76	20.65	9.14	8.04	9.04	26.79	15515.24	0.38
Kavre	0.27	3.75	132.90	2.41	7.36	3.26	2.87	3.22	9.55	5531.10	0.14
Lalitpur	0.24	3.28	116.40	2.11	6.45	2.85	2.51	2.82	8.36	4844.33	0.12
Makawanpur	0.28	3.82	135.29	2.45	7.49	3.32	2.92	3.28	9.72	5630.52	0.14
Nuwakot	0.20	2.80	99.41	1.80	5.51	2.44	2.14	2.41	7.14	4137.20	0.10
Ramechhap	0.15	2.06	73.19	1.33	4.05	1.79	1.58	1.77	5.26	3046.24	0.07
Sindhuli	0.20	2.69	95.54	1.73	5.29	2.34	2.06	2.32	6.87	3976.30	0.10
Bara	0.39	5.43	192.67	3.49	10.67	4.72	4.16	4.67	13.85	8018.82	0.20
Chitwan	0.33	4.59	162.66	2.95	9.01	3.99	3.51	3.94	11.69	6769.86	0.17
Dhanusa	0.47	6.53	231.35	4.19	12.81	5.67	4.99	5.61	16.62	9628.34	0.24
Mahaottari	0.39	5.38	190.73	3.46	10.56	4.67	4.11	4.63	13.71	7937.73	0.19
Parsa	0.35	4.83	171.34	3.11	9.49	4.20	3.70	4.15	12.31	7130.85	0.17
Rautahat	0.38	5.30	187.85	3.40	10.41	4.60	4.05	4.56	13.50	7817.99	0.19
Sarlahi	0.45	6.18	219.06	3.97	12.13	5.37	4.73	5.31	15.74	9116.89	0.22
Manang	0.01	0.09	3.30	0.06	0.18	0.08	0.07	0.08	0.24	137.49	0.00
Mustang	0.01	0.15	5.16	0.09	0.29	0.13	0.11	0.13	0.37	214.85	0.01
Argakhanchi	0.15	2.03	71.81	1.30	3.98	1.76	1.55	1.74	5.16	2988.63	0.07
Baglung	0.19	2.61	92.67	1.68	5.13	2.27	2.00	2.25	6.66	3856.95	0.09

Districts	Estimates of Emissions of Air Pollutants and GHGs from Commercial Sectors										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Gorkha	0.20	2.80	99.29	1.80	5.50	2.43	2.14	2.41	7.13	4132.26	0.10
Gulmi	0.21	2.88	102.23	1.85	5.66	2.51	2.20	2.48	7.35	4254.45	0.10
Kaski	0.27	3.70	131.13	2.38	7.26	3.21	2.83	3.18	9.42	5457.32	0.13
Lamjung	0.12	1.72	61.04	1.11	3.38	1.50	1.32	1.48	4.39	2540.58	0.06
Myagdi	0.08	1.11	39.44	0.71	2.18	0.97	0.85	0.96	2.83	1641.34	0.04
Palpa	0.19	2.61	92.54	1.68	5.13	2.27	2.00	2.24	6.65	3851.52	0.09
Parbat	0.11	1.53	54.39	0.99	3.01	1.33	1.17	1.32	3.91	2263.46	0.06
Syangja	0.22	3.08	109.35	1.98	6.06	2.68	2.36	2.65	7.86	4550.83	0.11
Tanahu	0.22	3.06	108.63	1.97	6.02	2.66	2.34	2.63	7.81	4520.96	0.11
Kapilbastu	0.34	4.68	166.09	3.01	9.20	4.07	3.58	4.03	11.93	6912.24	0.17
Nawalparasi	0.40	5.47	193.96	3.52	10.74	4.75	4.18	4.70	13.94	8072.38	0.20
Rupandehi	0.50	6.89	244.12	4.42	13.52	5.98	5.27	5.92	17.54	10159.77	0.25
Dolpa	0.02	0.21	7.61	0.14	0.42	0.19	0.16	0.18	0.55	316.53	0.01
Humla	0.03	0.39	13.99	0.25	0.77	0.34	0.30	0.34	1.01	582.19	0.01
Jumla	0.05	0.67	23.85	0.43	1.32	0.58	0.51	0.58	1.71	992.80	0.02
Mugu	0.02	0.31	10.84	0.20	0.60	0.27	0.23	0.26	0.78	451.25	0.01
Kalikot	0.01	0.11	3.97	0.07	0.22	0.10	0.09	0.10	0.29	165.07	0.00
Dailekh	0.16	2.19	77.60	1.41	4.30	1.90	1.67	1.88	5.58	3229.71	0.08
Jajarkot	0.09	1.31	46.47	0.84	2.57	1.14	1.00	1.13	3.34	1934.21	0.05
Pyuthan	0.15	2.07	73.22	1.33	4.06	1.79	1.58	1.78	5.26	3047.33	0.07

Districts	Estimates of Emissions of Air Pollutants and GHGs from Commercial Sectors										
	Air Pollutants								GHGs		
	SO_2	NO_X	CO	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2	N_2O
Rolpa	0.15	2.04	72.37	1.31	4.01	1.77	1.56	1.75	5.20	3011.77	0.07
Rukum	0.13	1.83	64.93	1.18	3.60	1.59	1.40	1.57	4.67	2702.48	0.07
Salyan	0.04	0.59	20.90	0.38	1.16	0.51	0.45	0.51	1.50	869.71	0.02
Surkhet	0.19	2.62	93.00	1.69	5.15	2.28	2.01	2.26	6.68	3870.33	0.09
Dang	0.33	4.49	159.33	2.89	8.83	3.90	3.44	3.86	11.45	6631.21	0.16
Banke	0.27	3.75	132.96	2.41	7.36	3.26	2.87	3.22	9.55	5533.51	0.14
Bardia	0.27	3.72	131.86	2.39	7.30	3.23	2.84	3.20	9.47	5487.75	0.13
Bajhang	0.12	1.62	57.56	1.04	3.19	1.41	1.24	1.40	4.14	2395.40	0.06
Bajura	0.07	0.98	34.68	0.63	1.92	0.85	0.75	0.84	2.49	1443.12	0.04
Darchula	0.09	1.19	42.04	0.76	2.33	1.03	0.91	1.02	3.02	1749.60	0.04
Accham	0.16	2.25	79.70	1.44	4.41	1.95	1.72	1.93	5.73	3316.97	0.08
Baitadi	0.16	2.28	80.78	1.46	4.47	1.98	1.74	1.96	5.80	3361.90	0.08
Dadeldhura	0.09	1.23	43.47	0.79	2.41	1.07	0.94	1.05	3.12	1809.35	0.04
Doti	0.15	2.01	71.35	1.29	3.95	1.75	1.54	1.73	5.13	2969.63	0.07
Kailali	0.43	5.99	212.51	3.85	11.77	5.21	4.58	5.15	15.27	8844.34	0.22
Kanchanpur	0.27	3.67	130.22	2.36	7.21	3.19	2.81	3.16	9.36	5419.63	0.13
Total	**16.00**	**221.00**	**7835.00**	**142.00**	**434.00**	**192.00**	**169.00**	**190.00**	**563.00**	**326081.00**	**8.00**

3.6. Agriculture Sector

Agriculture sector consumed around 3.6 million GJ of energy in FY 2008/09. The sector's share was only 0.9% in the total final energy consumption of Nepal in that year. Around 95.2% of the sector's energy consumption is based on petroleum products (High speed diesel (HS diesel) and Light diesel (L diesel)) and only 4.8% is electricity. Besides, human and animal powers are also used for agricultural production although they are difficult to quantify. Diesel and electric irrigation pumps and diesel tractors are the main energy using equipments used for agricultural production. Figure 28 shows the pattern of the agricultural sector energy consumption in FY 2008/09.

3.6.1. Emission Estimation Method

The emission estimation method used for the estimation of emissions from the agriculture sector is similar to the one used for the residential and commercial sectors. Main data required for emission estimation are the activity level (i.e., fuel consumption by type of enduse in the sector) and corresponding emission factors. Emission of a specific pollutant from fuel combustion in an enduse in the sector is estimated based on the following equation:

$$Em_{j,m,k} = A_{m,k} \times EF_{j,m,k} \qquad (13)$$

where,

$Em_{j,m,k}$ is emissions of pollutant type j, fuel type m and end use k, $A_{m,k}$ is level of fuel type m and enduse k, and $EF_{j,m,k}$, is the emission factor specific to pollutant type j, fuel type m, and enduse type k in the agriculture sector.

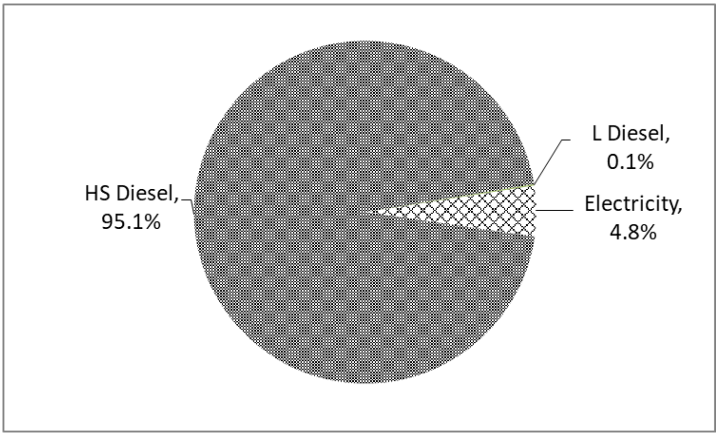


Figure 28: Structure of Energy Consumption in the Agriculture Sector in FY 2008/09, %

3.6.2. Data on Activity Levels

Diesel and electric pumps and diesel tractors are the energy using machineries used in the agricultural sector in Nepal. As tractors are already taken into account under the transport sector, they are not considered in this sector in order to avoid double counting of emissions. The data required on activity level in the case of irrigation is the rate of annual fuel consumption by pumps. The fuel consumption data on the agricultural diesel pumps for FY 2008/09 are obtained from the "Energy Synopsis Report 2010" (WECS, 2010). Around 3469 thousand GJ of high speed diesel and 3.7 thousand GJ of light diesel were used in the agricultural sector in FY 2008/09 (WECS, 2010). A large majority of farmers still use locally made agricultural tools and there is very low level of mechanization in agriculture in the country. According to Nepal Living Standard Survey (NLSS), around 52.3% of the farmers in Nepal own the most basic equipment i.e. plough, 33.0% own bins and containers for grain storage, 7.2% own water pumps, 1.2% own threshers and 1.0% own tractors or power tillers (CBS, 2011). Following WECS (2001), in this study it has been assumed that around 65% of the high speed and light diesel are used in agricultural pumps.

3.6.3. Emission Factors

Table 28 presents the emission factors used in this study for the estimation of emissions from the agriculture sector. The emission factors are based on Kato and Akimoto (1992), IPCC guidelines (1996) and USEPA AP-42 as cited in the Global Atmospheric Pollution Forum Air Pollutant Emissions Inventory Manual (GAPF, 2007).

Table 28: Emission Factors for the Agricultural Sector, kg/TJ

Air Pollutants	Emission Factor for Diesel Oil
NO_X	133[a]
CO	15[b]
NMVOC	5[b]
$PM_{2.5}$*	0.244[c]
PM_{10}*	0.333[c]
BC	5.7-8.3
OC	6.2

*Source: [a]Kato and Akimoto (1992) as cited in GAPF (2007); [b]IPCC Guidelines (1996) as cited in GAPF (2007); [c]USEPA AP-42 as cited in GAPF (2007);*unit in kg/tonne*

Table 29: Annual Emissions from the Agriculture Sector in FY 2008/09, tonne

Air Pollutant	Emissions	
	Low Case	High Case
NO_X	300	300
CO	34	34
NMVOC	11	11
$PM_{2.5}$	12	12
PM_{10}	16	16
BC	13	19
OC	14	14

3.6.4. Estimated Emissions

Table 29 presents the estimated emissions from the combustion of fuels in the agriculture sector in FY2008/09. The table shows estimated emissions in two cases (i.e., Low and High Emission Cases) considering the low and high level of emission factors. Note that due to lack of information on variation in EFs, estimated emissions in the table are the same in both cases except in the case of BC. A high EF value of 8.3 kg/TJ and a low value of 5.7 kg/TJ have been used to estimate variations in total BC emissions from the agriculture sector; accordingly the sector's BC emission was in the range of 13 to 19 tonnes in 2008/09.

3.6.5. Temporal and Spatial Variations

Due to lack of district-wise and monthly energy consumption data in the agriculture sector, temporal and spatial distribution of emissions from fuel combustion in the sector could not be estimated under this study.

4. Fugitive Emissions from Fuels

4.1. Overview

The emissions in this chapter cover fugitive emissions from all non-combustion activities related to the extraction, processing, storage, distribution and use of fossil fuels. The escape or release of gases or volatile components of liquid fuels may occur during all stages from the extraction of fossil fuels to their final use. Fugitive emissions from refining, transport and distribution of oil products are a major component of national NMVOC emissions in many countries. Since Nepal does not have oil refineries, fugitive emissions include NMVOC from coal mining/handling and gasoline distribution.

Activities related to fugitive emissions covers all the non-combustion activities, i.e., extraction, processing, storage, distribution and use of fossil fuels. The estimation of emissions in this chapter includes fugitive emissions from:

- coal mining and handling, including fugitive NMVOC, PM_{10} and $PM_{2.5}$ which may arise from production of coal, and
- gasoline distribution, including fugitive NMVOC which is evaporated

4.2. Emission Estimation Method

The method used for the estimation of fugitive emissions in this study has been adopted from EMEP/CORINAIR (2006). Given the limited availability of the activity specific emission factors and detailed activity data, a simple methodology has been used in this study, whereby the general emission factor is multiplied by the level of activity. Coal production and gasoline distribution are the main activity data required in this sector. The emission of a specific pollutant related to a particular type of fuel is calculated based on the following equation:

$$Em_{j,m,k} = A_{m,k} \times EF_{j,m,k} \tag{14}$$

where,

$Em_{j,m,k}$ is emissions from pollutant type j, fuel type m and sub-sector k (e.g., extraction, distribution), $A_{m,k}$ is activity rate of fuel type m and sub-sector k, and $EF_{j,m,k}$ is emission factors specific to pollutant type j, fuel type m, and sub-sector type k.

4.3. Data on Activity Levels

A fugitive emission is calculated based on production of a fuel, actual volume of fuel storage and volume of fuel sold. There exist some limted amounts of indigenous coal, peat and lignite in different parts of Nepal. However, the deposits are of low grade. These deposits of coal and lignite in the country are not commercially attractive. The deposits of coal can be classified in to four major categories: Quaternary lignite of Kathmandu valley, Coal from Dang (Eocene coal from Mid-Western Nepal), Siwalik coal and Gondwana coal. Out of these four types identified, the Quaternary lignite deposit of the Kathmandu valley and coal from Mid-Western Nepal are of some economic significance. The Siwalik coal deposits, though widely distributed throughout the Siwalik range of the country, are small and sporadic and have not been commercially exploited. Likewise the Gondwana coal from eastern parts of Nepal is of low quality, small in size and of no economic significance (WECS, 2010). Few small scale coal mines are in operation in Dang, Salyan, Rolpa and Palpa districts. A very small amount of the total coal supply is extracted in Dang district for consumption in brick industries. For the major industrial use, coal is imported from India and abroad. In FY 2008/09, around 293 thousand tonnes of coal were imported from India, while only 14.82 thousand tonnes of coal were produced in the country (WECS, 2010). Kathmandu alone consumed around 40% of the imported coal. Coal is consumed in two important sectors in Nepal, namely, cement production and bricks and tiles industries. The bulk of coal destined for Nepal comes from Assam, West Bengal or Bihar of India.

For coal mining and handling, annual coal produced is considered as the activity data. For gasoline distribution, annual sale of the fuel is taken as the activity data. The annual coal production data has been taken from WECS (2010) while the annual gasoline fuel sales data has been taken from Nepal Oil Corporation (NOC).

4.4. Emission Factors

The emission factors are mostly taken from EMEP/CORINAIR (1999) and US EPA (1995) since there were no reported Asian values. The emission factors used to estimate emissions from coal production are presented in Table 30. The emission factor of NMVOC for gasoline distribution has been considered to be 2880 kg/ktonne of gasoline consumed or sold (EMEP/CORINAIR, 2007).

Table 30: Emission Factors for Selected Air Pollutants from Coal Production

Activity	NMVOC (g/tonne coke)[a]	PM_{10} (kg/tonne coke)[c]	$PM_{2.5}$ (kg/tonne coke)[b]	BC (kg/tonne coke)[b]	OC (kg/tonne coke)[b]
Coking process	29-400	4.9[b]	1.53	0.68	0.49
COG purification	210	-	-	-	-
Coal crushing	-	0.055	-	-	-
Coal preheating	-	1.7	1	-	-
Oven charging	-	0.24	-	-	-
Oven door leaking	-	0.27	-	-	-
Oven pushing	-	0.25	0.1	-	-
Quenching	-	0.6	0.51	-	-

Source: [a]EMEP/CORINAIR (1999); [b]Kupiainen and Klimont (2004). Applicable for coke production, TSP (refer to PM_{10}, $PM_{2.5}$ refer to PM_1) emission factors from Klimont et al. (2002); [c]USEPA (1995)

Table 31: Annual Fugitive Emissions from Fuels in 2008/09, tonne

Air Pollutants	Fugitive Emissions		
	Coal mining and handling	Gasoline distribution	Total
NO_X	ne	ne	ne
CO	ne	ne	ne
NMVOC	3.5	275.4	278.9
NH_3	ne	ne	ne
$PM_{2.5}$	23.9	ne	23.9
PM_{10}	46.2	ne	46.2
BC	10.1	ne	10.1
OC	7.3	ne	7.3

Note: ne = not estimated due to unavailability of emission factor

4.5. Estimated Emissions

Estimated amounts of fugitive emissions are presented in Table 31. Note that the emission figures do not include emissions from oil refinery since there is no refinery in Nepal. Around 279 tonnes of NMVOC emissions are estimated to be emitted as a part of fugitive emissions in FY 2008/09. Similarly, the emissions of PM_{10}, $PM_{2.5}$, BC and OC in the year are estimated to be around 46, 24, 10, and 7 tonnes respectively.

4.6. Temporal and Spatial Variations

For temporal distribution of emissions on a monthly basis one would require information on monthly coal production and monthly gasoline consumption. In the absence of the monthly data on coal production temporal variation of fugitive emissions associated with coal production could not be estimated. As to the fugitive emissions from gasoline consumption, the monthly data on gasoline consumption obtained from the Nepal Oil Corporation (NOC) has been used as a proxy to estimate the monthly distribution of fugitive emissions during the year. Figure 29 presents the normalized values of monthly gasoline consumption. The monthly pattern of NMVOC emissions associated with gasoline handling has been derived on the basis of the monthly pattern of gasoline consumption (see Figure 30 for the monthly pattern of NMVOC emission).

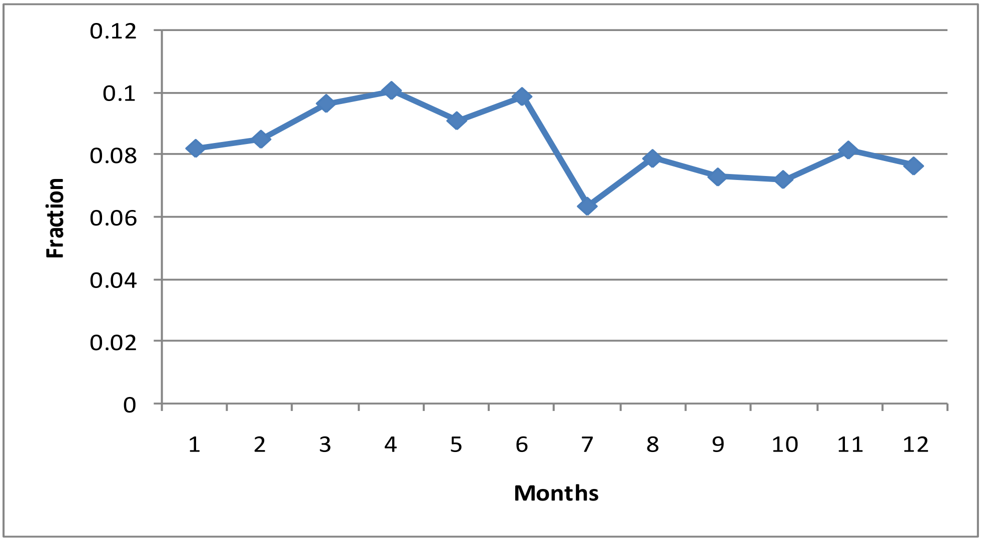


Figure 29: Temporal Variation Pattern of Fugitive Emissions from Gasoline Distribution

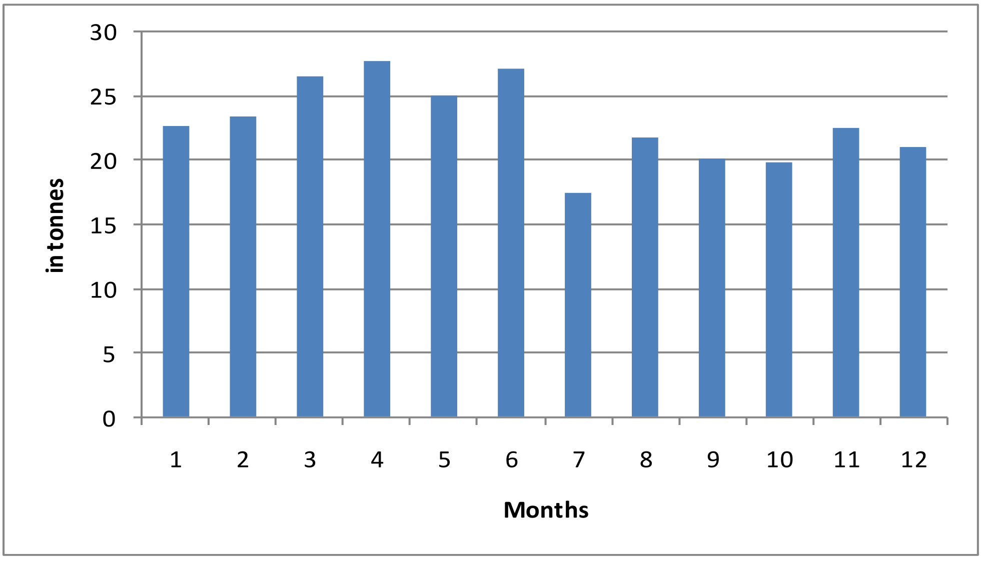
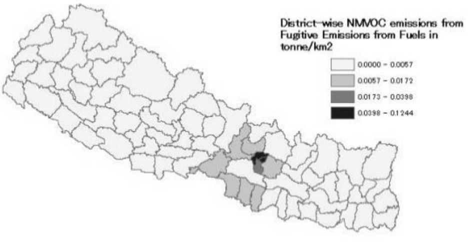
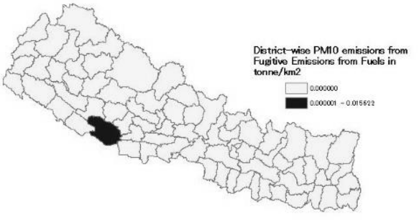


Figure 30: Temporal Variation of NMVOC Emissions from Gasoline Distribution (tonnes)

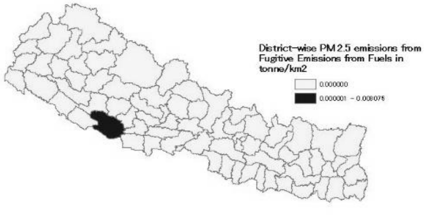
For estimation of the spatial distribution of emissions from the coal mining and handling sub-sector, the district-wise coal production data is required, while that for gasoline distribution, district wise information on gasoline vehicle population is needed. It has been known from the Department of Mines and Geology (DMG) that around 19 coal mines are in operation in Dang, Salyan, Rolpa and Palpa districts of Nepal. The primary yearly production of coal from Dang district was around 10 thousand tonnes. However, due to lack of data on coal production from other districts, coal production is assumed to be based in Dang district only. For spatial distributon of emissions from gasoline distribution, the total number of gasoline vehicles in each district has been estimated based on the population share of the districts in FY 2008/09 and the total number of respective zonal vehicles registration data. Figure 31 presents the spatial distribution of emission densities of different emissions associated with the fugitive sources, while Table 32 presents the district-wise emissions from the fugitive emissions of fuels. Among the districts, the NMVOC emission from fugitive sources (mainly gasoline distribution) from the Kathmandu district has been estimated to occupy the largest share (17.63%); this is followed by Bara (7.16%), Rautahat (6.98%), Parsa (6.37%), Kavre (6.29%), Dhading (5.52%), Lalitpur (5.51%), Makwanpur (5.03%), Sindhupalchowk (4.79%), Nuwakot (4.70%), and Bhaktapur (3.67%) districts. While the remaining of 26.35% of NMVOC emissions has been estimated to come from rest of the 64 districts of Nepal.



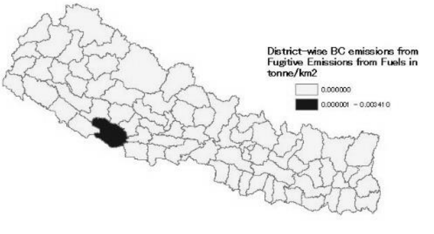
a) NMVOC Emission Density



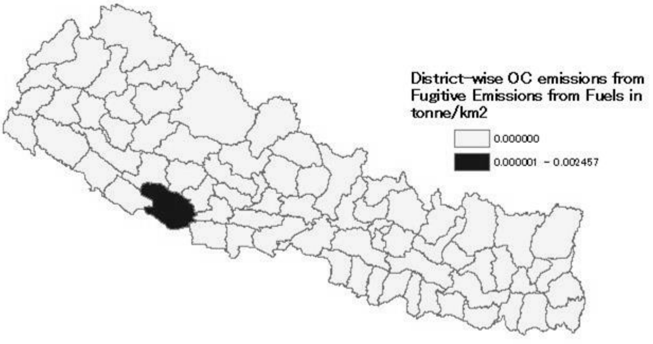
b) PM_{10} Emission Density



c) $PM_{2.5}$ Emission Density



d) BC Emission Density



e) OC Emission Density

Figure 31: Spatial Variation of Emission Densities due to Fugitive Emission from Fuels

Table 32: District-wise Annual Emissions of Air Pollutants from the Fugitive Emissions of Fuels, tonne

Districts	NMVOC	PM_{10}	$PM_{2.5}$	BC	OC
Sankhuwasabha	0.78	0.00	0.00	0.00	0.00
Solukhumbu	0.03	0.00	0.00	0.00	0.00
Taplejung	0.68	0.00	0.00	0.00	0.00
Bhojpur	1.00	0.00	0.00	0.00	0.00
Dhankuta	0.82	0.00	0.00	0.00	0.00
Ilam	1.42	0.00	0.00	0.00	0.00
Khotang	0.07	0.00	0.00	0.00	0.00
Okhaldhunga	0.05	0.00	0.00	0.00	0.00
Panchthar	1.01	0.00	0.00	0.00	0.00
Terhathum	0.56	0.00	0.00	0.00	0.00
Udaypur	0.09	0.00	0.00	0.00	0.00
Jhapa	3.18	0.00	0.00	0.00	0.00
Morang	4.15	0.00	0.00	0.00	0.00
Saptari	0.18	0.00	0.00	0.00	0.00
Siraha	0.18	0.00	0.00	0.00	0.00
Sunsari	3.08	0.00	0.00	0.00	0.00
Dolakha	0.06	0.00	0.00	0.00	0.00
Rasuwa	2.03	0.00	0.00	0.00	0.00
Sindhupalchowk	13.35	0.00	0.00	0.00	0.00
Bhaktapur	10.25	0.00	0.00	0.00	0.00
Dhading	15.39	0.00	0.00	0.00	0.00
Kathmandu	49.18	0.00	0.00	0.00	0.00
Kavre	17.53	0.00	0.00	0.00	0.00

Districts	NMVOC	PM_{10}	$PM_{2.5}$	BC	OC
Lalitpur	15.35	0.00	0.00	0.00	0.00
Makawanpur	14.03	0.00	0.00	0.00	0.00
Nuwakot	13.11	0.00	0.00	0.00	0.00
Ramechhap	0.07	0.00	0.00	0.00	0.00
Sindhuli	0.09	0.00	0.00	0.00	0.00
Bara	19.98	0.00	0.00	0.00	0.00
Chitwan	16.87	0.00	0.00	0.00	0.00
Dhanusa	0.22	0.00	0.00	0.00	0.00
Mahaottari	0.18	0.00	0.00	0.00	0.00
Parsa	17.77	0.00	0.00	0.00	0.00
Rautahat	19.48	0.00	0.00	0.00	0.00
Sarlahi	0.21	0.00	0.00	0.00	0.00
Manang	0.07	0.00	0.00	0.00	0.00
Mustang	0.04	0.00	0.00	0.00	0.00
Argakhanchi	1.51	0.00	0.00	0.00	0.00
Baglung	0.63	0.00	0.00	0.00	0.00
Gorkha	2.21	0.00	0.00	0.00	0.00
Gulmi	2.15	0.00	0.00	0.00	0.00
Kaski	2.92	0.00	0.00	0.00	0.00
Lamjung	1.36	0.00	0.00	0.00	0.00
Myagdi	0.27	0.00	0.00	0.00	0.00
Palpa	1.94	0.00	0.00	0.00	0.00
Parbat	0.37	0.00	0.00	0.00	0.00
Syangja	2.43	0.00	0.00	0.00	0.00
Tanahu	2.42	0.00	0.00	0.00	0.00
Kapilbastu	3.49	0.00	0.00	0.00	0.00
Nawalparasi	4.07	0.00	0.00	0.00	0.00
Rupandehi	5.13	0.00	0.00	0.00	0.00
Dolpa	0.00	0.00	0.00	0.00	0.00
Humla	0.00	0.00	0.00	0.00	0.00
Jumla	0.00	0.00	0.00	0.00	0.00
Mugu	0.00	0.00	0.00	0.00	0.00
Kalikot	0.00	0.00	0.00	0.00	0.00
Dailekh	0.24	0.00	0.00	0.00	0.00
Jajarkot	0.14	0.00	0.00	0.00	0.00
Pyuthan	0.03	0.00	0.00	0.00	0.00
Rolpa	0.03	0.00	0.00	0.00	0.00
Rukum	0.03	0.00	0.00	0.00	0.00
Salyan	0.01	0.00	0.00	0.00	0.00
Surkhet	0.29	0.00	0.00	0.00	0.00

Districts	NMVOC	PM_{10}	$PM_{2.5}$	BC	OC
Dang	3.61	46.16	23.86	10.08	7.26
Banke	0.41	0.00	0.00	0.00	0.00
Bardia	0.41	0.00	0.00	0.00	0.00
Bajhang	0.01	0.00	0.00	0.00	0.00
Bajura	0.01	0.00	0.00	0.00	0.00
Darchula	0.03	0.00	0.00	0.00	0.00
Accham	0.02	0.00	0.00	0.00	0.00
Baitadi	0.05	0.00	0.00	0.00	0.00
Dadeldhura	0.03	0.00	0.00	0.00	0.00
Doti	0.02	0.00	0.00	0.00	0.00
Kailali	0.05	0.00	0.00	0.00	0.00
Kanchanpur	0.09	0.00	0.00	0.00	0.00
Total	278.90	46.16	23.86	10.08	7.26

5. Process Related Emissions from Manufacturing/Process Industries

5.1. Overview

The emissions from the manufacturing/process Industries sector includes on-combustion emissions from the sector and some processes that involve combustion mainly in metal production industries. Types of manufacturing industries covered in the present study are mineral products (cement and lime production), metal production, pulp and paper industries, chemical industries, food and beverages industries, iron and steel and non-ferrous metal industries. In general, the activity data required for the estimation of emissions from these sectors are the annual production from these industries.

5.2. Emission Estimation Method

The simple method is used for emission estimation in this study; i.e., emissions are calculated by multiplying the activity rate by the corresponding emission factor. The equation used to estimate the emissions from this sector is given as:

$$Em_{j,m,k} = A_{m,k} \times EF_{j,m,k} \quad (15)$$

where,

$Em_{j,m,k}$ is emissions from pollutant type j, process type m and sub-sector k, $A_{m,k}$ is activity rate of process type m and sub-sector k, and $EF_{j,m,k}$ is emission factors specific to pollutant type j, process type m, and sub-sector type k.

5.3. Data on Activity Levels

The activity rate data required to estimate the process related emissions from the manufacturing/process industries include the annual outputs of each manufacturing sub-sector or process. Table 33 presents the production data from various manufacturing industries in FY 2008/09. The actual production of cement from national industries (both integrated and clinker based) are 644,325 tonnes in FY 2005/06, 613,643 tonnes in FY 2006/07, and 71,000 tonnes in FY 2008/09 (MOF, 2011). A study conducted by U.S. Geological Survey, estimates that in 2008, around 295,000 metric tons of cement and 822,000 metric tons of limestones were produced in Nepal (USGS, 2009). This study uses the data on total amount of cement production as reported in Economic Survey published by the Ministry of Finance (MOF, 2011). The annual production from pulp and paper industries as reported in the Economic Survey report were 29,904 tonnes in 2005/06, 31,399 tonnes in 2006/07 and 32,905 tonnes in 2007/08 (MOF, 2011). However, the production data from pulp and paper industries for FY 2008/09 was not provided. As a result, the annual production of paper in 2008/09 has been estimated assuming that the annual growth rate of 5% in FY 2007/08 was also applicable for FY 2008/09.

5.4. Emission Factors

Emission factors are taken mainly from the GAPF Inventory Manual (GAPF, 2007), which provides a compilation of EFs from several sources such as US EPA (1995), IPCC (1997), EMEP/CORINAIR (2006) and other publications in the absence of Asia specific EFs. Table 34 presents the EFs used in this analysis for the estimation of process related emissions from the manufacturing and process industries. Note that EFs compiled in the table assume the absence of control technologies in the industries.

Table 33: Annual Production Data of Manufacturing Industry in FY 2008/09

Industry type	Production (tonne/year)
Mineral product – cement	71000[a]
Mineral product - limestone	822000[b]
Metal production	-
Pulp and paper industry	34550
Chemical industry	-
Beverage industry*	579609[a]
Food industry	446739[a]

*Note: *unit is in hectoliter; 1 hectoliter = 100 liters*
Source: [a]MOF (2011); [b]USGS (2009)

Table 34: Emission Factors for Air Pollutants and GHGs from Manufacturing and Process Industries

Sub-sector/Process	Emission Factors							
	Air Pollutants							GHG
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	CO_2
Cement production (wet process) (in kg/tonne)	0.3[a]	-	-	-	-	16[b], 54.6[c]	4.64[b], 6.5[c]	520[a]
Lime production(in kg/tonne)	-	-	-	-	-	22[b], 12[c]	2.57[b], 0.46[c]	750[a]
Brick manufacturing (in kg/tonne)	-	-	-	-	-	0.68[b], 0.29-0.63 (0.46)	0.44[b]	-
Pulp and paper (in kg/tonne)	3.8[b]	1.5[a]	5.6[a]	3.7[a]	-	92[b], 103.6[c]	81[b], 41.4[c]	-
Alcoholic Beverage (in kg/hectoliter)								
Beer	-	-	-	0.035[e]	-	-	-	-
Other spirits	-	-	-	15[e]	-	-	-	-
Food Production (in kg/tonne)								
Sugar	-	-	-	10[e]	-	-	-	-
Margarines and solid cooking fats	-	-	-	10[e]	-	-	-	-
Cakes, biscuit and breakfast cereals	-	-	-	1[e]	-	-	-	-
Animal feed	-	-	-	1[e]	-	-	-	-

Source: [a]IPCC (1997); [b]USEPA (1995); [c]Kupiainen and Klimont (2004); [d]Le and Kim Oanh (2009). In parenthesis are central values; [e]EMEP/CORINAIR (2006)

Table 35: Annual Process Related Emissions from Manufacturing and Process Industries in FY 2008/09, tonne

No.	Pollutants	Mineral product	Pulp and paper	Food and beverage industry	Total
1	SO_2	21	131	ne	152
2	NO_X	ne	52	ne	52
3	CO	ne	193	115135	115328
4	NH_3	ne	ne	ne	ne
5	PM_{10}	19244	3179	1842156	1864579
6	$PM_{2.5}$	2458	2799	ne	5257
7	NMVOC	ne	128	1805990	1806118

Note: ne = not estimated

5.5. Estimated Emissions

Industrial production processes emit various types of process related greenhouse gases (GHGs), particulates and other gaseous species. These processes involve the chemical or physical transformation of raw materials into intermediate or final products.

Table 35 presents the process related emissions from manufacturing and process industries in FY 2008/09. Food and beverage industry occupy the largest share in the total process related emissions (see Table 35). The total process related emissions of SO_2, NOX, CO, PM_{10}, $PM_{2.5}$ and NMVOC in FY 2008/09 from the manufacturing/process industries are estimated to be 152, 52, 115328, 1864579, 5257 and 1806118 tonnes respectively.

5.6. Temporal and Spatial Variations

Temporal variations of emissions depend on the type of process, that is, whether it is continuous or intermittent. For most of the continuous processes, temporal disaggregation can be carried out by using the data on operation time. For some processing plants, daily material balance is carried out, which may enable disaggregation of emissions on an hourly basis. As the processes for most metal industries are neither continuous nor intermittent, temporal disaggregation would depend on the production rate. Since this quantitative information is difficult to obtain, temporal variations of emissions from this sector could not be estimated using the production rate. However, monthly industrial electricity consumption data has been used as a proxy factor to estimate the monthly emissions from this sector. Figure 32 shows the temporal variation pattern of emissions from the manufacturing/process industries in a normalized form, while

Figure 33 shows the estimated monthly emissions of different pollutants from the manufacturing/process industries. Since industrial electricity consumption data has been used to estimate the temporal variations in the emissions, the process related emissions are found to be relatively higher during the months of May, June and July, with the peak occurring in June.

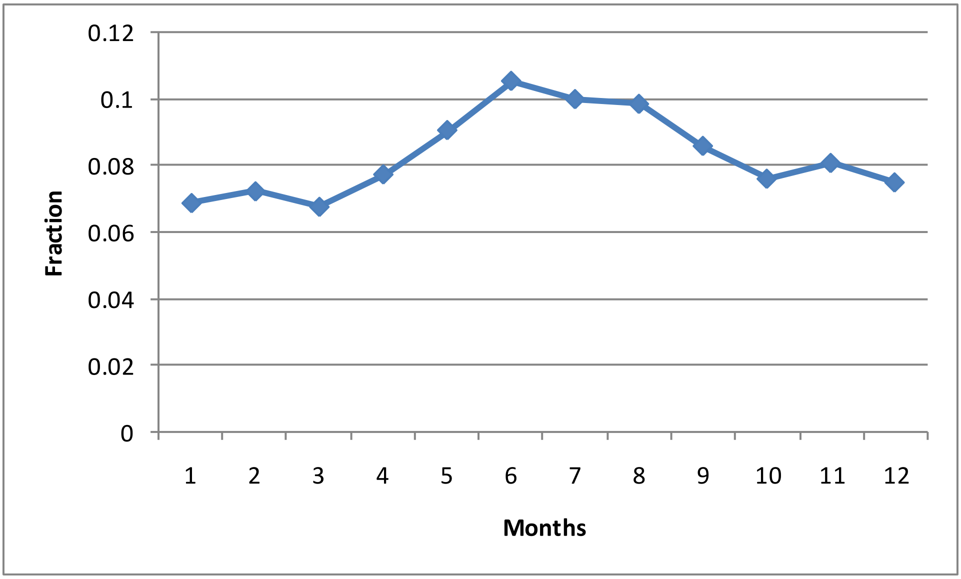


Figure 32: Monthly Variation of Process Related Emissions from Manufacturing/Process Industries

Spatial distribution of emissions from manufacturing and industrial processes could be carried out using several methods. For sources that are treated as point sources, the longitude/latitude (location, geographical coordinates) coordinates of each point source can be used. For those that are treated as an area source, industrial output data according to districts can be used as a proxy for spatial distribution of emissions. Industrial gross domestic product (GDP) can also be used, if district level data are available. In this analysis, in the absence of district-wise industrial value added data for FY 2008/09, the data for FY 2006/07 has been used as a factor for spatial distribution of the total national level emissions from the sector. Figure 34 shows the spatial distribution of the process related emission densities from the manufacturing and process industries. Table 36 shows the district-wise emissions by pollutant type from the process related emissions from the manufacturing and process industries. Among the districts, process related emissions from Bara district is found to occupy the largest share (25.6%), which is followed by Nawalparasi (9.63%), Kathmandu (9.56%), Morang (8.44%), Dhanusa (8.17%), Parsa (7.38%), Makwanpur (6.06%), Sunsari (5.25%), Rupandehi (4.27%), Lalitpur (2.05%), Jhapa (1.51%), Banke (1.49%), Kapilbastu (1.31%), Udaypur (1.29%), Chitwan (1.29%), Kaski (1.21%) and Bhaktapur (1.18%). The rest of the 58 districts are found to occupy a share of only 4.3% in the total process related emissions from the manufacturing and process industries.

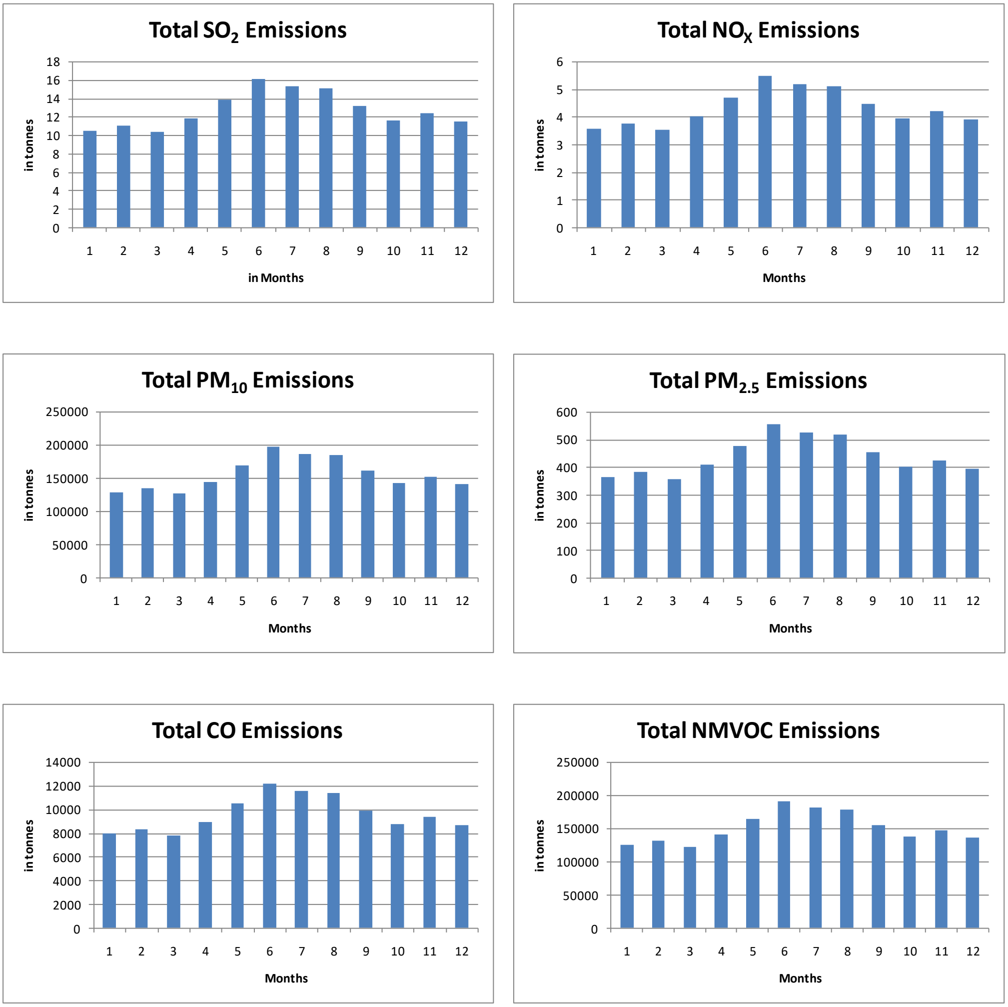
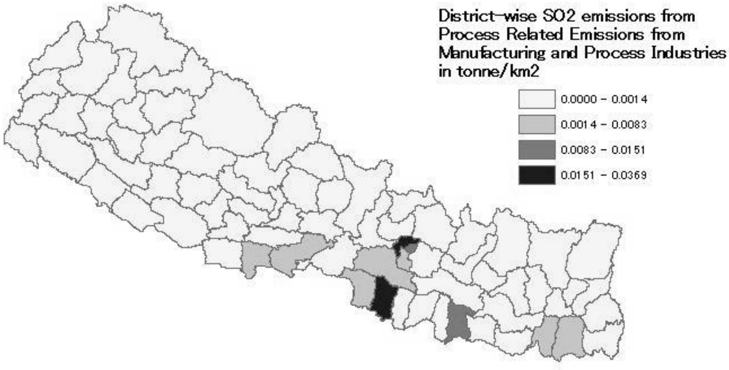
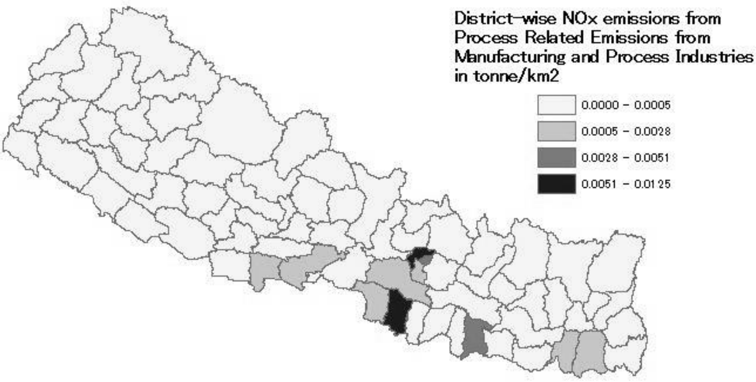


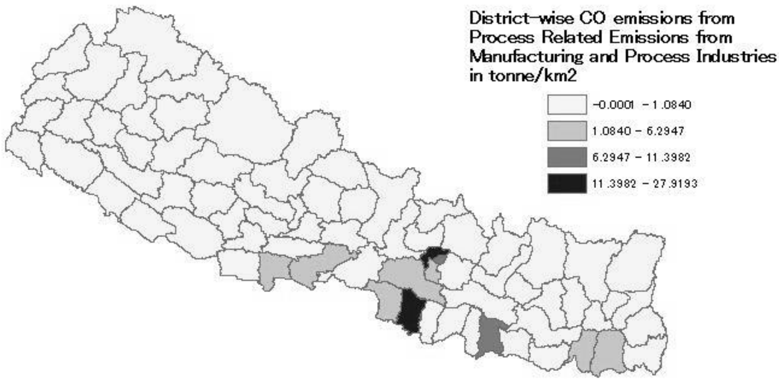
Figure 33: Monthly Patterns of Process Related Emissions Air Pollutants from Manufacturing and Process Industries in FY 2008/09



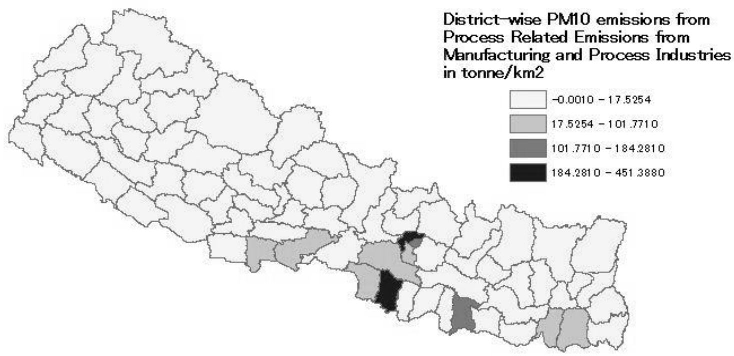
a) SO_2 Emission Density



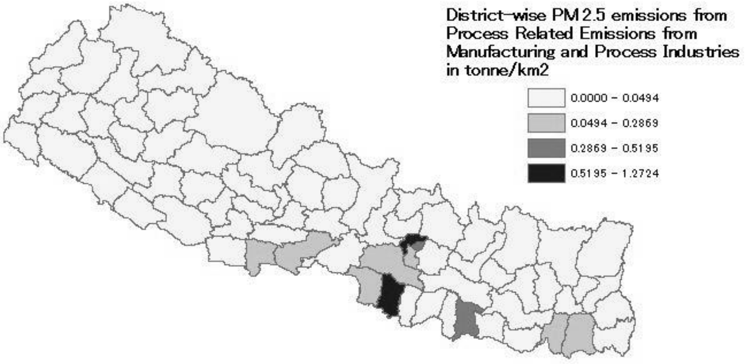
b) NO_X Emission Density



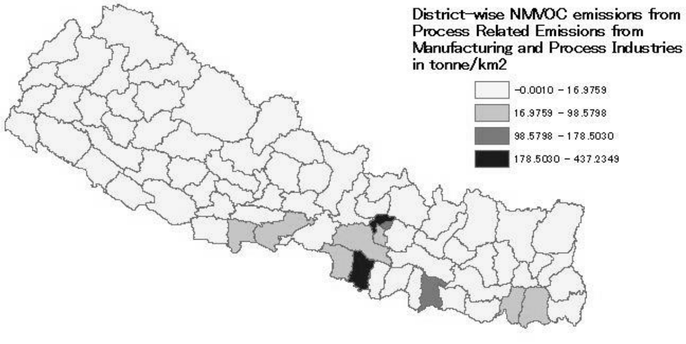
c) CO Emission Density



d) PM_{10} Emission Density



e) $PM_{2.5}$ Emission Density



f) NMVOC Emission Density

Figure 34: Spatial Variation of the Process Related Emission Densities from the Manufacturing and Process Industries in FY 2008/09

Table 36: District-wise Annual Emissions of Air Pollutants from Process Related Emissions from Manufacturing/Process Industries, tonne

Districts	SO_2	NO_X	CO	PM_{10}	$PM_{2.5}$	NMVOC
Sankhuwasabha	0.02	0.01	12.56	203.10	0.57	196.73
Solukhumbu	0.00	0.00	0.00	0.00	0.00	0.00
Taplejung	0.02	0.01	12.63	204.23	0.58	197.83
Bhojpur	0.01	0.00	5.46	88.24	0.25	85.48
Dhankuta	0.08	0.03	57.11	923.33	2.60	894.38
Ilam	0.15	0.05	113.51	1835.20	5.17	1777.66
Khotang	0.01	0.00	6.14	99.21	0.28	96.10
Okhaldhunga	0.01	0.00	10.50	169.76	0.48	164.43
Panchthar	0.03	0.01	21.19	342.56	0.97	331.82
Terhathum	0.03	0.01	22.62	365.67	1.03	354.20
Udaypur	1.97	0.67	1491.89	24120.18	67.99	23363.94
Jhapa	2.30	0.78	1740.88	28145.83	79.34	27263.37
Morang	12.87	4.37	9729.48	157302.12	443.43	152370.19
Saptari	0.53	0.18	402.70	6510.62	18.35	6306.49
Siraha	0.35	0.12	263.35	4257.67	12.00	4124.18

Districts	SO_2	NO_X	CO	PM_{10}	$PM_{2.5}$	NMVOC
Sunsari	8.02	2.72	6059.51	97967.64	276.17	94896.03
Dolakha	0.02	0.01	18.20	294.25	0.83	285.03
Rasuwa	0.00	0.00	0.00	0.00	0.00	0.00
Sindhupalchowk	0.07	0.03	55.92	904.04	2.55	875.70
Bhaktapur	1.79	0.61	1356.38	21929.46	61.82	21241.90
Dhading	0.18	0.06	136.17	2201.50	6.21	2132.48
Kathmandu	14.59	4.96	11028.12	178298.11	502.62	172707.88
Kavre	0.83	0.28	626.81	10134.03	28.57	9816.30
Lalitpur	3.12	1.06	2359.08	38140.58	107.52	36944.75
Makawanpur	9.25	3.14	6992.16	113046.33	318.67	109501.96
Nuwakot	0.01	0.00	10.69	172.85	0.49	167.43
Ramechhap	0.02	0.01	18.12	292.89	0.83	283.70
Sindhuli	0.00	0.00	0.00	0.00	0.00	0.00
Bara	39.01	13.25	29486.94	476732.57	1343.89	461785.45
Chitwan	1.97	0.67	1488.89	24071.78	67.86	23317.06
Dhanusa	12.47	4.24	9426.21	152398.99	429.61	147620.79

Districts	SO_2	NO_X	CO	PM_{10}	$PM_{2.5}$	NMVOC
Mahaottari	0.82	0.28	617.78	9988.02	28.16	9674.86
Parsa	11.27	3.83	8516.78	137695.75	388.16	133378.54
Rautahat	0.37	0.13	282.13	4561.43	12.86	4418.42
Sarlahi	0.71	0.24	538.86	8711.99	24.56	8438.84
Manang	0.00	0.00	0.00	0.00	0.00	0.00
Mustang	0.01	0.00	10.76	173.94	0.49	168.49
Argakhanchi	0.02	0.01	12.51	202.32	0.57	195.98
Baglung	0.02	0.01	13.08	211.51	0.60	204.88
Gorkha	0.36	0.12	271.74	4393.41	12.38	4255.66
Gulmi	0.04	0.01	27.57	445.68	1.26	431.70
Kaski	1.85	0.63	1395.58	22563.09	63.60	21855.66
Lamjung	0.01	0.00	9.80	158.38	0.45	153.42
Myagdi	0.03	0.01	21.85	353.34	1.00	342.26
Palpa	0.10	0.03	77.52	1253.38	3.53	1214.08
Parbat	0.03	0.01	22.53	364.26	1.03	352.84
Syangja	0.03	0.01	25.44	411.29	1.16	398.39

Districts	SO_2	NO_X	CO	PM_{10}	$PM_{2.5}$	NMVOC
Tanahu	0.18	0.06	135.92	2197.50	6.19	2128.60
Kapilbastu	2.00	0.68	1508.77	24393.15	68.76	23628.34
Nawalparasi	14.70	4.99	11109.57	179614.94	506.33	173983.43
Rupandehi	6.52	2.22	4930.25	79710.17	224.70	77210.99
Dolpa	0.00	0.00	0.49	7.87	0.02	7.62
Humla	0.00	0.00	0.00	0.00	0.00	0.00
Jumla	0.01	0.00	8.75	141.46	0.40	137.03
Mugu	0.00	0.00	0.00	0.00	0.00	0.00
Kalikot	0.00	0.00	0.00	0.00	0.00	0.00
Dailekh	0.00	0.00	1.89	30.52	0.09	29.56
Jajarkot	0.00	0.00	0.00	0.00	0.00	0.00
Pyuthan	0.00	0.00	0.00	0.00	0.00	0.00
Rolpa	0.00	0.00	0.00	0.00	0.00	0.00
Rukum	0.00	0.00	0.00	0.00	0.00	0.00
Salyan	0.00	0.00	0.00	0.00	0.00	0.00
Surkhet	0.05	0.02	37.95	613.52	1.73	594.29

Districts	SO_2	NO_X	CO	PM_{10}	$PM_{2.5}$	NMVOC
Dang	0.32	0.11	244.94	3960.01	11.16	3835.85
Banke	2.27	0.77	1713.04	27695.65	78.07	26827.30
Bardia	0.08	0.03	58.89	952.12	2.68	922.27
Bajhang	0.00	0.00	0.00	0.00	0.00	0.00
Bajura	0.02	0.01	11.67	188.72	0.53	182.81
Darchula	0.00	0.00	0.00	0.00	0.00	0.00
Accham	0.01	0.00	4.18	67.55	0.19	65.43
Baitadi	0.00	0.00	0.00	0.00	0.00	0.00
Dadeldhura	0.00	0.00	0.00	0.00	0.00	0.00
Doti	0.01	0.00	9.61	155.43	0.44	150.55
Kailali	0.73	0.25	549.34	8881.47	25.04	8603.01
Kanchanpur	0.27	0.09	206.83	3343.90	9.43	3239.05
Total	**152.59**	**51.83**	**115328.23**	**1864578.80**	**5256.19**	**1806118.16**

6. Crop Residue Open Burning

6.1. Overview

Large quantities of crop residues are produced annually and a significant part of them are burned openly in the field. This activity can release emissions that are directly related to ABCs, such as particulate matter (PM_{10} and $PM_{2.5}$), BC, OC and gaseous emissions (CO, CO_2, nitrogen oxides, NMVOC, CH_4, SO_2 and NH_3).

To prevent double counting, residue burning is classified under two types, on-site and off-site. This study defines crop residue open burning as any deliberate burning of various types of crop residues, that occur on-site or in an open field. Off-site burning (biofuel combustion) of some crop residues removed from the fields and burned as a source of energy is excluded because this is already covered in other sectors (industry, residential and commercial sectors) in this study.

6.2. Emission Estimation Method

Emission is estimated based on data on the type of crops and burning activity in specific countries/regions. It is noted that estimates of burning activities tend to vary widely in various publication sources. Thus, comprehensive data have to be compiled from several sources that include peer-reviewed literatures, FAO statistics, national communications to IPCC, and government and non-governmental sources in individual countries. In general, the agricultural emissions are estimated by multiplying activity rate by emission factor. The activity rate requires information on crop production, amount of residue produced per unit of crop production, amount of residues burned, burned area, and emission factors.

For open burning, emission from crop residue burning was estimated from total crop residue biomass burned, which is estimated using the data on production of particular agricultural crop. The amount of burned crop residue estimated is estimated using the following equation:

$$M_l = P_l \times N_l \times D_l \times B_l \times \eta \tag{16}$$

where,

M = Total mass of crop residue burned in the field

l = Type of crops

P = Crop production

N = Crop specific residue-to-production ratio

D = Dry-matter-to-crop residue ratio

B = Percentage of dry matter residues that are burned in the field

η = Crop specific burn efficiency ratio (fraction oxidized during combustion)

After obtaining the information on the burned biomass using Equation 16, the emission from the biomass open burning is estimated based on the following equation:

$$Em_{i,l} = \sum_l M_l \times EF_{i,l} \tag{17}$$

where,

$Em_{i,l}$ is emissions from pollutant type j and crop type l, M_l is the amount of burnt biomass in the field from crop type l, and $EF_{i,l}$ is emission factors specific to pollutant type i from crop type l.

Normally, data on the actual amount of biomass burned (M_l), if available, can be used directly to calculate emissions. However, only data on crop production or crop cultivation area are commonly provided in the current literature.

6.3. Data on Activity Levels

As already mentioned in sections above, activity rate requires information of dry biomass burned which can be derived either based on crop production or burned area. Due to the absence of the data on crop area burned, crop production data of each type of crop has been utilized for the emission estimation.

Agriculture is the mainstay of Nepalese economy and has been making notable contribution to the economy. Agriculture and forestry sector occupied a share of 34.3% in the national GDP in the year 2010/11, while it occupied a share of 35% in the FY 2008/09 (MOF, 2011b). About two-thirds of the agricultural GDP comes from the crops sub-sector with the remainder from the livestock sub-sector. Rice, wheat and maize are the most dominant cereal crops of Nepal. Each of the three main ecological zones of Nepal has its own unique characteristics, cropping patterns and farming systems leading to the difference in the commodities produced, production levels and productivity. Paddy is the main crop in the Terai while maize in the Hills and maize and potato in the mountainous regions of Nepal.

Table 37 shows the cultivated area, production and yields of cereal and cash crops in the FY 2008/09. The region wise area, production and yields of cereal and cash crops are presented in Annexes 14 and 15.

A number of agricultural practices and activities such as manure composting, flood irrigation for rice cultivation etc. are known to produce adverse environmental consequences including GHG emissions. The agriculture sector is also one of the major sources of GHG (mainly Methane (CH_4) and Nitrous Oxide (N_2O)) and other emissions in Nepal. The three major sources of these emissions from this sector are domestic livestock, rice cultivation and agricultural soils. However, this chapter only focuses on emissions produced due to the crop residue open burning.

Total CH_4 emission from agricultural sector in Nepal in FY 1994/95 was estimated to be around 867 thousand tonne. Around 61% of the total agricultural emissions were from enteric fermentation in livestock, while the remaining 35% and 4% was from rice cultivation and livestock manure management respectively (MOPE, 2004). Total N_2O emissions from the agricultural sector in FY 1994/95 was estimated to be 29 thousand tonne in which 27 thousand tonne was contributed by the agriculture soils and the remaining 2 thousand tonne by animal waste management system (MOPE, 2004). Total CH_4 emission from paddy fields in Nepal in FY 1994/95 was calculated to be 306 thousand tonne, which was 35% of the total CH_4 emissions in Nepal from the agricultural sector. CH_4 emissions from the irrigated and continuously flooded rice fields accounted for 41% of the total CH_4 emissions from paddy fields in Nepal. Drought prone rain-fed rice cultivation emitted 48% of the total CH_4 emission from paddy fields and the remaining 11% CH_4 was contributed by flood prone rain-fed rice cultivation (MOPE, 2004).

Table 37: Cultivated Area, Production and Yields of Cereal and Cash Crops in FY 2008/09

Crop Type	Area (ha)	Production (tonne)	Yield (kg per ha)
Paddy	1555940	4523693	2907
Maize	875428	1930669	2205
Millet	265889	292683	1101
Wheat	694950	1343862	1934
Barley	25817	23224	900
Oilseed	181361	135494	747
Potato	181900	2424048	13326
Tobacco	2542	2497	982
Sugarcane	58101	2354412	40523
Jute	11678	17658	1512

Source: MOAC (2010)

6.4. Emission Factors

Various research publications provide different values for crop-specific production-to-residue ratio, dry matter-to-crop ratio, fraction of dry matter residues burned in the field, and crop-specific burn efficiency ratio (see e.g., Streets et al. (2003) and the Global Atmospheric Pollution Forum Air Pollutant Emissions Inventory Manual (GAPF, 2007)). In the absence of the figures specific to Nepal, this study has adopted such parameters from various international sources. The parameter values for major crops used in the current analysis are presented in Table 38. For biomass burning, normally an emission factor is expressed in terms of grams of a pollutant released per kilogram of burned dry matter. Area- or region-specific emission factors for specific types of crops are not widely available. Some publications provide emission factors for crop residues only without specific information on types of crops. Compiled values of emission factors from various sources are presented in Table 39.

Table 38: Parameters for Estimation of Emissions from Crop Residue Burning

Crop type	Residue to crop ratio (N)[a]	Dry matter to crop residue ratio (D)[a]	Fraction burned in field (B)[c]	Burn efficiency fraction (F)[a]
Rice	1.76	0.85	0.8	0.89
Maize	0.33	0.4[b]	0.8	0.9[b]
Potatoes	0.4[b]	0.45[b]	0.8	0.9[b]
Oil crops	0.6	0.6	0.8	0.82
Sugarcane	0.3	0.3	0.8	0.68
Wheat	1.75	0.83	0.8	0.86
Jute	2.15	0.8	0.8	0.9
Others	2.15	0.8	0.8	0.9

Source: [a]Compiled by GAPF (2007); [b]IPCC (1997). Suggested values are 0.25 (developing countries) and <0.17 (developed countries). However, local value is desirable to be used, since this component is a large source of uncertainty; [c]Pant (2014)

Table 39: Emission Factors of Air Pollutants and GHGs from Crop Residue Open Burning

Crop Type	Air Pollutants									GHGs	
	NO_X	CO	NMVOC	PM_{10}	$PM_{2.5}$	BC	OC	SO_2	NH_3	CO_2	CH_4
Rice	0.62[a], 1.81[b]	180[a], 93[c]	7[d]	3.5[e], 9.1[c]	3.2[e], 8.3[c]	0.69[d], 0.49[f]	3.3[d], 2.8[c]	0.4[d], 0.18[f]	4.1[a]	1216[a], 1200[c]	9.6[a]
Wheat	1.7[h], 2.28[f]	28[h], 57.78[f]	2.16[g]	3.9[g]	3.7[g]	0.52[g], 0.42[f]	1.26[g], 3.46[f]	0.4[d], 0.04[f]	0.95[g]	1613[d], 1558[b]	3.55[h]
Maize	1.7[h], 3.05[f]	36.4[g], 86.73[f]	7[d]	3.9[d]	3.9[d]	0.69[d], 0.73[i]	3.3[a], 2.04[f]	0.4[d]	1.3[d]	1613[d], 1836[f]	2.7[d]
Potatoes	1.7[h]	36.4[g]	7[d]	3.9[d]	3.9[d]	0.69[d], 0.73[i]	3.3[a], 0.7[j]	0.4[d]	1.3[d]	1613[d]	2.7[d]
Jute	1.7[h]	36.4[g]	7[d]	3.9[d]	3.9[d]	0.69[d], 0.73[i]	3.3[a], 0.7[j]	0.4[d]	1.3[d]	1613[d]	2.7[d]
Oil crops	1.7[h]	36.4[g]	7[d]	3.9[d]	3.9[d]	0.69[d], 0.73[i]	3.3[a], 0.7[j]	0.4[d]	1.3[d]	1613[d]	2.7[d]
Sugarcane	2.6[g]	36.4[g]	2.16[g]	3.9[g]	3.7[g]	0.69[d], 0.73[i]	3.3[a], 0.7j	0.4[d]	0.95[g]	1613[d]	0.4[g]
Others	1.7[h]	36.4[g]	7[d]	3.9[d]	3.9[d]	0.69[d], 0.73[i]	3.3[a], 0.7[j]	0.4[d]	1.3[d]	1613[d]	2.7[d]

Source: [a]Christian et al. (2003). Values are taken from the Open-path Fourier Transform Infrared Spectrometry (OP-FTIR). Most of the values are applicable for rice straw in Indonesia; [b]Zhang et al. (2008). Laboratory study of crop residue combustion of wheat, rice and corn in China; [c]Kim Oanh et al. (2011).Values are taken from field burning of rice straw in Thailand; [d]Andreae and Merlet (2001). Values are best guess and are applicable for any combination of crop residue. Those presented are average values; [e]Jenkins et al. (1996). Values are applicable for rice straw open field burning which has been generated in wind tunnel experiments; [f]Cao et al. (2008). Average emission factors from crop residues, such as wheat, rice, and corn, were carried out in a burning tower in China; [g]Dennis et al. (2002). Values are specific for corn, sugarcane, and wheat, while the rest is assumed to be similar to sugarcane. Units are converted from lb/tonne to g/kg. The emission factor study was developed in the USA; [h]Sahai et al. (2007). Values are suitable for the burning of wheat straw residue and mostly applicable in India; [i]Streets et al. (2001); [j]Reddy and Venkataraman (2002). OM/OC ratio assumed as 1.3

6.5. Estimated Emissions

Table 40 presents the estimated emissions due to crop residue burning in the fields in FY 2008/09 using high values of emission factors as shown in Table 39 ("High Case"), whereas Table 4 presents the same using the low values of emission factors ("Low Case"). In the High Case, the total estimations for CO, NO_X, SO_2, NMVOC, NH_3, PM_{10}, $PM_{2.5}$, BC, OC, CO_2 and CH_4 are estimated to be 992.6, 13.9, 2.9, 43.5, 22.4, 53.2, 49.1, 4.8, 24.0, 9777.8 and 53.6 thousand tonnes, respectively. Rice is found to account for the largest share in total emission of each type of pollutant, followed by potatoes, wheat, maize, sugarcane, oil crops and jute.

6.6. Temporal and Spatial Variations

Due to lack of district-wise crop production data for FY 2008/09, spatial distributions of emissions due to crop residue burning has been estimated using the shares of individual districts in the national crop production in FY 2007/08. The estimated district wise data for crop production in FY 2008/09 are presented in Annex 16.

Figure 35 shows the spatial variation of CO_2 and SO_2 emission densities from crop residue open burning, whereas Table 42 presents the district-wise emissions from the crop residue open burning. The spatial variations of other type of emissions from the crop residue open burning are presented in the Annex 17. Ten districts (Sarlahi, Siraha, Dhanusha, Mahottari, Rautahat, Kailali, Bara, Nawalparasi Morang, and Jhapa) account for about one third of the total national emissions from crop residue burning, with Sarlahi district having the largest share (i.e. 5.71%) in the national emissions, followed by Siraha (3.87%), Dhanusa (3.64%), Mahottari (3.23%), Rautahat (2.98%), Kailali (2.95%), Bara (2.92%), Nawalparasi (2.75%), Morang (2.66%), and Jhapa (2.56%); the remaining 65 districts account for about two third of the emissions. Due to lack of monthly crop production data, the temporal variations of emissions from the crop residue burning could not be estimated in this study.

Table 40: Annual Emissions of Air Pollutants and GHGs from Crop Residue Open Burning in the High Case, tonne

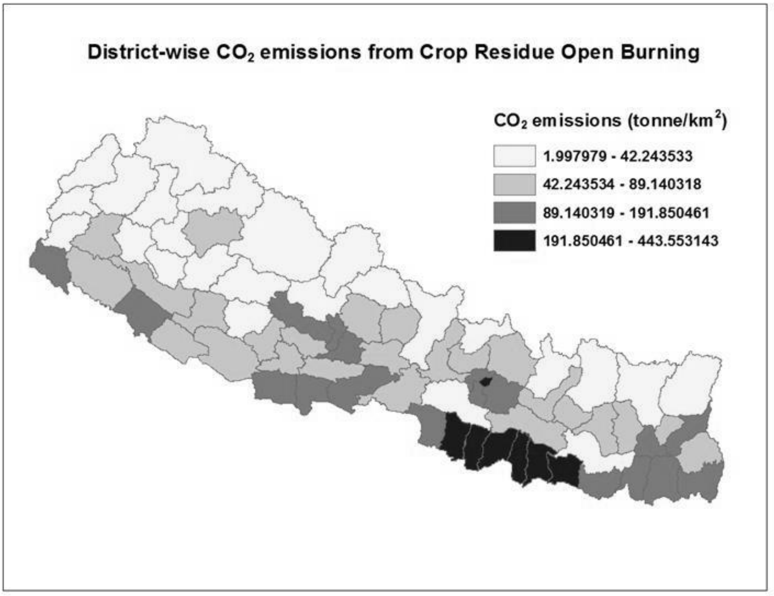
Air Pollutants	Crop Type							
	Rice	Wheat	Maize	Potatoes	Jute	Oil Crops	Sugarcane	Others*	Total
CO	867316	77596	15914	11435	796	1165	3988	14353	**992563**
NO_X	8721	3062	560	534	37	54	300	670	**13939**
SO_2	1927	537	73	126	9	13	46	158	**2889**
NMVOC	33729	2901	1284	2199	153	224	249	2760	**43499**
NH_3	19756	1276	239	408	28	42	110	513	**22370**
PM_{10}	43848	5237	716	1225	85	125	450	1538	**53223**
$PM_{2.5}$	39993	4969	716	1225	85	125	427	1538	**49077**
BC	3325	698	134	229	16	23	84	288	**4798**
OC	15901	4647	606	1037	72	106	380	1301	**24049**
GHGs									
CO_2	5859200	2166175	336889	506735	35273	51613	185934	636024	**9777843**
CH_4	46257	4767	495	848	59	86	46	1065	**53624**

*Note: *Others include millet, barley and tobacco*

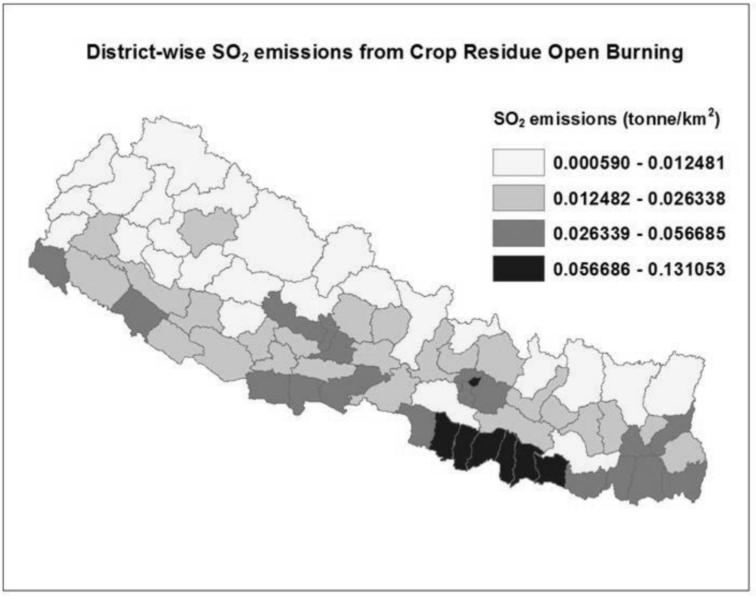
Table 41: Annual Emissions of Air Pollutants and GHGs from Crop Residue Open Burning in the Low Case, tonne

Air Pollutants	Crop Type							
	Rice	Wheat	Maize	Potatoes	Jute	Oil Crops	Sugarcane	Others*	Total
CO	448113	37603	6679	11435	796	1165	3988	14353	**524132**
NO_X	2987	2283	312	534	37	54	300	670	**7178**
SO_2	1927	537	73	126	9	13	46	158	**2889**
NMVOC	33729	2901	1284	2199	153	224	249	2760	**43499**
NH_3	19756	1276	239	408	28	42	110	513	**22370**
PM_{10}	16864	5237	716	1225	85	125	450	1538	**26240**
$PM_{2.5}$	15419	4969	716	1225	85	125	427	1538	**24503**
BC	2361	564	127	217	15	22	80	272	**3657**
OC	13492	1692	374	220	15	22	81	276	**16172**
GHGs									
CO_2	5782105	2092313	295971	506735	35273	51613	185934	636024	**9585967**
CH_4	46257	4767	495	848	59	86	46	1065	**53624**

*Note: *Others include millet, barley and tobac*



a) CO_2 Emission Density



b) SO_2 Emission Density

Figure 35: Spatial Variation of CO_2 and SO_2 Emission densities from Crop Residue Open Burning in FY 2008/09

Table 42: District-wise Annual Emissions of Air Pollutants and GHGs from Crop Residue Open Burning in the High Case, tonne

Districts	Emisions										
	Air Pollutants									GHGs	
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2
Sankhuwasabha	25.2	121.6	8660.0	379.5	195.2	464.4	428.2	41.9	209.8	467.9	85310.2
Solukhumbu	18.3	88.1	6270.2	274.8	141.3	336.2	310.0	30.3	151.9	338.8	61768.8
Taplejung	21.0	101.4	7221.5	316.5	162.8	387.2	357.1	34.9	175.0	390.2	71140.0
Bhojpur	20.9	100.8	7174.3	314.4	161.7	384.7	354.7	34.7	173.8	387.6	70674.5
Dhankuta	26.8	129.4	9215.0	403.9	207.7	494.1	455.6	44.5	223.3	497.9	90778.3
Ilam	27.8	134.1	9547.4	418.4	215.2	512.0	472.1	46.2	231.3	515.8	94052.4
Khotang	37.8	182.1	12969.3	568.4	292.3	695.4	641.3	62.7	314.2	700.7	127761.5
Okhaldhunga	24.7	119.3	8498.4	372.5	191.5	455.7	420.2	41.1	205.9	459.1	83718.8
Panchthar	42.2	203.7	14503.2	635.6	326.9	777.7	717.1	70.1	351.4	783.6	142872.9
Terhathum	13.0	62.6	4459.1	195.4	100.5	239.1	220.5	21.6	108.0	240.9	43927.3
Udaypur	25.8	124.2	8846.6	387.7	199.4	474.4	437.4	42.8	214.4	477.9	87148.4
Jhapa	74.0	357.0	25420.0	1114.0	572.9	1363.1	1256.9	122.9	615.9	1373.3	250415.5
Morang	76.9	371.2	26432.3	1158.4	595.7	1417.4	1306.9	127.8	640.4	1428.0	260387.3
Saptari	46.4	223.8	15933.9	698.3	359.1	854.4	787.9	77.0	386.1	860.8	156966.2
Siraha	111.8	539.5	38415.7	1683.6	865.8	2059.9	1899.5	185.7	930.8	2075.4	378437.2
Sunsari	71.3	343.8	24480.1	1072.9	551.7	1312.7	1210.4	118.3	593.1	1322.6	241156.0
Dolakha	15.0	72.2	5138.6	225.2	115.8	275.5	254.1	24.8	124.5	277.6	50620.7
Rasuwa	11.0	53.2	3788.7	166.0	85.4	203.2	187.3	18.3	91.8	204.7	37322.8
Sindhupalchowk	44.7	215.4	15340.4	672.3	345.7	822.6	758.5	74.2	371.7	828.8	151120.0
Bhaktapur	10.0	48.3	3438.9	150.7	77.5	184.4	170.0	16.6	83.3	185.8	33876.6
Dhading	27.6	133.2	9486.1	415.7	213.8	508.7	469.0	45.9	229.8	512.5	93448.2

Districts	Emisions										
	Air Pollutants									GHGs	
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2
Kathmandu	16.9	81.3	5792.4	253.9	130.6	310.6	286.4	28.0	140.4	312.9	57061.8
Kavre	52.9	255.0	18161.6	795.9	409.3	973.9	898.0	87.8	440.0	981.2	178911.5
Lalitpur	14.6	70.3	5006.4	219.4	112.8	268.5	247.5	24.2	121.3	270.5	49318.1
Makawanpur	29.5	142.1	10120.7	443.5	228.1	542.7	500.4	48.9	245.2	546.8	99700.2
Nuwakot	27.5	132.5	9432.8	413.4	212.6	505.8	466.4	45.6	228.6	509.6	92923.4
Ramechhap	25.2	121.8	8672.3	380.1	195.5	465.0	428.8	41.9	210.1	468.5	85431.4
Sindhuli	36.7	177.1	12607.4	552.5	284.2	676.0	623.4	60.9	305.5	681.1	124197.2
Bara	84.2	406.5	28943.4	1268.5	652.3	1552.0	1431.1	139.9	701.3	1563.7	285124.1
Chitwan	47.5	229.2	16318.3	715.2	367.8	875.0	806.9	78.9	395.4	881.6	160753.4
Dhanusa	105.3	508.0	36173.6	1585.3	815.3	1939.7	1788.6	174.9	876.5	1954.3	356350.1
Mahaottari	93.3	449.9	32039.3	1404.1	722.1	1718.0	1584.2	154.9	776.3	1731.0	315622.1
Parsa	60.7	292.7	20842.7	913.4	469.8	1117.6	1030.6	100.8	505.0	1126.1	205323.6
Rautahat	86.2	415.8	29605.3	1297.5	667.3	1587.5	1463.8	143.1	717.3	1599.5	291645.1
Sarlahi	165.0	796.1	56687.4	2484.4	1277.6	3039.7	2802.9	274.0	1373.5	3062.6	558433.4
Manang	4.2	20.3	1442.9	63.2	32.5	77.4	71.3	7.0	35.0	78.0	14214.2
Mustang	7.9	38.1	2714.7	119.0	61.2	145.6	134.2	13.1	65.8	146.7	26743.1
Argakhanchi	19.9	95.8	6818.8	298.8	153.7	365.6	337.2	33.0	165.2	368.4	67173.0
Baglung	58.0	279.6	19911.3	872.6	448.8	1067.7	984.5	96.2	482.4	1075.7	196147.9
Gorkha	36.8	177.8	12658.2	554.8	285.3	678.8	625.9	61.2	306.7	683.9	124697.2

Districts	Emisions										
	Air Pollutants									GHGs	
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2
Gulmi	23.8	114.7	8165.5	357.9	184.0	437.9	403.7	39.5	197.8	441.2	80439.2
Kaski	40.0	192.8	13725.4	601.5	309.3	736.0	678.7	66.3	332.6	741.5	135210.3
Lamjung	23.6	113.7	8094.3	354.7	182.4	434.0	400.2	39.1	196.1	437.3	79737.8
Myagdi	20.1	97.0	6904.3	302.6	155.6	370.2	341.4	33.4	167.3	373.0	68014.7
Palpa	18.2	87.8	6249.5	273.9	140.9	335.1	309.0	30.2	151.4	337.6	61564.7
Parbat	20.7	99.8	7107.6	311.5	160.2	381.1	351.4	34.4	172.2	384.0	70017.7
Syangja	47.9	231.0	16451.8	721.0	370.8	882.2	813.5	79.5	398.6	888.8	162068.2
Tanahu	24.4	117.5	8365.0	366.6	188.5	448.6	413.6	40.4	202.7	451.9	82404.6
Kapilbastu	67.8	327.3	23305.3	1021.4	525.3	1249.7	1152.3	112.7	564.7	1259.1	229583.0
Nawalparasi	79.3	382.6	27247.2	1194.1	614.1	1461.1	1347.2	131.7	660.2	1472.1	268415.3
Rupandehi	71.4	344.4	24525.1	1074.8	552.8	1315.1	1212.6	118.5	594.2	1325.0	241599.0
Dolpa	4.7	22.5	1600.0	70.1	36.1	85.8	79.1	7.7	38.8	86.4	15762.1
Humla	13.2	63.7	4533.1	198.7	102.2	243.1	224.1	21.9	109.8	244.9	44656.3
Jumla	54.9	265.0	18868.1	826.9	425.3	1011.8	932.9	91.2	457.2	1019.4	185871.8
Mugu	18.5	89.2	6351.5	278.4	143.2	340.6	314.1	30.7	153.9	343.2	62569.6
Kalikot	17.8	85.8	6107.7	267.7	137.7	327.5	302.0	29.5	148.0	330.0	60167.2
Dailekh	15.1	73.1	5203.0	228.0	117.3	279.0	257.3	25.2	126.1	281.1	51255.0
Jajarkot	20.5	98.7	7031.4	308.2	158.5	377.0	347.7	34.0	170.4	379.9	69267.5
Pyuthan	21.3	102.9	7329.5	321.2	165.2	393.0	362.4	35.4	177.6	396.0	72204.0

Districts	Emisions										
	Air Pollutants									GHGs	
	SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	CO_2
Rolpa	16.7	80.4	5722.9	250.8	129.0	306.9	283.0	27.7	138.7	309.2	56376.4
Rukum	25.3	122.0	8689.0	380.8	195.8	465.9	429.6	42.0	210.5	469.4	85596.7
Salyan	33.5	161.8	11521.7	504.9	259.7	617.8	569.7	55.7	279.2	622.5	113501.5
Surkhet	42.2	203.3	14479.7	634.6	326.3	776.4	716.0	70.0	350.8	782.3	142641.5
Dang	59.2	285.5	20327.1	890.9	458.1	1090.0	1005.1	98.3	492.5	1098.2	200244.9
Banke	36.9	177.8	12659.9	554.8	285.3	678.9	626.0	61.2	306.7	684.0	124713.8
Bardia	63.3	305.4	21750.2	953.2	490.2	1166.3	1075.4	105.1	527.0	1175.1	214263.5
Bajhang	22.0	106.0	7548.3	330.8	170.1	404.8	373.2	36.5	182.9	407.8	74358.8
Bajura	20.0	96.7	6885.0	301.7	155.2	369.2	340.4	33.3	166.8	372.0	67824.5
Darchula	16.9	81.6	5812.1	254.7	131.0	311.7	287.4	28.1	140.8	314.0	57255.5
Accham	10.4	49.9	3555.0	155.8	80.1	190.6	175.8	17.2	86.1	192.1	35020.6
Baitadi	13.2	63.7	4538.1	198.9	102.3	243.3	224.4	21.9	110.0	245.2	44704.8
Dadeldhura	9.0	43.2	3074.0	134.7	69.3	164.8	152.0	14.9	74.5	166.1	30282.3
Doti	31.6	152.4	10852.8	475.6	244.6	582.0	536.6	52.5	263.0	586.3	106912.0
Kailali	85.2	411.1	29272.7	1282.9	659.8	1569.7	1447.4	141.5	709.3	1581.5	288368.9
Kanchanpur	56.8	274.1	19520.1	855.5	440.0	1046.7	965.2	94.4	473.0	1054.6	192294.9
Total	2889.0	13938.6	992562.8	43499.5	22370.4	53223.4	49077.0	4797.6	24049.0	53624.1	9777842.6

7. Forest Fires

7.1. Overview

Forest fires are a major problem in Nepal. Most of the forest fires in Nepal are anthropogenic. Terai faces a higher risk of forest fires than other regions. A study carried out by International Forest Fire Network (IFFN) in Terai reports that 58 percent of the total forest fires were deliberate burning by grazers, poachers, hunters and non-timber forest products (NTFPs) collectors. Forest fires due to negligence and accidental fire (both related to agricultural activities) accounted for 22% and 20% of the total forest fires respectively in the country (IFFN, 2006).

Forest fires are common in Nepal during the dry spring season, particularly in the months of March, April and May. The high wind velocity during these months aids the wildfires to spread over a large area destroying hundreds of hectares of forest and croplands. A total of 100 active fire locations were reported for the period of March in 2008. In March 2009, there were 1583 fire locations. In 2010, several incidences of forest fires were reported in the districts of Dang, Palpa, Parvat, Kavre, Rupandehi, Chitwan and most of the Terai belt districts in Nepal during the months of March and April (ICIMOD, 2010).

7.2. Emission Estimation Method

For forest fires, the total dry matter burned from an area could be estimated as follows:

$$M_l = A_{ba} \times \rho_l \times \eta_l \tag{18}$$

where,

M_l = Mass of dry matter burned (ton/year)

A_{ba} = Actual burned area (ha)

ρ_l = Dry matter density (ton/ha)

η_l = Burning efficiency (oxidized in the combustion).

The actual burned area (A_{ba}) is calculated as follows:

$$A_{ba} = A_j \times f_j \tag{19}$$

where,

A_j = Area of land cover type j (ha)

f_j = Fraction of total area of land cover type j burned annually.

For forest fire, it is difficult to find the reliable data on burned area. The daily report on recorded burned area was not available for FY 2008/09.

7.3. Data on Activity Levels

Forest is the most important natural resource of Nepal after water and is the main source of fuelwood, fodder, timber and herbal medicines in the country. Forestry is an integral part of agriculture and rural livelihood as fuelwood is the principal source of rural energy. About 80% of the population in the country are dependent on forest resources for their daily fuelwood supply. High consumption of fuelwood and deforestation has decreased the forest area from 37.8% in 1998 to about 29.0% in 2009 (CBS, 2008a). Forests act both as a source and a sink for CO_2 emissions. According to Food and Agriculture Organization (FAO), Nepal's forestry sector contributed 3.5% to the GDP of the country in 2000 and 4.4% for the period 1990 to 2000 (MOFSC, 2009).

Table 43 shows the estimated forest and shrub land areas in 2000 and 2005.

Table 43: Estimation of Forest and Shrub Land Area

Cover Type	Unit	Year	
		2000	2005
Forest	Area (000 ha)	3900	3636
	%	26.5%	24.7%
Shrub	Area (000 ha)	1753	1897
	%	11.9%	12.9%
Total	Area (000 ha)	5653	5533
	%	38.4%	37.6%

Source: WECS (2010)

Table 44: Forest Area by Type of Forest in Nepal, km^2

Forest Type	Year	
	1994/95	2008/09
Total Forest Area (km^2)	58280	3636000* (in ha)
Shorea Robusta (SAL)	5761	-
Tropical mixed hardwood	12554	-
Lower mixed hardwood	7679	-
Conifer	2567	-
Upper mixed hardwood	13135	-
Other forest	992	-
Shrub	15592	-

*Note: *2005 data*
Source: MOPE (2004)

According to the last forest inventory carried out in Nepal in the early nineties, forest and shrub together covered about 5.83 million ha, which is 39.6% of the total land area of the country (MoFSC, 2009). The rate of forest area decrease was 1.7% per annum during 1978/79 to 1994/95, whereas the rate of forest and shrub depletion was 0.5% per annum during the same period. There are 35 major forest types and 118 ecosystems in Nepal (MoFSC, 2009).

Table 44 shows the types of forest resource in Nepal in FY 1994/95 and 2008/09. As can be seen in Table 44, the total forest area in 2005 was 3,636,000 ha, of which primary, modified natural, semi-natural, and production/plantation forests were 349,000 ha, 384,000 ha, 2,850,000 ha, and 53,000 ha respectively[19]. The area annually affected by fire has been estimated to be 400,000 ha[20].

Table 45: Land Use Pattern of Nepal

Land Use Type	Area (000 ha)		Percent of total area (%)	
	1986	**2001**	**1986**	**2001**
Cultivated Land	2968	3091	19.9	21.0
Non-cultivated Land	987	1030	6.6	7.0
Forest	5618	4268	37.8	29.0
Shrubs Lands/Degraded Forest	688	1560	4.6	10.6
Grass Lands	1757	1766	11.8	12.0
Others	2859	3002	19.2	20.4
Total	**14855**	**14718**	**100.0**	**100.0**

Source: CBS (2008a)

[19]*Based on http://rainforests.mongabay.com/20nepal.htm.*

[20]*Same as footnote 15.*

Table 45 presents the land use pattern of Nepal in 1986 and 2001. The sustainable supply of fuelwood from reachable area of all land resources type in FY 2008/09 was 12506.6 thousand tonne. Forest land contributes more than three forth of the total sustainable fuelwood production in the country. Around 9.3% of the sustainable fuelwood comes from the cultivated land, followed by non-cultivated land (5.5%), shrub land (4.5%) and grass land (0.4%) (WECS, 2010). The annual sustainable fuelwood supply in Nepal in 2008/09 is presented in Table 46.

Table 46: Annual Sustainable Fuelwood Supply in Nepal in FY 2008/09, thousand tonne

Land Use Type	Development Region					Grand Total
	FWDR[1]	MWDR[2]	WDR[3]	CDR[4]	EDR[5]	
Cultivated Land	131.3	197.4	251.6	269.8	315.7	1165.9
Non-cultivated Inclusion	78.0	122.8	158.0	164.9	164.9	688.6
Grass Land	11.0	18.5	9.4	5.4	7.2	51.5
Forest*	1619.6	2177.2	1306.7	2372.9	2561.2	10037.6
Shrub Land	95.0	116.2	63.3	92.7	195.9	563.1
Grand Total	**1934.9**	**2632.1**	**1789.0**	**2905.7**	**3245.0**	**12506.6**

*Note: * includes community forest as well as other forests; [1]FWDR: Far Western Development Region; [2]MWDR: Mid Western Development Region; [3]WDR: Western Development Region; [4]CDR: Central development region; [5]EDR: Eastern Development Region*

Source: WECS (2010)

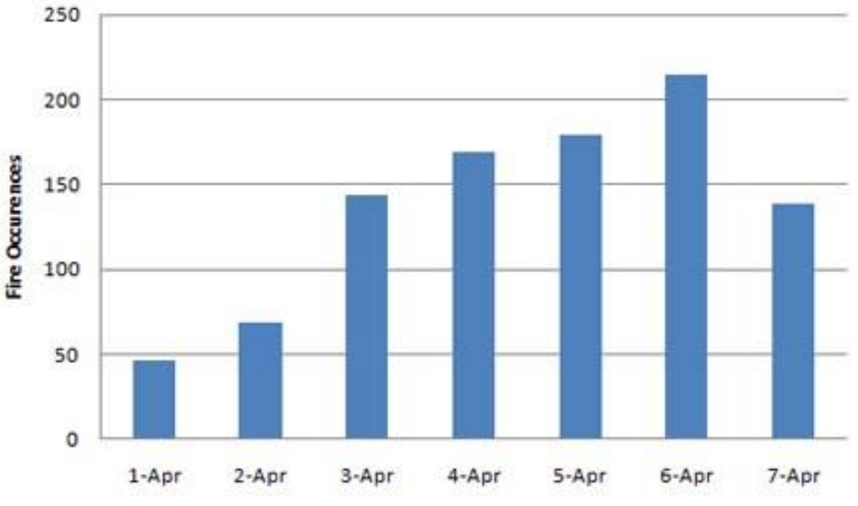


Figure 36: Number of Forest Fire Incidences in Nepal during 1-7 April 2010
(Source: ICIMOD (2010))

Forest fire is a major problem in the management of forest system in Nepal. In the mixed forest of Sal in Terai, the forest fire season starts from the mid-March and the forest fires occur 1 to 3 times till the end of May. Most of the forest fires in Nepal are surface fires. Figure 36 shows the occurrences of forest fires in Nepal during 1-7 April 2010. However, not much reliable data was available on forest fires in Nepal (DoSC, 1996).

7.4. Emission Factors

The emission factors for forest fires considered in this study are presented in Table 47 following Andreae and Merlet (2001) as reported in the Atmospheric Brown Cloud Emission Inventory Manual (Shrestha et al., 2013).

Table 47: Emission Factors of Air Pollutants and GHGs from Tropical Forest Fires

Air Pollutants	Emission Factor (g/kg)
SO_2	0.57
NO_X	2.45
CO	104
NMVOC	8.1
PM_{10}	10.5
$PM_{2.5}$	9.1
NH_3	1.3
BC	0.66
OC	5.2
GHGs	
CO_2	1580
CH_4	6.8

Source: Andreae and Merlet (2001)

Table 48: Estimated Emissions from Forest Fires in FY 2008/09, tonne/year

Air Pollutants	Forest Fire
SO_2	16,361
NO_x	70,325
CO	2,985,216
NMVOC	232,502
NH_3	37,315
$PM_{2.5}$	261,206
PM_{10}	301,392
BC	18,945
OC	149,261
GHGs	
CO_2	45,352,320
CH_4	195,187

7.5. Estimated Emissions

The total forest area of Nepal was estimated to be 3,636,000 ha in 2005. Due to lack of forest inventory data in later years, the same area as in 2005 has been considered to estimate emissions from forest fires in FY 2008/09. The fraction of total area burned in the year has been estimated to be 0.11, since the annual area affected by forest fires has been estimated to be 400,000 ha[21].

Following IPCC (2006), the ground biomass density and the fraction of biomass actually burnt have been assumed to be 119.6 tons dry matter/ha and 0.6 respectively. The estimated emissions from forest fires are presented in Table 48.

7.6. Temporal and Spatial Variations

Due to the lack of monthly/district-wise forest fires data, the temporal and spatial variation of emissions based on forest fires could not be estimated for FY 2008/09.

[21] *http://rainforests.mongabay.com/20nepal.htm.*

8. Municipal Solid Waste Open Burning

8.1. Overview

Like in many cities in the developing countries, management of increasing amounts of solid waste has become a major challenge in Nepal. According to a survey conducted by Central Bureau of Statistics (CBS) in 1996, solid waste management is considered as the most important environmental problem in urban areas of Nepal (CBS, 1997).

8.2. Emission Estimation Method

The methodology used in the present study for the estimation of emissions from open burning of municipal solid waste (MSW) requires knowledge of the amount of MSW generated by a community and the fraction of MSW burned. For the calculation of the emission of a pollutant, the following relation has been used,

$$Em_i = M_s \times EF_i \quad (20)$$

where,

Em_i = Emission of pollutant i
EF_i = Emission factor of pollutant i
M_s = Amount of MSW burned

Open burning of solid waste has been differentiated into two categories, i.e., burning at the source (communities that generate solid waste) and burning at the disposal site.

a. Solid waste open burning at source

The daily amount of MSW open-burned at the source is estimated as:

$$M_s = P \times P_{frac} \times MSW_{GR} \times \delta \times \eta \quad (21)$$

where,

M_s = Amount of MSW open-burned (kg/day)
P = Population (capita)
P_{frac} = Fraction of population burning waste (fraction)
MSW_{GR}= Per capita MSW generation factor (kg waste/capita/day)
δ = Fraction of combustible MSW
η = Burning or oxidation efficiency (fraction)

b. Solid waste open burning at disposal site

The daily amount of MSW open-burned at the disposal site is estimated as:

$$M_{ds} = P \times MSW_{GR} \times \varepsilon \times \lambda \times \delta \times \eta \quad (22)$$

where,
M_{ds} = Amount of MSW open-burned (kg/day)
P = Population (capita)
MSW_{GR}= Per capita MSW generation factor (kg waste/capita/day)
ε = MSW collection efficiency (fraction that is dumped/land filled)
λ = Fraction of the waste that is actually burned relative to the total amount of waste dumped at a dumpsite
δ = Fraction of combustible MSW
η = Burning or oxidation efficiency (fraction)

8.3. Data on Activity Levels

The activity data required for the estimation of emissions from the municipal solid waste burning is the amount of openly burned solid waste. However, in the absence of such data, population and solid waste generation factor could be used to estimate the total amount of open-burned municipal solid waste generated. Since the data on amount of openly burned waste was not available in the case of Nepal, it has been estimated based on the urban and rural population data of 2008/09 by different ecological belts and the solid waste generation factor. The total population of Nepal in FY 2008/09 was 27.6 million (MOF, 2011a). The urban population in the country accounted for about 16% of the total population. According to the "National Population and Housing Census 2011" of Nepal, hilly areas have the highest share of urban population at 54.6%, followed by Terai at 44.3% and mountain region at 1.1% (CBS, 2012). Of the total rural population in the country, around 50% live in Terai, 42% in hills and rest 8% in the mountains. ADB (2013) estimates that the average household waste generation in municipalities in different ecological regions was 0.49 kg/household/day in the mountain region, 0.72 kg/household/day in the hills, and 0.88 kg/household/day in the Terai. This amounts to 121, 178 and 186 gm/day/person in the mountain, hills and Terai considering the corresponding urban household size of 4.04, 4.05 and 4.72 respectively (CBS, 2012 and ADB, 2013)[22]. The waste collection efficiency in Nepal is reported to be 39.7%, 72.3%, and 55.6% in the physiographic regions of mountain, hill and Terai respectively (Amatya, undated). Similarly, the values of waste collection efficiency by the development region are 83.7%, 38.9%, 93.8%, 58.6% and 39.4% in Central, Eastern, Far-Western, Mid-Western and Western regions respectively (Amatya, undated). However, according to ADB (2013), the average waste collection efficiency based on the data of 58 municipalities was 62.3%. The present study has considered the waste collection efficiency to be 62.3% (ADB, 2013) in the urban sector and 39.7% (Amatya, undated) in the rural sector. The fraction of population burning waste is considered to be around 35%.[23] According to IPCC (1997), the burning/oxidation efficiency (fraction) should be lower than 0.58. A value of 0.4 has been considered in the present analysis.

[22] *According to another study (SWMRMC (2009) as cited in Amatya (undated)), the amounts of per capita solid waste generations in Nepal were 109, 283 and 162 gm/day in mountain, hills and Terai regions respectively.*

[23] *This is the figure based on Ministry of Public Work (1998) in Indonesia; it has been adopted in this study in the absence of the similar information for Nepal.*

Table 49: Emission Factors of Air Pollutants and GHGs for Municipal Solid Waste Open Burning, g/kg

Air Pollutant	Emission Factor
SO_2	0.5[a]
NO_X	3[a]
CO	42[a]
NMVOC	15[a]
PM_{10}	8[a]
BC	5.5[b]
OC	5.5[b]
GHG	
CH_4	6.5[a]

Source: [a]USEPA (1995); [b]Bond et al. (2004)

8.4. Emission Factors

The emissions from municipal solid waste open burning are affected by several factors such as ambient temperature, waste composition, moisture content and local meteorological conditions. The emission factors used for the estimation of emissions from the open burning of the municipal solid waste in this study are mostly based on USEPA (1995) and Bond et al. (2004); they are presented in Table 49.

8.5. Estimated Emissions

The estimated emissions from open burning of solid waste in FY 2008/09 from rural areas in different ecological regions are presented in Table 50, while similar emissions from urban areas are presented in Table 51. As can be seen from the tables, the hilly region has the largest share in total emissions from municipal solid waste open burning both at source and disposal sites.

Table 50: Annual Emissions of Air Pollutants and GHGs from Municipal Solid Waste Open Burning from Rural Areas of Different Ecological Regions of Nepal in FY 2008/09, tonne

Air Pollutant	At Source				At Disposal Site				Total			
	Mountain	Hill	Terai	Total	Mountain	Hill	Terai	Total	Mountain	Hill	Terai	Total
SO_2	6	80	54	**140**	1	8	6	**14**	6	88	60	**154**
NO_X	33	482	325	**840**	3	49	33	**85**	37	531	358	**925**
CO	468	6,743	4,545	**11,756**	48	685	462	**1,194**	516	7,428	5,007	**12,950**
NMVOC	167	2,408	1,623	**4,199**	17	245	165	**427**	184	2,653	1,788	**4,625**
PM_{10}	89	1,284	866	**2,239**	9	130	88	**227**	98	1,415	954	**2,467**
BC	61	883	595	**1,539**	6	90	60	**156**	68	973	656	**1,696**
OC	61	883	595	**1,539**	6	90	60	**156**	68	973	656	**1,696**
GHG												
CH_4	72	1,044	703	**1,819**	7	106	71	**185**	80	1,150	775	**2,004**

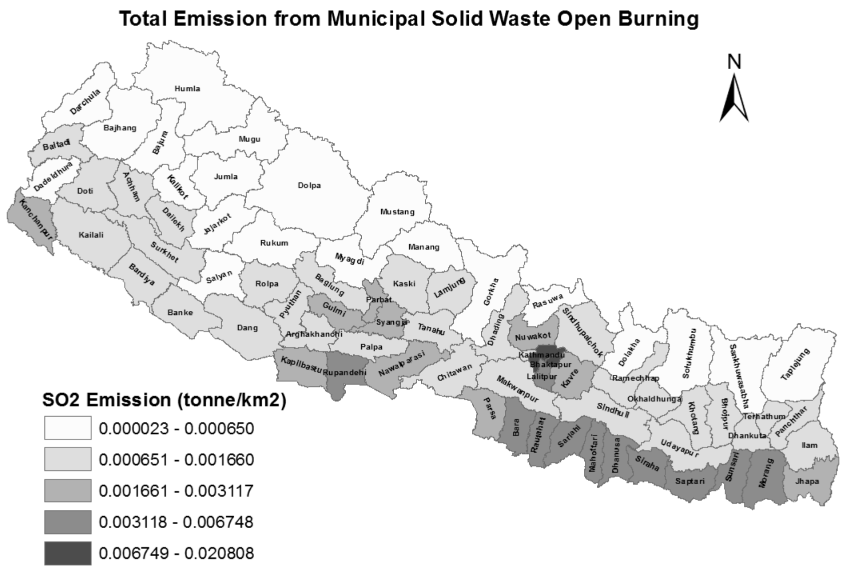
Table 51: Annual Emissions of Air Pollutants and GHGs from Municipal Solid Waste Open Burning from Urban Areas of Different Ecological Regions of Nepal in FY 2008/09, tonne

Air Pollutants	At Source				At Disposal Site				Total			
	Mountain	Hill	Terai	Total	Mountain	Hill	Terai	Total	Mountain	Hill	Terai	Total
SO_2	0.2	12.1	10.3	**22.6**	0.0	1.9	1.6	**3.6**	0.2	14.0	11.9	**26.1**
NO_X	1.0	72.5	61.8	**135.3**	0.2	11.5	9.8	**21.4**	1.2	84.0	71.6	**156.7**
CO	14.0	1,014.9	864.9	**1,893.8**	2.2	160.6	136.9	**299.6**	16.2	1,175.4	1,001.8	**2,193.4**
NMVOC	5.0	362.5	308.9	**676.4**	0.8	57.4	48.9	**107.0**	5.8	419.8	357.8	**783.4**
PM_{10}	2.7	193.3	164.7	**360.7**	0.4	30.6	26.1	**57.1**	3.1	223.9	190.8	**417.8**
BC	1.8	132.9	113.3	**248.0**	0.3	21.0	17.9	**39.2**	2.1	153.9	131.2	**287.2**
OC	1.8	132.9	113.3	**248.0**	0.3	21.0	17.9	**39.2**	2.1	153.9	131.2	**287.2**
GHGs												
CH_4	2.2	157.1	133.9	**293.1**	0.3	24.9	21.2	**46.4**	2.5	181.9	155.0	**339.5**

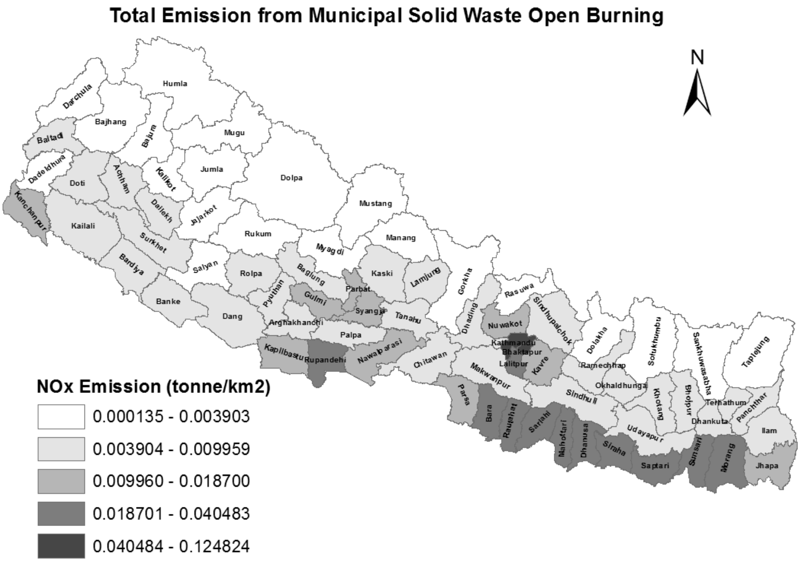
8.6. Temporal and Spatial Variations

For spatial variation of emissions from the open burning of municipal solid waste, district wise urban and rural population data have been used. However, due to lack of data on monthly municipal solid waste burning, temporal patterns of emissions could not be estimated.

Figure 37 shows the spatial variation of SO_2 and NO_X emissions of different pollutants from municipal solid waste open burning in 2008/2009, whereas the spatial variations of other emissions are presented in Annex 18. The estimated district-wise emission figures are also presented in Table 52. Municipal solid waste open burning emissions from the Kathmandu district occupy the largest share of about 4.56% among the 75 districts of Nepal. This is followed by Morang (3.69%), Dhanusa (2.96%), Sarlahi (2.83%), Jhapa (2.78%), Sunsari (2.72%), Kailali (2.70%), Saptari (2.53%), Siraha (2.52%), Nawalparasi (2.50%), Mahaottari (2.46%), Rautahat (2.42%), Parsa (2.17%), Kapilbastu (2.14%), and Dang (2.02%) districts. The remaining 59.0% of municipal solid waste emissions comes from the rest of the 60 districts of Nepal.



a) SO_2 Emission Density



b) NO_X Emission Density

Figure 37: Spatial Variations of SO_2 and NO_X Emission Densities from Municipal Solid Waste Open Burning (both at Source and Disposal Site)

Table 52: District-wise Annual Emissions of Air Pollutants and GHGs from Municipal Solid Waste (both at Source and Disposal Site) Open Burning, tonne

Districts	Emission							
	Air Pollutants							GHG
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	CH_4
Sankhuwasabha	1.26	7.57	105.93	37.83	20.18	13.87	13.87	16.39
Solukhumbu	0.87	5.20	72.76	25.98	13.86	9.53	9.53	11.26
Taplejung	1.08	6.50	91.01	32.50	17.33	11.92	11.92	14.08
Bhojpur	1.63	9.80	137.17	48.99	26.13	17.96	17.96	21.23
Dhankuta	1.32	7.91	110.71	39.54	21.09	14.50	14.50	17.13
Ilam	2.26	13.57	189.92	67.83	36.17	24.87	24.87	29.39
Khotang	1.86	11.17	156.33	55.83	29.78	20.47	20.47	24.19
Okhaldhunga	1.26	7.56	105.88	37.81	20.17	13.86	13.86	16.39
Panchthar	1.63	9.75	136.52	48.76	26.00	17.88	17.88	21.13
Terhathum	0.91	5.46	76.42	27.29	14.56	10.01	10.01	11.83
Udaypur	2.27	13.60	190.41	68.01	36.27	24.94	24.94	29.47
Jhapa	5.01	30.03	420.45	150.16	80.08	55.06	55.06	65.07
Morang	6.65	39.91	558.76	199.56	106.43	73.17	73.17	86.47
Saptari	4.56	27.37	383.22	136.86	72.99	50.18	50.18	59.31
Siraha	4.54	27.26	381.60	136.29	72.69	49.97	49.97	59.06
Sunsari	4.90	29.38	411.38	146.92	78.36	53.87	53.87	63.67
Dolakha	1.40	8.39	117.51	41.97	22.38	15.39	15.39	18.19
Rasuwa	0.36	2.16	30.22	10.79	5.76	3.96	3.96	4.68
Sindhupalchowk	2.36	14.18	198.45	70.88	37.80	25.99	25.99	30.71

Districts	Emission							
	Air Pollutants							GHG
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	CH_4
Bhaktapur	1.72	10.34	144.72	51.68	27.56	18.95	18.95	22.40
Dhading	2.72	16.34	228.81	81.72	43.58	29.96	29.96	35.41
Kathmandu	8.22	49.31	690.29	246.53	131.48	90.40	90.40	106.83
Kavre	3.05	18.31	256.28	91.53	48.82	33.56	33.56	39.66
Lalitpur	2.60	15.59	218.20	77.93	41.56	28.57	28.57	33.77
Makawanpur	3.10	18.60	260.36	92.99	49.59	34.10	34.10	40.29
Nuwakot	2.30	13.79	193.13	68.98	36.79	25.29	25.29	29.89
Ramechhap	1.71	10.25	143.51	51.25	27.34	18.79	18.79	22.21
Sindhuli	2.20	13.21	184.97	66.06	35.23	24.22	24.22	28.63
Bara	4.47	26.83	375.63	134.15	71.55	49.19	49.19	58.13
Chitwan	3.68	22.09	309.25	110.45	58.90	40.50	40.50	47.86
Dhanusa	5.34	32.02	448.24	160.09	85.38	58.70	58.70	69.37
Mahaottari	4.44	26.62	372.62	133.08	70.98	48.80	48.80	57.67
Parsa	3.92	23.49	328.90	117.46	62.65	43.07	43.07	50.90
Rautahat	4.36	26.19	366.60	130.93	69.83	48.01	48.01	56.74
Sarlahi	5.10	30.59	428.24	152.94	81.57	56.08	56.08	66.27
Manang	0.08	0.46	6.48	2.31	1.23	0.85	0.85	1.00
Mustang	0.12	0.72	10.12	3.61	1.93	1.33	1.33	1.57
Argakhanchi	1.68	10.06	140.80	50.29	26.82	18.44	18.44	21.79
Baglung	2.14	12.84	179.82	64.22	34.25	23.55	23.55	27.83

Districts	Emission							
	Air Pollutants							GHG
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	CH_4
Gorkha	2.29	13.75	192.47	68.74	36.66	25.20	25.20	29.79
Gulmi	2.39	14.32	200.43	71.58	38.18	26.25	26.25	31.02
Kaski	2.88	17.27	241.74	86.33	46.04	31.66	31.66	37.41
Lamjung	1.42	8.55	119.69	42.75	22.80	15.67	15.67	18.52
Myagdi	0.92	5.52	77.33	27.62	14.73	10.13	10.13	11.97
Palpa	2.14	12.82	179.49	64.10	34.19	23.50	23.50	27.78
Parbat	1.27	7.62	106.63	38.08	20.31	13.96	13.96	16.50
Syangja	2.51	15.05	210.66	75.24	40.13	27.59	27.59	32.60
Tanahu	2.50	15.03	210.38	75.14	40.07	27.55	27.55	32.56
Kapilbastu	3.86	23.15	324.05	115.73	61.72	42.44	42.44	50.15
Nawalparasi	4.51	27.05	378.75	135.27	72.14	49.60	49.60	58.62
Rupandehi	5.59	33.54	469.50	167.68	89.43	61.48	61.48	72.66
Dolpa	0.18	1.07	14.91	5.33	2.84	1.95	1.95	2.31
Humla	0.33	1.96	27.43	9.80	5.22	3.59	3.59	4.24
Jumla	0.56	3.34	46.77	16.70	8.91	6.12	6.12	7.24
Mugu	0.25	1.52	21.26	7.59	4.05	2.78	2.78	3.29
Kalikot	0.09	0.56	7.78	2.78	1.48	1.02	1.02	1.20
Dailekh	1.80	10.79	151.00	53.93	28.76	19.77	19.77	23.37
Jajarkot	1.08	6.51	91.12	32.54	17.36	11.93	11.93	14.10
Pyuthan	1.71	10.25	143.56	51.27	27.35	18.80	18.80	22.22

Districts	Emission							
	Air Pollutants							GHG
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	CH_4
Rolpa	1.69	10.13	141.89	50.67	27.03	18.58	18.58	21.96
Rukum	1.52	9.09	127.32	45.47	24.25	16.67	16.67	19.70
Salyan	0.49	2.93	40.97	14.63	7.80	5.37	5.37	6.34
Surkhet	2.14	12.85	179.88	64.24	34.26	23.56	23.56	27.84
Dang	3.65	21.89	306.39	109.43	58.36	40.12	40.12	47.42
Banke	3.06	18.37	257.14	91.84	48.98	33.67	33.67	39.80
Bardia	3.04	18.24	255.39	91.21	48.65	33.44	33.44	39.52
Bajhang	1.34	8.06	112.85	40.30	21.50	14.78	14.78	17.46
Bajura	0.81	4.86	67.99	24.28	12.95	8.90	8.90	10.52
Darchula	0.98	5.89	82.43	29.44	15.70	10.79	10.79	12.76
Accham	1.86	11.16	156.27	55.81	29.77	20.46	20.46	24.18
Baitadi	1.87	11.24	157.39	56.21	29.98	20.61	20.61	24.36
Dadeldhura	1.00	6.00	84.03	30.01	16.01	11.00	11.00	13.00
Doti	1.65	9.88	138.32	49.40	26.35	18.11	18.11	21.41
Kailali	4.87	29.20	408.83	146.01	77.87	53.54	53.54	63.27
Kanchanpur	2.97	17.85	249.86	89.23	47.59	32.72	32.72	38.67
Total	**180.29**	**1081.68**	**15143.53**	**5408.42**	**2884.47**	**1983.09**	**1983.09**	**2343.63**

9. Other Sectors

The other sector mainly focuses on the emission of GHGs from agriculture activity, NMVOC emission from solvent and product use, and emissions from waste treatment and disposal (includes methane emission from solid waste final disposal site and solid waste incineration). However, emissions from solvent and product use could not be estimated in the present study due to lack of data. Agricultural emissions here include emissions from livestock's manure management and fertilizer application.

9.1. Emissions from the Agriculture Sector

9.1.1. Overview

Apart from activities related to energy use and open burning of agricultural biomass, the agriculture sector includes activities dealing with livestock production and fertilizer application; these activities include different emissions, i.e., ammonia (NH_3) emission from livestock source and fertilizer application, methane (CH_4) emission from manure management and enteric fermentation and nitrous oxide (N_2O) emission from animal waste. The main activity data for livestock related emissions is the number of animal head while that for fertilizer application is the annual amount of fertilizer sold/applied.

9.1.2. Emission Estimation Method

The agricultural emissions are calculated based on a simple methodology, i.e., by multiplying the activity rate by the corresponding emission factor. Total emission from enteric fermentation is estimated based on number of animal belonging to each livestock type and the relevant emission factor. The same method is used to estimate emissions from manure management and fertilizer application. The non-combustion emissions from the agricultural activity are estimated as:

$$Em_{i,j} = \sum Na_j \times EF_{i,j} \quad (23)$$

where,

$Em_{i,j}$ = Emission of pollutant i (CH_4 and NH_3) from livestock (or fertilizer) type j
Na_j = Number of animals (head/year) (or amount of nitrogen fertilizer) type j
$EF_{i,j}$ = Emission factors for pollutant type i emitted by livestock (or fertilizer) type j

For the estimation of N_2O emissions from animal waste, the following equation has been used:

$$N_2O_{(AW)} = \sum (N_{ex(AW)} \times EF_{(AW)}) \quad (24)$$

where,

AW = Animal waste
$N_{ex(AW)}$ = Total Nitrogen excretion from animal waste
EF(AW) = N_2O emission factor for animal waste

The total nitrogen excretion associated with animal waste is calculated as follows:

$$N_{ex(AW)} = \sum_j (Na_j \times N_{ex(j)} \times AW_j) \quad (25)$$

where,
Na_j = Population of livestock type j
$N_{ex(j)}$ = Nitrogen excretion of livestock type j
AW_j = Fraction of $N_{ex(j)}$ that is managed in particular waste management systems.

9.1.3. Data on Activity Levels

Nepal includes both ruminant[24] and non-ruminant type of livestocks and they are cattle, buffalo, sheep, goat, swine and poultry.

[24] *A ruminant is a mammal of the order Artiodactyla that digests plant-based food by initially softening it within the animal's first compartment of the stomach, principally through bacterial actions, then regurgitating the semi-digested mass, now known as cud, and chewing it again (Sejian et al., 2012).*

Table 53 shows the animal population data for FY 2008/09. The total CH_4 emissions from the domestic livestock enteric fermentation for FY 1994/95 were estimated to be about 527 thousand tonnes. Non-dairy cattle contributed to the highest share of about 53% (i.e. 280 thousand tonnes) in the total CH_4 emission from the livestock enteric fermentation. Buffaloes were also found to be a significant source of CH_4 emissions with their enteric fermentation accounting for about 32% of the total CH_4 emissions, mainly due to their large numbers, sizes and ruminant digestive system. Dairy cattle, goats and other animals (e.g. sheep, swine etc.) contributed to 8%, 5% and 1% to the total CH_4 emission by enteric fermentation (MOPE, 2004).

Total CH_4 emissions from domestic livestock manure management system were estimated to be 34 thousand tonnes in FY 1994/95. Around 44% (i.e. around 15 thousand tonnes) of the total CH_4 emission from the livestock manure management came from the dairy cattle, followed by non-dairy cattle (26%), buffalo (21%) and swine (9%). Dairy and non-dairy cattles were found to be the most notable sources of CH_4 emissions from manure management (MOPE, 2004).

In 1994/95, total emission of N_2O in Nepal from animal waste management system was estimated to be about 2 thousand tonnes. Solid storage and dry-lot contributed to most (i.e., about 94%) of the N_2O emissions from the animal waste management system, while the remaining 6% came from liquid system, anaerobic lagoons and others.

The anthropogenic use of fertilizers, synthetic nitrogen fertilizers, synthetic multi-nutrient fertilizers, organic fertilizers etc. are the main causes of N_2O emissions from the agricultural soil. The total N_2O emission from the agricultural soil management system in Nepal was estimated to be 27 thousand tonnes in 1994/95.

Among the various processes, the indirect N_2O emissions from grazing pasture range and paddock contributed to about 41% of the total N_2O emission. Direct N_2O emissions from agriculture fields, excluding cultivation of histosols, amounted to 31%, while indirect N_2O emissions from atmospheric decomposition of NH_3 and NO_X as well as leaching accounted for 28% (MOPE, 2004).

Table 54 presents the amount of fertilizer used in Nepal in the fiscal year 2008/09.

9.1.4. Emission Factors

The NH_3 emission factors used to estimate emissions from various livestock types and fertilizer applications in this study are presented in Table 55 and 56 respectively.

Table 53: Livestock Population in Nepal in 2008/09

Livestock Category	Population (in number)
Cattle	7,175,198
Buffaloes	4,680,486
Sheep	802,993
Goat	8,473,082
Pigs	1,044,498
Fowl	24,481,286
Duck	383,123
Milking Cow	932,876
Milking Buffaloes	1,211,495
Laying Hen	7,124,054
Laying Duck	179,187

Source: MOAC (2010)

Table 54: Chemical Fertilizer Type and its Use in FY 2008/09

Fertilizer Type	Fertilizer Use (tonne/year)
Nitrogen	2918
Phosphorus	239
Potash	0
Total	**3157**

Source: MOF (2011b)

Table 55: NH_3 Emission Factors for Livestock Source, kgNH_3/head

Livestock Type	Emission Factor
Dairy Cow	38.3[a], 28[b]
Poultry	0.27[a], 0.37[b]
Sheep	3.4[a], 1.34[b]
Goats	6.4[a]
Buffalo	11[a,#]

Note: [#]This data refers to beef cow.
Source: [a]USEPA (2003); [b]Battye et al. (1994)

Table 56: NH_3 Emission Factors of for Fertilizer Application, kg NH_3/tonne Fertilizer N

Fertilizer Type	Emission Factor
Nitrogen solutions	97
Urea	242
Potassium nitrate	12

Note: The emission factor data are based on warm, temperate areas with a large proportion of calcareous soils.

Source: USEPA (2003)

Table 57: Emission Factors of CH_4 Emissions from Enteric Fermentation and Manure Management, kg CH_4/head-year

Livestock Type	Enteric Fermentation	Manure Management
Buffalo	55	-
Sheep	5	0.16
Goats	5	0.17
Poultry	-	0.018

Note: The CH_4 emission factor data considered refer to the values that are specific to developing countries. For manure management, temperate climate specific data has been considered. (Source: IPCC (2006))

Table 58: Annual Emission from Agricultural Activities in 2008/09, tonne

No.	Agriculture activity	NH_3	N_2O	CH_4
1	Livestock source	369,714	-	-
2	Fertilizer application	372	-	-
3	Manure management and enteric fermentation	-	-	699,734
4	Animal waste	-	5,630,949	-

The CH_4 emission factors used in this study for livestock enteric fermentation and manure management are presented in Table 57, whereas the N_2O emission factors for pasture range and paddock animal waste management is taken as 0.02 kg N_2O-N/kg of nitrogen excreted (IPCC, 2006). As the information on established animal manure management system in Nepal is lacking, it has been assumed that animal manure management was done largely under the pasture range and paddock system.

9.1.5. Estimated Emissions

The estimated emissions from agricultural activities in FY 2008/09 are presented in Table 58. According to the Second National Communication (SNC) of Nepal, total emission of GHGs from the manure management and enteric fermentation was estimated to be 12,308 thousand tonnes of CO_2e in 2000 (MoSTE, 2014). In this study the total GHG emissions from the manure management and enteric fermentation have been estimated to be 14,694 thousand tonnes in FY 2008/09. The total GHG emissions from the agricultural activities in the year are estimated to be 1760 million tonnes.[25]

9.1.6. Temporal and Spatial Variations

Since information on variations of livestock population and fertilizer application over months and different districts were not available for FY 2008/09, the temporal and spatial pattern of emissions from non-combustion of agricultural activities could not be analyzed.

[25] *For the calculations of the GHG emissions, Global Warming Potential (GWP) of 21 is used for CH_4 emissions and 310 is used for N_2O emissions (IPCC, 1995).*

9.2. Solid Waste Treatment and Disposal

9.2.1. Overview

This sector covers thermal incineration of solid wastes including municipal solid waste (MSW), industrial waste and medical waste. It also includes methane emission from landfill.

9.2.2. Emission Estimation Method

The simple method proposed by EMEP/CORINAIR (2006) has been used to calculate emissions from the waste incineration sector. The emission estimation is based on the following equation:

$$Em_{i,j} = M_{i,j} \times EF_{i,j} \quad (26)$$

where,

i,j = Pollutant i and waste type j (MSW, medical waste, etc.)

$Em_{i,j}$ = Emission of pollutant i from waste type j

$M_{i,j}$ = Mass related to pollutant i from waste type j (tonnes)

$EF_{i,j}$ = Emission factor of pollutant i from waste type j (kg/tonnes of waste)

In order to calculate methane emissions from the solid waste disposal sites, the method suggested by IPCC (2006) has been used; it is given by the following relation:

$$Em = (MSW_t \times MSW_f \times MCF \times DOC \times DOC_f \times F \times \frac{16}{12} - R) \times (1 - OX) \quad (27)$$

where,

Em = Emission of methane

MSW_t = Total MSW generated

MSW_f = Fraction of MSW disposed in solid waste disposal sites

MCF = Methane correction factor

DOC = Fraction of degradable organic carbon

DOC_f = Fraction of DOC dissimilated

F = Fraction of CH_4 in landfill gas

R = Recovered CH_4

OX = Oxidation factor

9.2.3. Data on Activity Levels

The various activity data required to estimate the amount of MSW incinerated and disposed as landfill are the national population data, MSW generation factor, fraction of MSW disposed as landfill, and fraction of degradable organic carbon. The national population data of Nepal has been taken from MOF (2011a). As already mentioned in Section 8.3, the per capita solid waste generation in Nepal has been considered to be 109, 283 and 162 gm/day/person in mountain, hills and Terai regions respectively (SWMRMC (2009) as cited in Amatya (undated)). The national average waste generation rate is 0.25 kg/capita/day and the value for the Kathmandu metropolitan area is 0.39 kg/person/day (cited as SWMRMC (2008) in Practical Action (2008)).

In 2003, the total municipal waste generation in Nepal was 1,369 tons per day or about 500,000 tons per year. Household waste constitutes about 75% of the municipal waste (ADB, 2007). The municipal waste varies from 0.11 to 0.93 kg per person per day, with an average of 0.34 kg per person per day (cited as SWMRMC (2004) in ADB (2007)). On an average, only 35% of municipal waste is collected; however, the collection rates vary from 7% to as high as 86% from across the municipalities. The fraction of MSW disposed to landfill has been considered to be 0.6 while the fraction of degradable organic carbon has been considered to be 0.18 based on the relevant data for India (IPCC, 2006).The fraction of CH_4 in landfill gas has been considered to be 0.5 while the oxidation factor is considered to be zero as suggested by IPCC (2006) in order to estimate methane emissions from the solid waste disposal site. In order to estimate emissions from solid waste incineration from municipal, industrial, and medical wastes, the corresponding activity data considered are the population of Nepal, number of industries and number of hospital beds respectively. As of 2008/09, a total of 36,284 industries were registered in Nepal including large, medium and small manufacturing establishments (CBS, 2009c). According to MOF (2011b), around 6944 hospital beds were registered in FY 2008/09.

9.2.4. Emission Factors

The emission factors considered in this study for estimation of emissions from solid waste incineration are presented in Table 59.

9.2.5. Estimated Emissions

Table 60 presents the emissions of different pollutants from solid waste incineration and methane emission from solid waste disposal at landfill sites.

9.2.6. Temporal and Spatial Variations

The district-wise population data has been used to estimate the spatial distribution of emissions across various districts. Figure 38 shows the spatial distribution of methane emission density from solid waste disposed at landfill sites. The district-wise methane emission figures from solid waste disposed at landfill sites are presented in Annex 19. As can be seen from the spatial distribution, Kathmandu district has the largest share of about 4.76% in the total methane emissions from solid waste disposed at landfill sites among the districts of Nepal; it is followed by Morang (3.71%), Rupandehi (3.12%), Dhanusa (2.95%), Sarlahi (2.80%), Jhapa (2.78%), Sunsari (2.75%), and Kailali (2.71%) districts. The remaining 74.42% of the methane emissions from solid waste disposed at landfill sites comes from rest of the districts of Nepal.

Table 59: Emission Factors for Solid Waste Incineration, kg/tonne

Air Pollutants	Municipal Solid Waste	Medical Waste	Industrial Waste
SO_2 [a]	1.73	0.07	1.25
NO_X [a]	1.8	2.5	1
NMVOC[a]	0.05	7.4	7.4
CO[a]	1.1	0.13	10
PM_{10} [a]	19	-	7.5
BC[c]	0.044	0.044	0.044
OC[c]	0.0013	0.0013	0.0013
GHGs			
CO_2 [b]	985	-	-
N_2O [a]	0.1	-	-

Source: [a]EMEP/CORINAIR (2007); [b]USEPA (1995); [c]Bond et al. (2004)

Table 60: Annual Emissions of Air Pollutants and GHGs from Solid Waste Incineration and Methane from Landfill Gas, tonne

Air Pollutants	Solid Waste Incineration	Disposal Site
SO_2	1400	-
NO_X	808	-
CO	4853	-
NMVOC	724	-
PM_{10}	6360	-
CO_2	39692	-
BC	2	-
OC	0.1	-
GHGs		
N_2O	4	-
CH_4	-	383

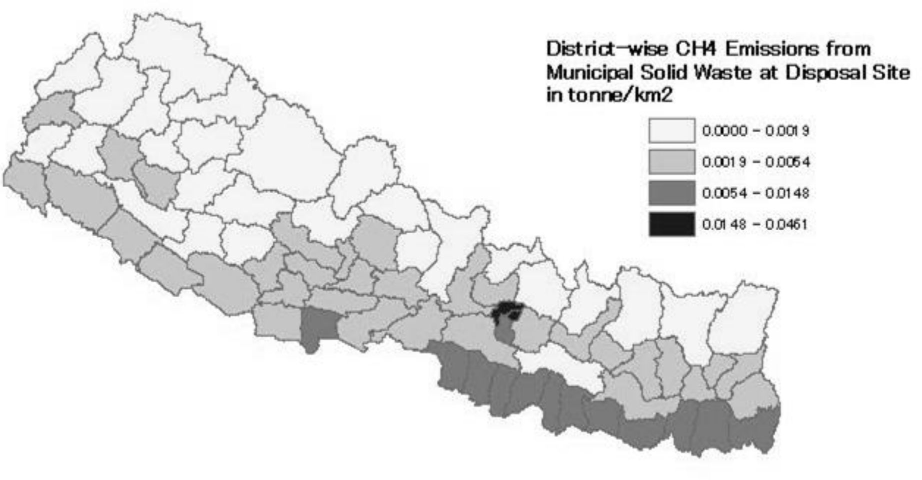
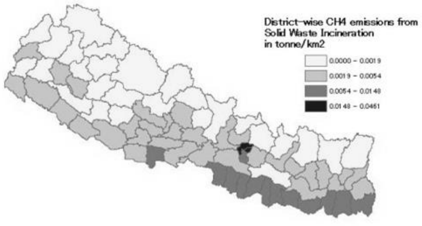
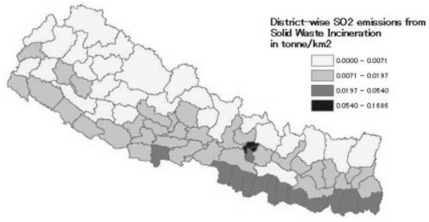


Figure 38: Spatial Distribution of Methane Emission Density from Landfill Gas in 2008/2009

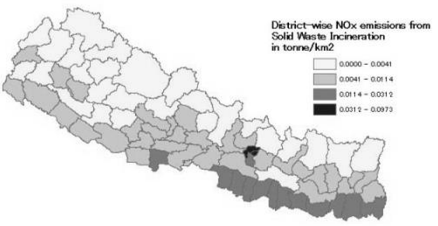
Figure 39 (a to h) shows the spatial distributions of various pollutant emission densities from solid waste incineration. The district-wise emission levels from solid waste incineration are presented in Annex 20. Kathmandu district accounts for the largest share (4.76%) in total emissions from solid waste incineration among the districts of Nepal; it is followed by Morang (3.71%), Rupandehi (3.12%), Dhanusa (2.95%), Sarlahi (2.80%), Jhapa (2.78%), Sunsari (2.75%), and Kailali (2.71%) districts. The remaining 74.42% of the emissions from solid waste incineration comes from rest of the districts of Nepal.



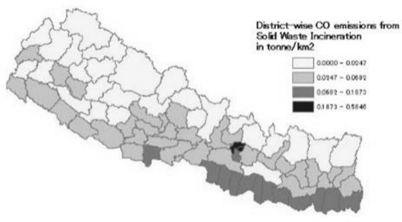
a) CH_4 Emission Density



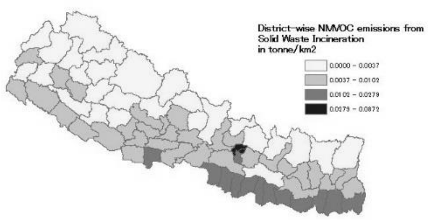
b) SO_2 Emission Density



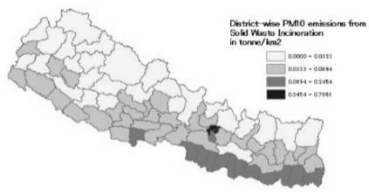
c) NO_X Emission Density



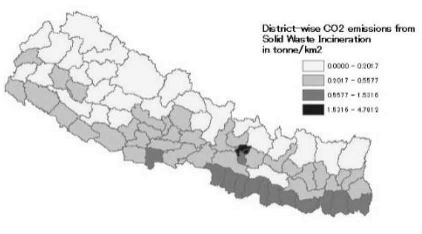
d) CO Emission Density



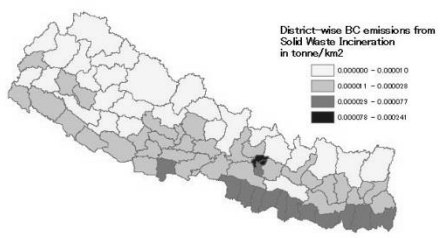
e) NMVOC Emission Density



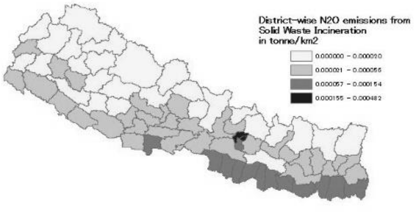
f) PM_{10} Emission Density

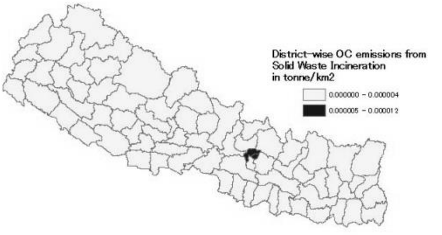


g) CO_2 Emission Density



h) BC Emission Density





i) N_2O Emission Density j) OC Emission Density

Figure 39: Spatial Distribution of Emission Densities of Air Pollutants and GHGs from Solid Waste Incineration in FY 2008/2009

10. Summary of Key Findings

10.1. Emissions of Air pollutants and GHGs

10.1.1. Carbon Dioxide (CO_2)

It is estimated that 89,674 thousand tonnes of CO_2 was emitted from Nepal in FY 2008/09. Figure 40 presents the sectoral shares in the total CO_2 emissions. Forest fire accounts for the largest share (around 50.6%) in the total CO_2 emissions, followed by the residential sector (33.7%), crop residue open burning (10.9%), transport sector (3.2%), and manufacturing industries (1.1%).

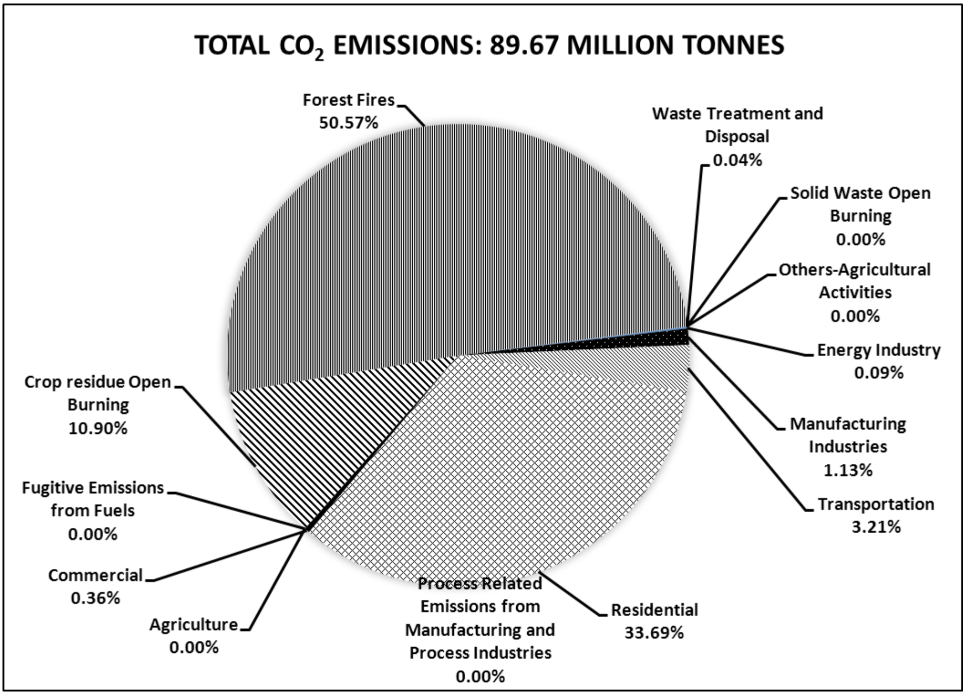


Figure 40: Sectoral Shares in Total CO_2 Emissions in FY 2008/2009

10.1.2. Carbon Monoxide (CO)

This study estimates that about 6,059 thousand tonnes of CO was emitted from the country in FY 2008/09. Figure 41 presents the sectoral contributions in total CO emissions. Forest fire occupies the largest share (around 49.3%) in the total CO emissions; this is followed by the residential sector (27.6%), crop residue open burning (16.4%), transportation (4.3%), process related emissions from manufacturing and process industries (1.9%) and solid waste open burning (0.2%).

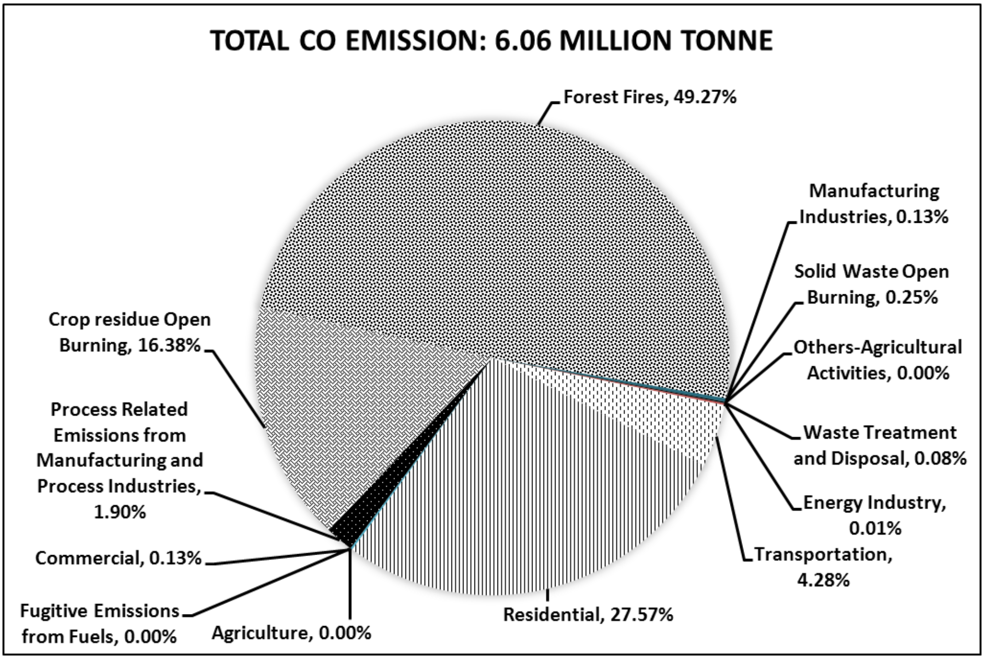


Figure 41: Sectoral Shares in Total CO Emissions in FY 2008/2009

10.1.3. Sulphur Dioxide (SO_2)

Total emission of SO_2 from Nepal in FY 2008/09 is estimated to be 85.9 thousand tonnes. As shown in 42, the transport sector accounts for the highest share (57.5%) in the total SO_2 emissions; it is followed by the forest fires (19.1%), residential sector (10.9%), manufacturing industries (7.1%) and crop residue open burning (3.4%). The process related manufacturing industries is found to occupy a share of 0.1% in the total SO_2 emissions from both the energy and non-energy sectors.

10.1.4. Particulate Matters (PM_{10} & $PM_{2.5}$)

The total national emissions of PM_{10} and $PM_{2.5}$ in FY 2008/09 are estimated to be 2,344 thousand tonnes and 399 thousand tonnes respectively.

Figure **43** presents the sectoral shares in total PM_{10} emissions. Process related emissions from industrial production contribute most (around 79.5%) to the total PM_{10} emissions, followed by forest fires (12.9%), residential (3.9%), crop residue open burning (2.3%), manufacturing industries (0.9%), transport (0.2%) and solid waste open burning (0.1%), while waste treatment and disposal sector would account for 0.3%.

Figure 44 presents the sectoral shares in total $PM_{2.5}$ emissions. Forest fire contributes the most in the total $PM_{2.5}$ emissions with a share of around 65.5%, followed by residential (14.6%), crop residue open burning (12.3%), manufacturing industries (5.4%), manufacturing and process industries (1.3%) and transport (0.9%).

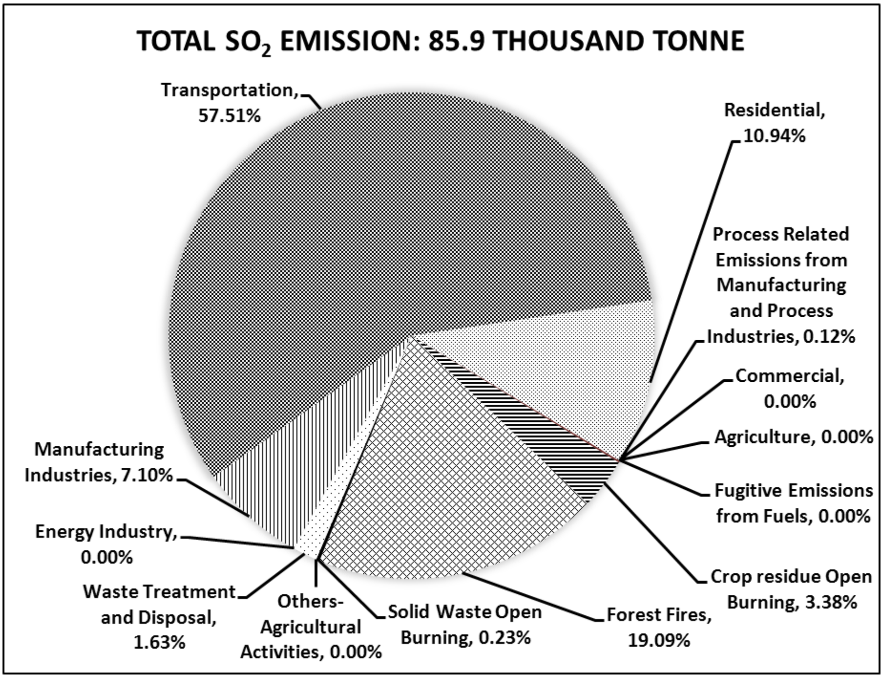


Figure 42: Sectoral Shares in Total SO_2 Emissions

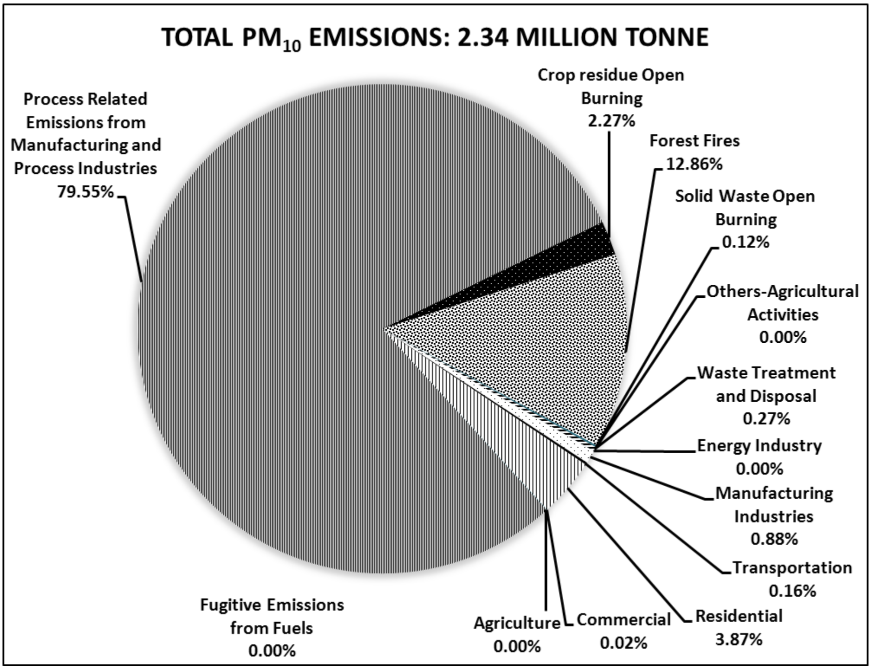


Figure 43: Sectoral Shares in Total PM_{10} Emissions

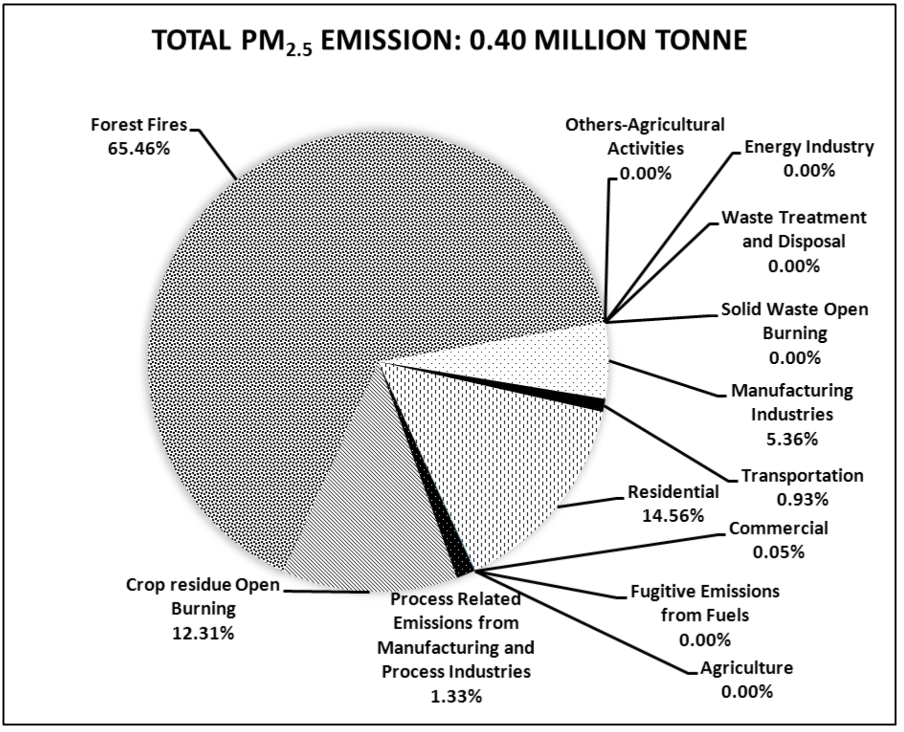


Figure 44: Sectoral Shares in Total $PM_{2.5}$ Emissions

10.1.5. Nitrogen Oxides (NO_X)

Altogether it is estimated that 157 thousand tonnes of NO_X was emitted in FY 2008/09. The sectoral shares in total NO_X emissions are presented in Figure 45. As can be seen, forest fire accounts for around 44.7% of the total NO_X emissions; this is followed by transport (24.6%), residential sector (17.7%), crop residue open burning (8.8%), manufacturing industries (1.3%), solid waste open burning (0.7%), agriculture (0.2%) and commercial (0.1%) sectors. Waste treatment and disposal would account for 0.5% of NO_X emissions.

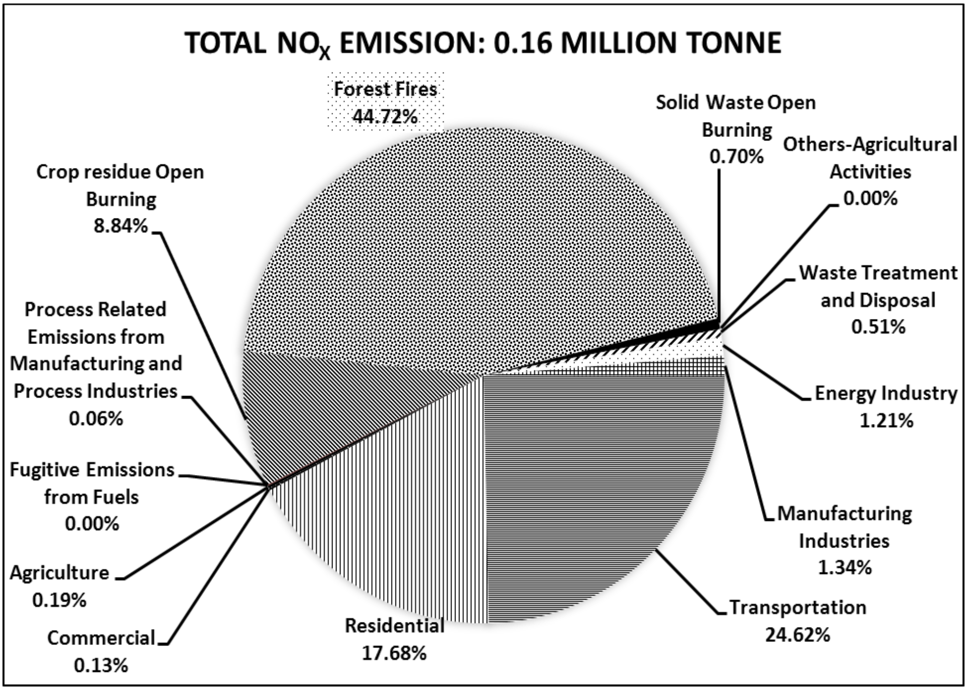


Figure 45: Sectoral Shares in Total NO_X Emissions

10.1.6. Ammonia (NH_3)

A total of 445 thousand tonnes of NH_3 emission is estimated in FY 2008/09. The sectoral composition of total NH_3 emissions is presented in Figure 46. The ammonia emission from livestock source has the largest share (around 83.1%) in the total NH_3 emissions, while forest fire, crop residue open burning and residential account for 8.4%, 5.0%, and 3.5% respectively.

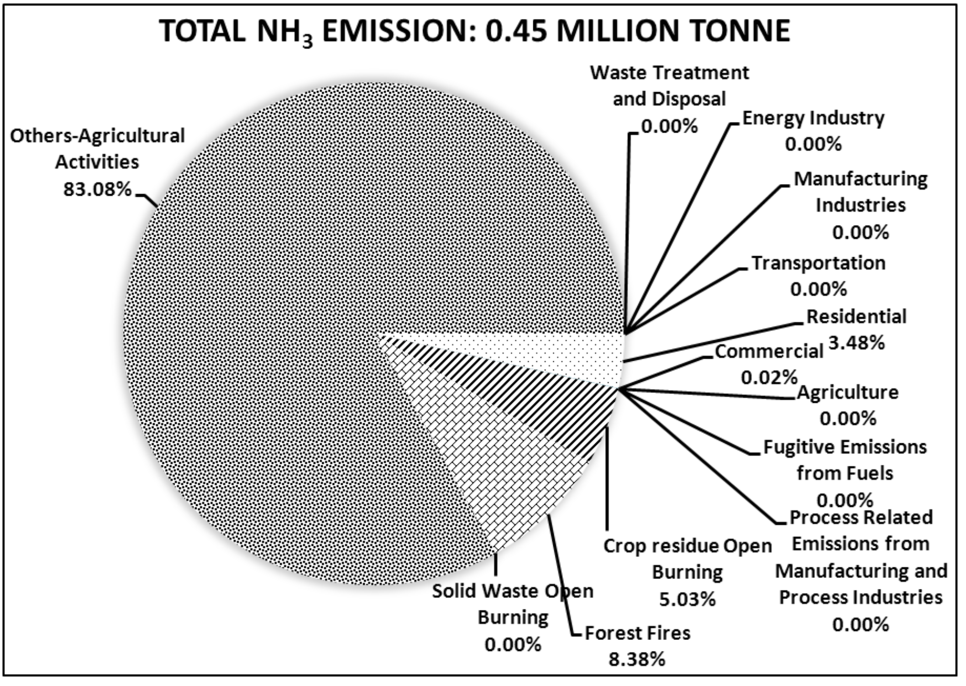


Figure 46: Sectoral Shares in Total NH_3 Emissions

10.1.7. Non Methane Volatile Organic Compound (NMVOC)

Altogether it is estimated that 2,150 thousand tonnes of NMVOC was emitted in FY 2008/09. The sectoral shares in total NMVOC emissions are shown in Figure 47. The manufacturing and process industries sector is responsible for around 84.0% of the emission, while forest fire, transport, crop residue open burning, and solid waste open burning sectors account for 10.8%, 2.9%, 2.0% and 0.3% of the total NMVOC emission respectively.

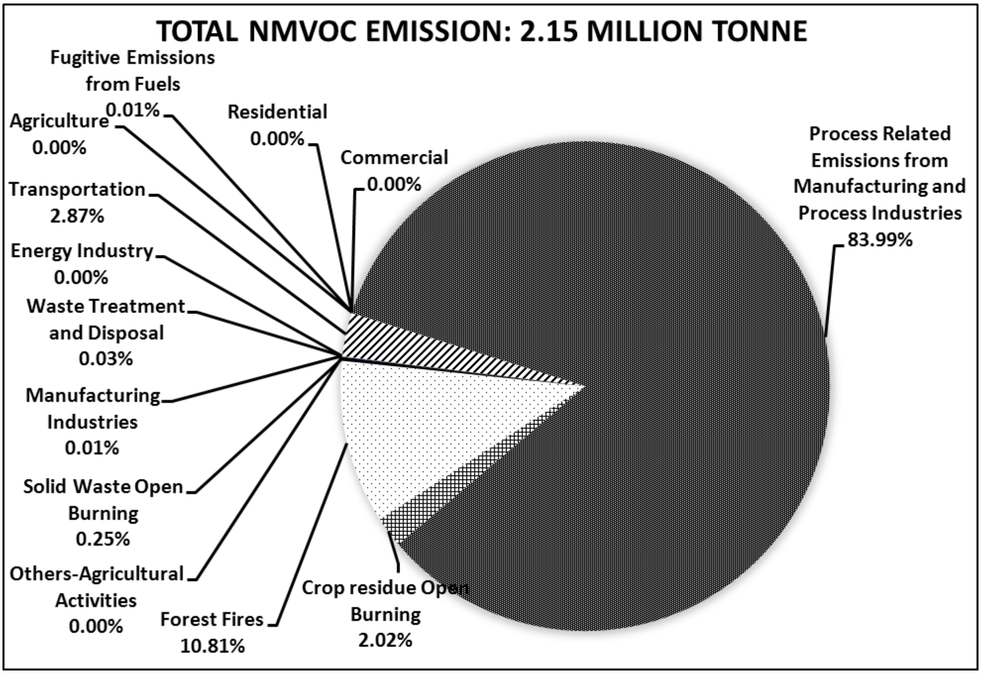


Figure 47: Sectoral Shares in Total NMVOC Emissions

10.1.8. Methane (CH_4)

It is estimated that a total of 1,053 thousand tonnes of methane was emitted from the country in FY 2008/09. Figure 48 presents the sectoral shares in total CH_4 emissions. The "others-agricultural activities" sector (which includes methane emissions from manure management and enteric fermentation) and solid waste at final disposal site has the largest share (66.5%) in the total CH_4 emissions and is followed by forest fire (18.5%), residential (9.3%), crop residue open burning (5.1%), solid waste open burning (0.2%) and transport (0.2%) sectors.

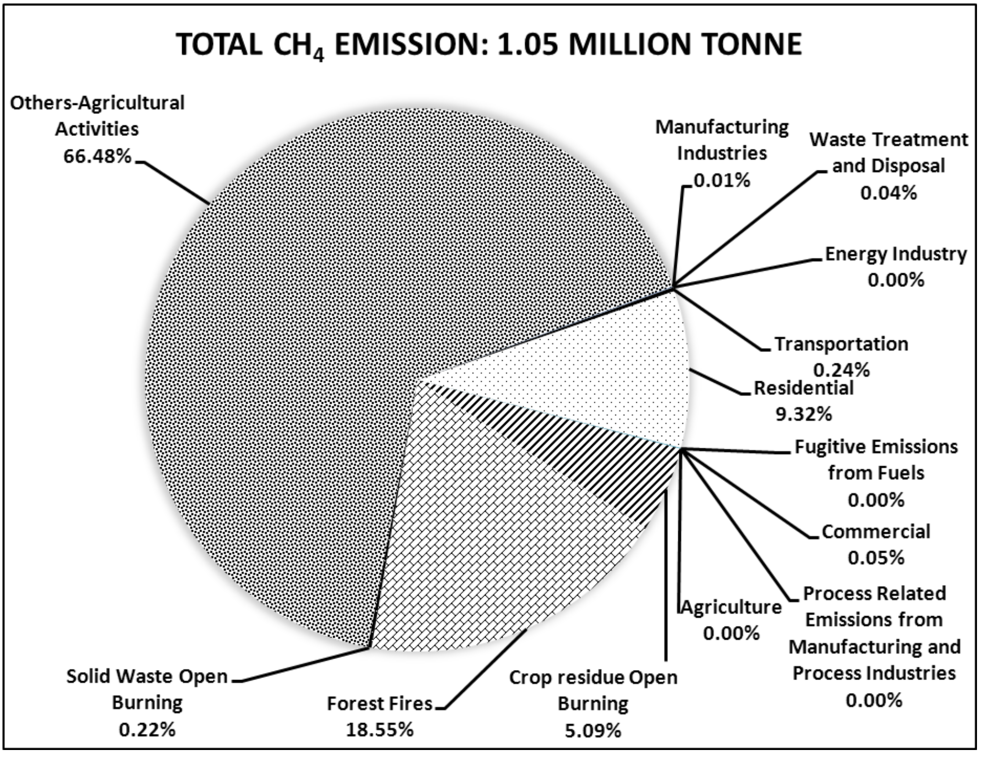


Figure 48: Sectoral Shares in Total CH_4 Emissions

10.1.9. Black Carbon (BC)

It is estimated that about 53.4 thousand tonnes of BC were emitted from Nepal in FY 2008/09.

Figure 49 presents the sectoral shares in total BC emissions. About 50.2% of the BC is emitted by residential, this is followed by forest fire (35.4%), crop residue open burning (9.0%), solid waste open burning (3.7%), transport (0.4%), manufacturing industries (0.7%) and commercial (0.4%) sectors.

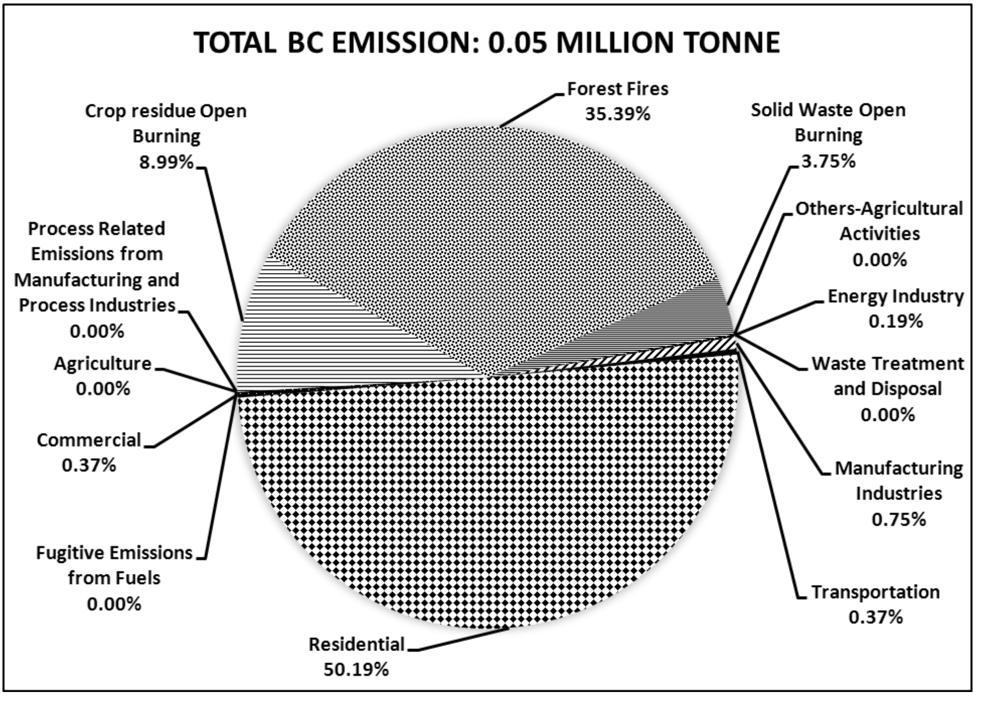


Figure 49: Sectoral Shares in Total BC Emissions

10.1.10. Organic Carbon (OC)

Total amount of OC emission in FY 2008/09 is estimated to be about 242 thousand tonnes. The sectoral shares in total OC emissions are presented in Figure 50. Forest fire alone contributed to 61.6% of the total OC emissions and was followed by residential (27.1%), crop residue open burning (9.9%), solid waste open burning (0.8%), transport (0.2%), manufacturing industries (0.2%), and commercial (0.1%) sectors.

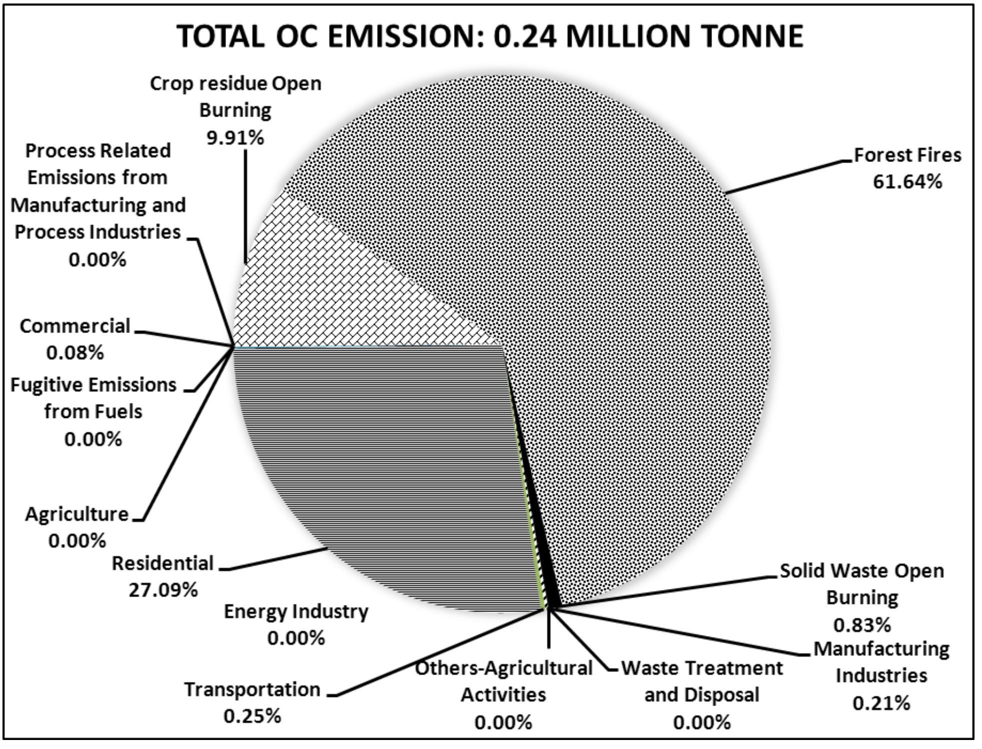


Figure 50: Sectoral Shares in Total OC Emissions

10.1.11. Nitrous Oxide (N_2O)

At the national level, total N_2O emission is estimated to be 5,632 thousand tonnes. The other-agricultural activities sector (which includes agricultural activities such as N_2O emissions from animal waste) accounts for almost all of the emission (i.e., 99.98%); the rest being accounted for mainly by the residential sector.

10.2. Roles of Different Sectors in Emissions of Major Air pollutants and GHGs in FY 2008/09

The energy using sectors (i.e., energy industries, manufacturing, transport, residential, commercial and agriculture) are found to be the dominant sources for the emissions of SO_2 emissions. Together they accounted for 75.6% of SO_2 emission. On the other hand, forest fire is found to be the main source of CO, $PM_{2.5}$, CO_2 and OC emissions from the country. Residential sector (particularly cooking and water heating occupying the major share) accounted for 33.7%, 50.2%, 27.6%, and 17.7% of total emission of CO_2, BC, CO and NO_X respectively, while brick making accounted for 0.22%, and 0.19% of total emissions of CO_2 and BC emissions respectively.

The transport sector is the largest contributor of SO_2 emissions with a share of around 57.5%, followed by forest fires (19.1%) and residential sector (10.9%). For NO_x emissions, forest fire is the largest contributor with 44.7% share followed by transportation (24.6%) and residential (17.7%) sectors. The two top contributors of CO emissions are forest fires (49.3%), and residential sector (27.6%). Typical pattern of sectoral shares are observed for NMVOC, NH_3, and N_2O emissions where manufacturing and process industries are very dominant for NMVOC (84.0%), while the agriculture sector emissions mainly from livestock source and fertilizer application are the major contributors for NH_3 (83.1%) whereas animal waste is the major source for N_2O (99.98%). Manufacturing and process industries are the largest emitter of PM_{10} emissions (around 79.5%). For BC, the residential sector (mainly cooking and water heating) accounts for 50.2% of total BC emissions while the forest fires accounts for 35.4% of BC emissions. Crop residue open burning, solid waste open burning, manufacturing industries, and transportation sector occupies a share of 9.0%, 3.7%, 0.7% and 0.4% respectively in the total BC emissions. The same sectoral pattern has been observed in the case of OC emissions, i.e. both residential and forest fire sectors are found to be dominating. Forest fire also occupies a higher share (50.6%) in total CO_2 emissions followed by residential sector (33.7%). In the case of CH_4 emissions, the largest contributor is the agriculture sector (mainly manure management and enteric fermentation) occupying a share of 66.5% in the total CH_4 emissions.

Tables 61 and 62 present the total sectoral GHG and air pollutants emissions respectively from the energy sector. Tables 63 and 64 present the total sectoral GHG and air pollutants emissions from the non-energy sectors respectively. The present study has estimated the total GHG emissions from the energy sector to be 34,607 thousand tonnes in the FY 2008/09. The residential sector is found to have the largest share (about 87.6%) in the total energy related GHG emissions from the country. The transport and manufacturing industries sectors contributed about 8.3% and 2.9% in the total energy related GHG emissions. The Second National Communication (SNC) of Nepal estimated that the total energy related GHG emissions was about 6827 thousand tonnes in FY 2000/01, in which the the residential sector (mainly for cooking, heating and lighting purposes) occupied a share of about 71% (MoSTE, 2014).

Table 61: Annual Emissions of GHGs in FY 2008/09 from Energy Using Sectors, thousand tonne*

Source Sector	Sub Sector	GHGs		
		CO_2	N_2O	CH_4
Energy industry	Power generation	9.31	0.00	0.00
	Captive Power Generation	68.37	-	-
Manufacturing Industry	Iron and Steel	0.70	0.00	0.00
	Non-ferrous metals	13.98	0.00	0.00
	Non-metallic minerals	45.18	0.00	0.01
	Chemicals manufacture	41.02	0.00	0.01
	Pulp and paper	124.43	0.00	0.04
	Brick	196.86	0.00	0.02
	Food, beverage and tobacco	335.43	0.01	0.04
	Textiles	56.07	0.00	0.01
	Other	202.85	0.00	0.02
Transportation	Road	2679.42	0.04	2.17
	Air	197.16	0.03	0.31
Residential and Commercial	Residential	30207.53	1.31	98.14
	Commercial	326.08	0.01	0.56
Agriculture		-	-	-
Total		34504.39	1.4	101.33

*Note: *All the zero values shown in this table is very small and is greater than zero*.

Table 62: Annual Emissions of Air Pollutant in FY 2008/09 from Energy Using Sectors, thousand tonne*

Source Sector	Sub Sector	Air Pollutants								
		SO_2	NOx	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC
Energy industry	Power generation	0.0	0.1	0.0	0.0	-	0.0	0.0	0.0	0.0
	Captive Power Generation	-	1.8	0.4	0.1	-	0.1	-	0.1	0.0
Manufacturing Industry	Iron and Steel	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0
	Non-ferrous metals	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
	Non-metallic minerals	0.1	0.1	0.8	0.0	-	3.1	2.7	0.0	0.1
	Chemicals manufacture	0.1	0.1	0.6	0.0	-	0.0	4.2	0.0	0.1
	Pulp and paper	0.1	0.1	4.9	0.1	-	14.2	12.3	0.0	0.0
	Brick	1.5	0.0	0.0	0.0	-	0.0	0.0	0.1	0.1
	Food, beverage and tobacco	2.3	1.0	1.0	0.1	0.0	2.3	1.7	0.2	0.1
	Textiles	0.4	0.2	0.2	0.0	0.0	0.3	0.3	0.0	0.0
	Other	1.5	0.6	0.3	0.0	0.0	0.4	0.2	0.1	0.1
Transportation	Road	4.7	38.0	258.9	58.9	0.0	3.7	3.7	0.1	0.2
	Air	44.7	0.7	0.7	2.8	-	0.01	0.0	0.1	0.4
Residential & Commercial	Residential	9.4	27.8	1670.6	-	15.5	90.7	58.1	26.8	65.6
	Commercial	0.0	0.2	7.8	-	0.1	0.4	0.2	0.2	0.2
Agriculture		-	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		**64.9**	**71.0**	**1946.2**	**62.0**	**15.6**	**115.5**	**83.4**	**27.7**	**66.9**

*Note: *All the zero values shown in this table is very small and is greater than zero.*

Table 63: Annual Emissions of GHGs in FY 2008/09 from Non-Energy Sectors, thousand tonne

Source Sector	Sub Sector	GHGs		
		CH_4	CO_2	N_2O
Fugitive Emissions from Fuels	Coal Mining and Handling	-	-	-
	Gasoline Distribution	-	-	-
Manufacturing and Process Industries	Mineral Products	-	-	-
	Metal Production and Pulp and Paper Industries	-	-	-
	Food and Drink Industries	-	-	-
Open Burning	Crop Residue Open Burning	53.6	9777.8	-
	Forest Fires	195.2	45352.3	-
Solid Waste Open Burning	At Source	2.1	-	-
	At Disposal Site	0.2	-	-
Others – Agricultural Activity	Livestock Source	-	-	-
	Fertilizer Application	-	-	-
	Manure Management and Enteric Fermentation	699.7	-	-
	Animal Waste	-	-	5630.9
Others- Waste Treatment and Disposal	Solid Waste Disposal Site	0.4	-	-
	Solid Waste Incineration	-	39.7	0.0*
Total		**910.2**	**48,321.2**	**5,631.0**

*Note: *This value is very small but greater than zero.*

Table 64: Annual Emissions of Air Pollutant in FY 2008/09 from Non-Energy Sectors, thousand tonne*

Source Sector	Sub Sector	Air Pollutants								
		SO_2	NO_X	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC
Fugitive Emissions from Fuels	Coal Mining and Handling	-	-	-	0.0	-	0.0	0.0	0.0	0.0
	Gasoline Distribution	-	-	-	0.3	-	-	-	-	-
Manufacturing and Process Industries	Mineral Products	0.0	-	-	-	-	19.2	2.5	-	-
	Metal Production and Pulp and Paper Industries	0.1	0.1	0.2	0.1	-	3.2	2.8	-	-
	Food and Drink Industries	-	-	115.1	1806.0	-	1842.2	-	-	-
Open Burning	Crop Residue Open Burning	2.9	13.9	992.6	43.5	22.4	53.2	49.1	4.8	24.0
	Forest Fires	16.4	70.3	2985.2	232.5	37.3	301.4	261.2	18.9	149.3
Solid Waste Open Burning	At Source	0.2	1.0	13.6	4.9	-	2.6	-	1.8	1.8
	At Disposal Site	0.0	0.1	1.5	0.5	-	0.3	-	0.2	0.2
Others– Agricultural Activity	Livestock Source	-	-	-	-	369.7	-	-	-	-
	Fertilizer Application	-	-	-	-	0.1	-	-	-	-
	Manure Management and Enteric Fermentation	-	-	-	-	-	-	-	-	-
	Animal Waste	-	-	-	-	-	-	-	-	-
Others- Waste Treatment and Disposal	Solid Waste Disposal Site	-	-	-	-	-	-	-	-	-
	Solid Waste Incineration	1.4	0.8	4.9	0.7	-	6.4	-	0.0	0.0
Total		**18.9**	**76.4**	**3357.1**	**2057.4**	**412.5**	**2188.6**	**278.9**	**22.3**	**158.0**

*Note: *All the zero values shown in this table is very small and is greater than zero.*

10.3. Uncertainties in the Study and Scope for Refinements

In this study, an attempt has been made to carry out to prepare a national emission inventory of air pollutants and GHGs for Nepal. In the absence of the data needed for emission estimation using rigorous (or detailed) methods, this study has mostly used simple methods which are based on activity levels and emission factors. Data on activity levels are mostly based on national and official sources in Nepal, while some data are based on international sources. In the absence of Nepal specific emission factors, most of the emission factors have been borrowed either from neighboring country sources or from international sources. Two sets of emissions are estimated in the present study – one using the minimum value of the emission factor and the other using the maximum value reported in the ABC EIM wherever a range of emission factor is given in the ABC EIM. However, this study has not quantified the level of uncertainty involved in the estimation of emissions.

The spatial distribution of emissions presented in this study is still in a coarse form since the estimated national level emissions from the energy combustion have been distributed over different districts using proxy variables such as district level data on population in the residential sector, registered vehicle population in the transport sector, and total value added in the manufacturing/industrial sector. In the case of open burning of crop residues, the national emissions are distributed over different districts using district level annual crop production data. The national emissions from open burning of solid waste have been spatially distributed at district level on the basis of the shares of districts in the national population. The national level emissions and their spatial distribution could be improved if district level activity data were available.

Monthly temporal variation may also involve a large uncertainty in the present study as the study has used most relevant proxy factors to distribute the estimated annual emission figures over different months. For example, monthly electricity consumption patterns of major industries were used as a proxy to distribute estimated annual emissions over different months in this study due to lack of availability of monthly production data of the industries. Clearly, there is a room for improvements in temporal distribution of emissions if monthly activity data become available.

District level activity data of different sectors should be compiled for a more accurate estimation of spatial distribution of emissions. Basic field level observations/measurements would be needed to improve the quality of the data to reduce uncertainties in the estimation of emissions, particularly from open burning sources. In order to improve the temporal distribution of emission estimates, activity level data need to be compiled at temporal units (e.g., months). There is also a need for research to derive technology specific emission factors that reflect the technologies used in the country in order to refine the ABC emission inventory of Nepal presented in this report.

11. National Environmental Policies and Policy Implications of the Study

11.1. National Pollution Control Plans and Policies

Ministry of Science, Technology, and Environment (MoSTE) has established National Ambient Air Quality Standard (NAAQS) and the National Diesel Generators Emission Standard (NDGES). Apart from this, there are several other environmental related standards set by the ministry, namely Nepal vehicle mass emission standard, standard on chimney height and emission for brick kiln industry, vehicle emission standards for green stickers (for petrol, gas and diesel operated vehicles), standard for inspection of used vehicles, standard on emission for industrial boiler, standard on chimney height for industrial boiler, and indoor air pollution standard (MoSTE, 2010).

According to the Environmental Protection Act 1997, the use of certain vehicles has been prohibited in order to control emissions. Further, the registration of vehicles with two stroke engine has been prohibited in the country. The Government has restricted the use of farm tractor, truck, and lorries that carry sand/gravel, dumpers (that carry waste materials) from being operated inside the ring road of Kathmandu valley every day from 8 in the morning to 7 in the evening. The Government has also banned new registration of diesel operated three wheelers and its operation in Kathmandu valley (MoSTE, 2010). The Government has set the following compensation plans in order to reduce emissions from the transportation sector of the country (MoSTE, 2010):

a. 99% custom rebate for import of petrol operated microbus in Kathmandu against each banned diesel 3-wheelers
b. Up-to 99% tax rebate for the import of parts that complement the transformation of 2-stroke gasoline engine to run on LPG
c. Only 1% import tax on parts of electric vehicles to be assembled in Nepal
d. 100% tax rebate for the import of pollution control aids and devices
e. Lesser import tax for mass transport and goods carrier vehicles

The imports of second hand or reconditioned vehicle are restricted in the country since December 1999. An enforcement plan was set by the Government to import only unleaded fuel since January 2000. A 10% annual tax was raised for vehicles older than 15 years since August 2001. In 1999, standard was set for import of vehicles, which included Nepal standard for mass emission (EURO I based) and it also mandated that the vehicles entering into Nepal should not be more than 5 years old (MoSTE, 2010). The quality of petrol imported into Nepal is equivalent to Euro III standard. From December 2001, the commercial vehicles older than 20 years were phased out and operation of 2-stroke 3-wheelers have been banned from Kathmandu valley. The Government had given a compliance period of one and half years for banning the use of commercial vehicles older than 20 years in Kathmandu valley by December 2001. The Government had also given a compliance period of one and half years for changing 2-stroke gasoline vehicles to run on LPG and a 3 months period for repair and maintenance of vehicles that fail the emission test before re-testing (MoSTE, 2010).

Table 65 presents the national indoor air quality standards set for Nepal (MoSTE, 2010). The national ambient air quality standard, which was first adopted in 2003 and was revised and

Table 65: National Indoor Air Quality Standards, 2009

Pollutant	Maximum Concentration	
	Level	Averaging Time
PM_{10}	120 µg/m^3	24-hour
	200 µg/m^3	1-hour
$PM_{2.5}$	60 µg/m^3	24-hour
	100 µg/m^3	1-hour
CO	9 ppm (10 mg/m^3)	8-hour
	35 ppm (40 mg/m^3)	1-hour
CO_2	1000 ppm (1800 µg/m^3)	8-hour

Note:

1. *No need to monitor/measure both Particulate Matter (PM_{10}) and Particulate Matter ($PM_{2.5}$). In accordance with the World Health Organization (WHO) Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide, 2005, the $PM_{2.5}$ values can be converted to the corresponding PM_{10} values by application of a $PM_{2.5}/PM_{10}$ ratio of 0.5.*
2. *Averaging time can be fixed as per convenience.*
3. *When 1 hour averaging time is chosen, monitoring should be done during cooking time.*
4. *When 8 hour averaging time is taken, monitoring should cover cooking time too.*
5. *Monitoring of CO_2 is to ensure the adequacy of the ventilation of the monitoring sites.*

Source: MoSTE (2010)

Table 66: National Ambient Air Quality Standards for Nepal in µg/m^3, 2012

Parameters	Averaging Time	Concentration in Ambient Air, Maximum	Test Methods
Total Suspended Particulates (TSP)	Annual	-	-
	24-hours[a]	230	High volume sampling and Gravimetric analysis
Particulate Matter- 10 (PM_{10})	Annual	-	-
	24-hours[a]	120	High volume sampler and Gravimetric analysis, TOEM, Beta attenuation
Sulphur Dioxide (SO_2)	Annual[b]	50	Ultraviolet fluorescence, West and Gaeke method
	24-hours[a]	70	Same as annual
Nitrogen Dioxide (NO_2)	Annual	40	Chemiluminescence
	24-hours[a]	80	Same as annual
Carbon Monoxide (CO)	8 hours[a]	10,000	Non dispersive infrared spectrophotometer (NDIR)
Lead (pb)	Annual[b]	0.5	High volume sampling followed by atomic absorption spectrometry
Benzene (C_6H_6)	Annual[b]	5	Gas chromatographic technique
Particulate Matter ($PM_{2.5}$)	24-hours[a]	40	$PM_{2.5}$ sampling gravimetric analysis
Ozone (O_3)	8 hours[a]	157	UV spectrophotometer

Note: [a]The 24-hour and 8-hour values shall be met 95 percent of the time in a year. The standard may be exceeded 18 days per calendar year, but not on two consecutive days; [b]Yearly average of any specific area shall be calculated from at least 104 readings taken twice a week for 24 hours, or the same interval of time for a week.

Source: MoSTE (2010)

published in 2012 by the MoSTE is presented in Table 66.

According to the Energy Efficiency Centre (EEC) of Federation of Nepalese Chambers of Commerce and Industry (FNCCI), about 575 brick kilns were in operation in 2014 in Nepal whose capacities range from 15,000 to 50,000 bricks per day (EEC, 2014). Moving Chimney Bull Trench Kilns (MC-BTK) were the most commonly used brick making technology in the past in the country. As the Government has banned the use of MC-BTKs from the Kathmandu valley, these types of kilns have been replaced by the Fixed Chimney Bull Trench Kilns (FC-BTKs). Apart from BTKs, Clamp, Hoffman and Vertical Shaft Brick Kilns (VSBK) are also in operation in the country (EEC, 2014). However, since 2008 the Government has set the standards on chimney heights and emissions for brick industries (see Table 67).

Table 67: Chimney Height and Emission Standards for Brick Kilns in Nepal

S.No.	Type of Kiln	Height of Chimney in m[1] (minimum limit)	Suspended Particulate Matter in mg/Nm^3 (Maximum limit)
1.	Bull's Trench kiln, Forced Draught (Fixed Chimney)	17	600
2.	Bull's Trench Kiln, Natural Draught (Fixed Chimney)	30	700
3.	Vertical Shaft Brick Kiln (VSBK)	15	400

Note: [1]Chimney height shall be measured from ground level

Source: MoSTE (2010)

According to the target set by the Government in 2012, the total suspended particulate matter (TSP) emitted by the cement industries should be less than 500 $\mu g/m^3$ while that from the crusher industries should be less than 600 $\mu g/m^3$. According to the Environmental Protection policy of Nepal, there is a maximum limit set for the emission of pollutant from diesel generators and industrial boiler. In October 2012, the MoSTE introduced the National Diesel Generator Emission Standard (NDGES) for new and in-use diesel generators under the 1997 Environment Protection Act (see Table 68). The emission limits are set for four major pollutants, namely CO, HC, NO_X and PM. Table 69 presents the standard on particulate matter emission for industrial boiler.

Table 68: Maximum Pollution Limit for Diesel Generators (g/kWh)[1]

Capacity (kW)	For Imported New Diesel Generators[2]			For In-Use Diesel Generators[3]			
	CO	HC + NO_X	PM	CO	HC	NO_X	PM
< 8	8.00	7.50	0.80	8.00	1.30	9.20	1.0
8 to <19	6.60	7.50	0.80	6.60	1.30	9.20	0.85
19 to <37	5.50	7.50	0.60	6.50	1.30	9.20	0.85
37 to <75	5.00	4.70	0.40	6.50	1.30	9.20	0.85
75 to <130	5.00	4.00	0.30	5.00	1.30	9.20	0.70
130 to <560	3.50	4.00	0.20	5.00	1.30	9.20	0.54

Note: [1]Sampling collection point should be located at one-third of the diesel generator set stack height; [2]Equivalent to Bharat III standards of India; [3]Equivalent to Bharat II standards of India

Source: MoSTE (2010)

Table 69: Standard on Particulate Matter Emission from Industrial Boilers

Steam Generation Capacity of Boiler (kg/hour)	Maximum Limit (mg/Nm^3)
Less than 2000	1200[a]
2000 to less than 10000	800[a]
10000 to less than 15000	600[a]
15000 and above	150[b]

Note: [a]Control device should be cyclone/multi-cyclone along with the industrial boiler; [b]Control device should be bag filter/electrostatic precipitator (ESP) along with the industrial boiler

Source: MoSTE (2010)

11.2. Policy Implications

Biomass accounts for almost 87% of the Nepal's total primary energy supply and is mostly consumed by the households for cooking and space heating purposes using traditional stoves. The traditional stoves used in the households have very low energy efficiency (less than 10%); similarly, the energy efficiency of other end use devices is also well below the satisfactory level (WECS/NEEP, 2014a). Based on the emission inventory in the present study, the residential sector, being mainly dependent on fuelwood for cooking and heating purposes, has been found to be one of the major sources of CO_2, CO, BC and NO_X emissions in the country. The use of inefficient traditional cookstoves has been identified to be the major source of these emissions from the sector. Even though the usage of LPG has been increasing in the past several years, they have been confined mostly in the urban households and commercial sectors. The percentage of people using LPG for cooking in Nepal has increased from 8% to 18% during 2003-2010 (based on CBS (2004) and CBS (2011)). However, the statistics shows that only those lying under the highest income quintile have been found to be using LPG while around 80% of the poorer people rely on fuelwood for cooking and heating purposes (NPC, 2013).

Predominant use of traditional cookstoves (mostly in the rural areas) has been contributing to the reduced quality of life and living standards of the rural population thus posing health hazards especially to women and children through increased indoor air pollution. The heavy reliance on traditional biomass cookstoves for cooking and heating in Nepal has put considerable pressure on the environment both by increasing deforestation and emissions (both local and greenhouse gases); it has also been affecting the human health and safety significantly. As mentioned in IRIN (2012), around 7,500 Nepalese are estimated to die each year due to indoor air pollution, with women and children being the most affected as they are the ones normally exposed to the pollution for longer duration. Improved biomass cookstoves (ICS) possess higher energy efficiency (around 20-25%) than the traditional cookstoves and are cleaner. They emit lower level of pollutants and reduce household's exposure to indoor air pollution. Thus replacing traditional cookstoves by ICS could be an effective option to reduce indoor air pollution. While the government has policies and programs to promote ICSs, their penetration level is not yet significant; as such most of the households in the rural areas are still using traditional cookstoves. Thus there is a need for more aggressive and effective policies/ programs to introduce ICS in the country in order to reduce emissions of key precursors of indoor air pollution in the sector. Given that biomass is relatively abundant and more affordable, a policy to promote ICS appears to be a financially viable option for reducing different emissions from the household sector in Nepal.

Adoption of ICS requires behavioral change in the users' cooking practices, for example, chopping of fuelwood, regular repair and maintenance of stove etc. Lack of such behavioral changes would obstruct wide scale acceptance of ICS (NPC, 2013). However, there exists a lack of awareness about the benefits of using ICS and behavioral changes needed in Nepal (NPC, 2013). This indicates the need for policies and programs to raise popular awareness about the benefits of ICS and to educate households about their effective operation.

Substitution of traditional biomass with cleaner fossil fuels and renewable energy sources for cooking and heating would be another option for reducing emissions from the residential sector. Although there exist policies and programs to subsidize biogas plants in Nepal, only a limited number of households have installed such plants at present. Therefore, more effective biogas promotion policies needs to be introduced. Policies to promote the use of electricity and LPG in cooking could also be an option for reducing emissions. However, due to lack of adequate electricity supply capacity in the short to medium term, electric cooking could only be a longer term option in the case of Nepal. In the case of LPG, the high costs of fuel and stoves, which are both imported, do not appear to make them financially viable for lower income people in the rural areas unless the fuel is heavily subsidized.

This study has found that manufacturing industries are one of the major sources of CO_2, SO_2, PM_{10}, $PM_{2.5}$, BC and OC emissions. Among the manufacturing industries, food, beverage and tobacco (FBT) and brick industries have been found to be the key sources of industrial SO_2 emissions. The FBT industries are also found to be the highest emitters of NO_X, CO_2 and BC from the industrial sector. Pulp and paper industries are found to have the largest share in the total industrial sector emissions of CO, PM_{10} and $PM_{2.5}$. The study also found the brick, FBT, pulp and paper and textile industries as the major emitters of CO_2 in the country. Energy efficiency improvements in the industrial sector would be a major option to reduce different emissions from the country. A study conducted by the Nepal Energy Efficiency Programme (NEEP) says that there exists a huge potential for the Nepalese industries to cut down production cost and emissions by using energy more efficiently (WECS/NEEP, 2014d). Even though Ministry of Environment has stack emission standards for brick industries, it fails to regularly monitor the emissions. The study by NEEP has also identified eight energy intensive industries in Nepal, such as hotel, metal, food and beverage, cement, pulp and paper, cold storage, soap and chemical and brick industries. The study shows that around 15% of electrical energy and 30% of thermal energy savings potential exist in the eight industries. Cement and food industries have high potenitals for both electricity as well as thermal energy saving potentials. The hotel industries are among those having high potential for electricity savings, while the brick industries have high potential for thermal energy saving. Among the fuels, the highest potential for saving energy lies in the use of coal, which is followed by diesel and electricity. Around 507,247 metric tonne of CO_2 emissions could be avoided through the application of energy efficiency measures in the eight industries identified by NEEP. The brick industry has been reported to have the highest potential for CO_2 emission reduction (around 62%), followed by cement (17%) and food (11%) industries (WECS/NEEP, 2014d). These energy saving and emission reduction potential of the industries could only be realized if there are policy measures and incentives to promote industrial energy efficiency improvement.

The transport sector has been found to be a major source of SO_2 emission in the country.

The sector is estimated to account for more than 79% of the SO_2 emissions in the country. The sector also emits significant amounts of CO_2, NO_X, CO, PM_{10}, $PM_{2.5}$, NMVOC and BC emissions. To minimize and prevent the air pollution from vehicles, the Government of Nepal should develop and enforce strong transport policies. The existing policies should be strengthened and monitoring and an enforcement mechanism needs to be made more effective in order to reduce emissions from this sector. Additional policies for reduction of emissions would include vehicle inspection and maintenance, stricter vehicle fuel efficiency standard, phasing out of old and inefficient vehicles from the whole country, and policy of promoting electric vehicles, and mass transport system like buses, mass rapid transit (MRT) and railways. Poor road condition is another factor for the increased vehicular pollution in Nepal. A hydropower rich country like Nepal should develop policies to utilize its untapped hydropower resources to electrify the transport sector and reduce the transport related emissions in future.

Forest fires are found to be the major emitter of CO, $PM_{2.5}$, CO_2 and OC in Nepal. Forest fire incidents are serious issues during the dry season in Nepal and are often worsened by climate change, agricultural practices, careless attitudes and lack of awareness (ICIMOD, 2013). However, the forest fire database is poor at present. For proper formulation of measures to reduce the incidence of forest fires and their associated emissions, continuous monitoring of forest fires in different regions of the country is desirable. Continuous education and training programs with proper follow-up should be conducted in order to prevent/reduce the incidence of man-made forest fires. Effective measures for raising public awareness to prevent forest fires would also be necessary.

According to WECS/NEEP (2014a), energy efficiency improvement has the greatest potential for reducing GHG and local pollutant emissions from all energy consuming sectors. In particular, there exists a huge potential of energy conservation in residential cooking (a major source of indoor air pollution), industrial thermal application and commercial enterprises. However, the country lacks comprehensive energy efficiency strategy and integrated energy policy including energy efficiency (WECS/NEEP, 2014a). Even with growing awareness about the potential benefits of energy efficiency programs, Nepal lags far behind in realizing the energy efficiency potential because of several policy related, institutional, informational, technical, financial and market barriers. There is a need for designing and implementing effective policies and measures to address these barriers.

The SNC of Nepal (MOSTE, 2014) has identified several mitigation measures to curb GHG emissions. Some of the mitigation measures in the energy using sectors include increasing plant efficiency; switching to lower-carbon fuels (for e.g., from coal to gas); reducing losses in the transmission and distribution of electricity and fossil fuels; increasing the use of renewable energy (such as solar, hydropower, wind, and biomass energy); and use of carbon capture and storage. The mitigation measures suggested in the SNC for reducing GHG emission from the agriculture sector include decreasing the use of artificial fertilizer to minimize N_2O emission and improving cultivation methods to increase carbon storage in soil; establishing hay meadows with high-yielding fodder legumes and grasses under high nutrient supply condition to reduce grazing pressure on forests; increasing cropping intensity, organic farming, promotion of integrated soil fertility (crop intensification and diversification); improving crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; increasing area under organic farming; improving traditional agricultural practices; establishing farmers' cooperatives that will oversee proper utilization of forage resources through monitoring of the number of livestock, their grazing duration and grazing time, nutrient management and control of shrub and weed; and dedicated energy crops to replace fossil fuel use as well as improved energy efficiency. Apart from this, the SNC suggests the need for guidelines for farmers on appropriate farming practices, cultivation technologies and livestock management. The report also mentions policies for waste minimization and GHG reduction such as taxes on solid waste disposal (bag fees), market incentives (e.g., offsets) for improved waste management and recovery of CH_4 and regulatory standards for waste disposal and wastewater management (e.g., mandatory capture of landfill gas). Further, the SNC emphasizes the need for policy interventions to develop hydropower as the main source of energy, to promote use of energy efficient technologies, to establish a Cleaner Production Centre and to implement Environment Management System (EMS) (MoSTE, 2014).

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Annexes

Annex 1: Summary of Activity Data and Data Sources

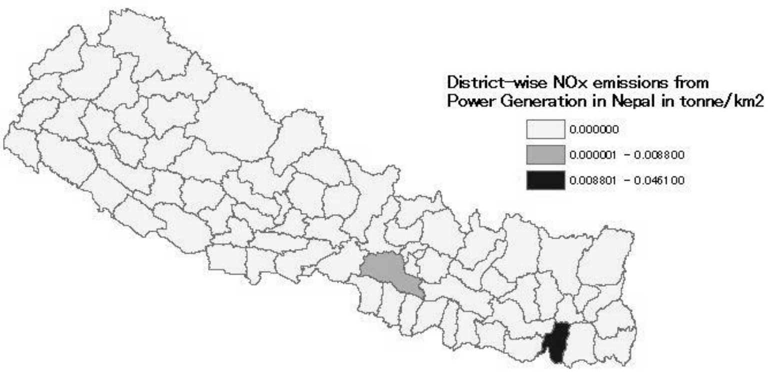
Source sectors		Activity data	Data sources
Combustion in energy sector	Energy industry	Fuel consumption	NEA (2009), WECS (2010)
	Manufacturing		WECS (2010), CBS (2009)
	On road transport	Number of vehicles; Vehicle kilometre travelled (VKT)	WECS (1997), WECS (2000), Dhakal (2006)
	Air traffic	Landing and takeoff; Aviation fuel consumption	CAAN (2010), NOC (2011)
	Residential & commercial	Fuel consumption	WECS (2010), WECS (1997)
Fugitive emission from fuel		Production and sales data	WECS (2010)
Agro residue open burning		Crop production	WECS (2010)
Forest fire		Forest Area	WECS (2010)
Solid waste open burning		Population data	CBS (2011 and 2001)
Manufacturing and process industries		Production data	DOI (2009), CBS (2009)
Others	Solvent and product use	Production data/consumption data	Not estimated
	Agriculture related activities	Livestock counting, fertilizer consumption	MOF (2011b)
	Solid waste incineration and disposal site	SW incinerated and disposed	MOF (2011a and 2011b)

Annex 2: Physiographic Categories of the Districts in Nepal

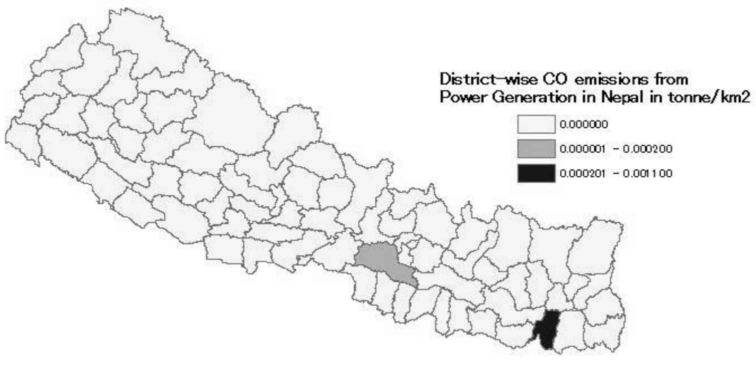
Development Region	Physiographic Region	Districts
EDR	Mountain	Sankhuwasabha, Solukhumbu, Taplejung
	Hilly	Bhojpur, Dhankuta, Ilam, Khotang, Okhaldhunga, Panchthar, Terhathum, Udaypur
	Terai	Jhapa, Morang, Saptari, Siraha, Sunsari
CDR	Mountain	Dolakha, Rasuwa, Sindhupalchowk
	Hilly	Bhaktapur, Dhading, Kathmandu, Kavre, Lalitpur, Makawanpur, Nuwakot, Ramechhap, Sindhuli
	Terai	Bara, Chitwan, Dhanusa, Mahaottari, Parsa, Rautahat, Sarlahi
WDR	Mountain	Manang, Mustang
	Hilly	Argakhanchi, Baglung, Gorkha, Gulmi, Kaski, Lamjung, Myagdi, Palpa, Parbat, Syanja, Tanahu
	Terai	Kapilbastu, Nawalparasi, Rupandehi
MWDR	Mountain	Dolpa, Humla, Jumla, Mugu, Kalikot
	Hilly	Dailekh, Jajarkot, Pyuthan, Rolpa, Rukum, Salyan, Surkhet
	Terai	Dang, Banke, Bardia
FWDR	Mountain	Bajhang, Bajura, Darchula
	Hilly	Accham, Baitadi, Dadeldhura, Doti
	Terai	Kailali, Kanchanpur

Source: WECS (2010)

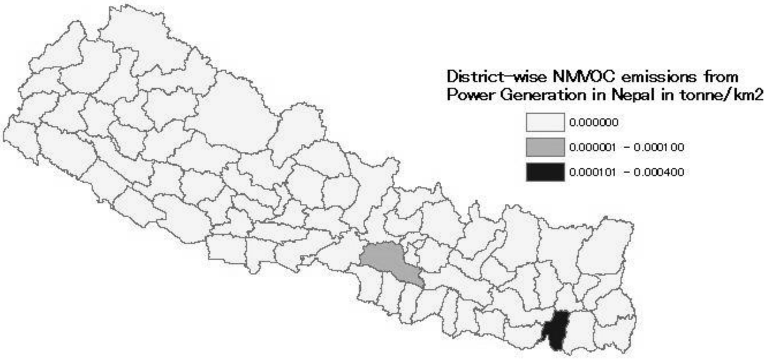
Annex 3: Spatial Variations of Emission Densities from Fuel Combustion in the Power Generation Sector



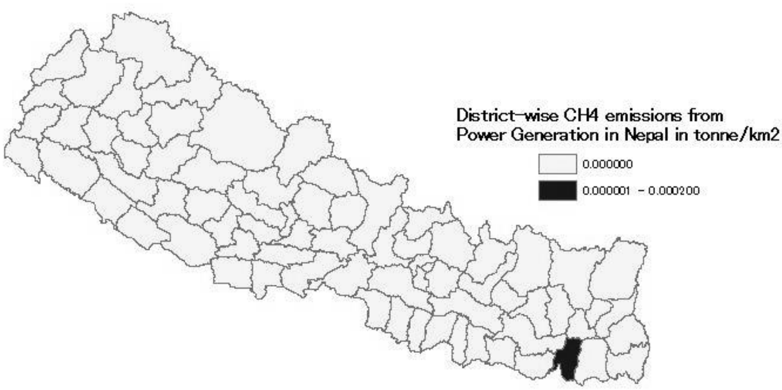
3A: NO_x Emission Density



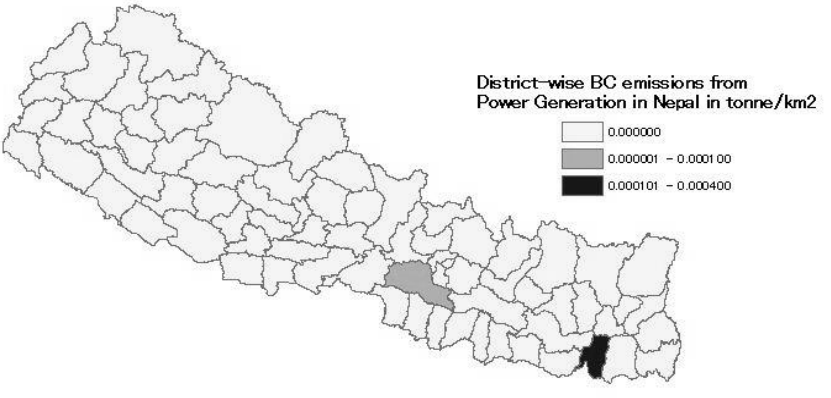
3B: CO Emission Density



3C: NMVOC Emission Density

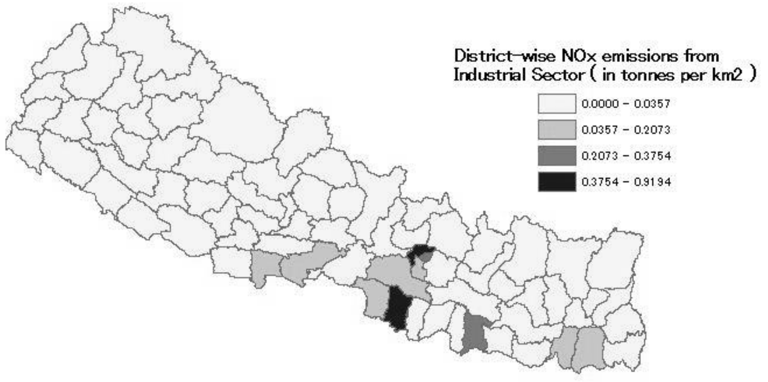


3D: CH_4 Emission Density

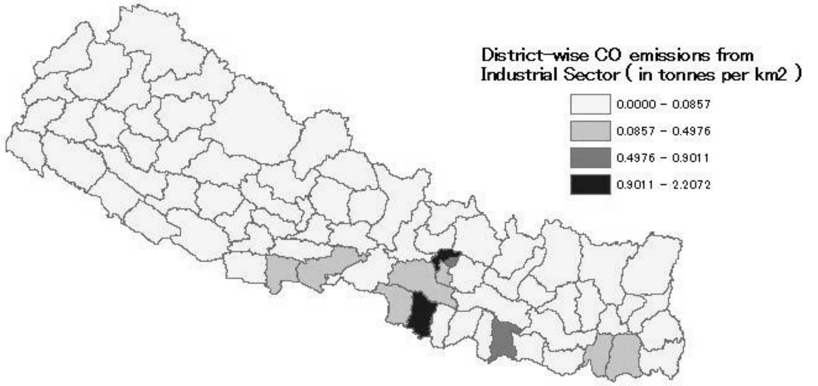


3E: BC Emission Density

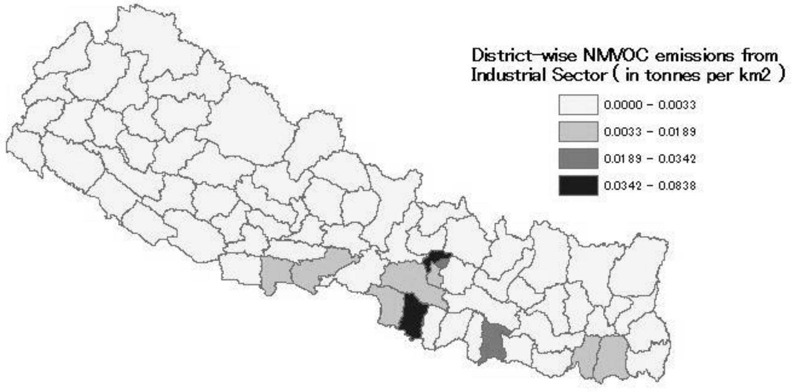
Annex 4: Spatial Variations of Emission Densities from Fuel Combustion in the Industrial Sector



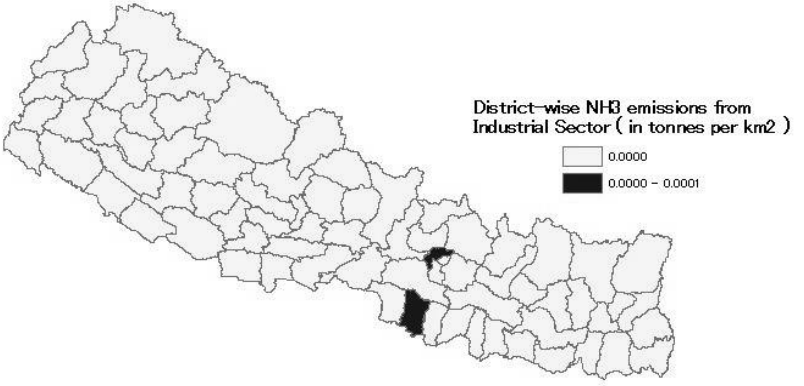
4A: NO_x Emission Density



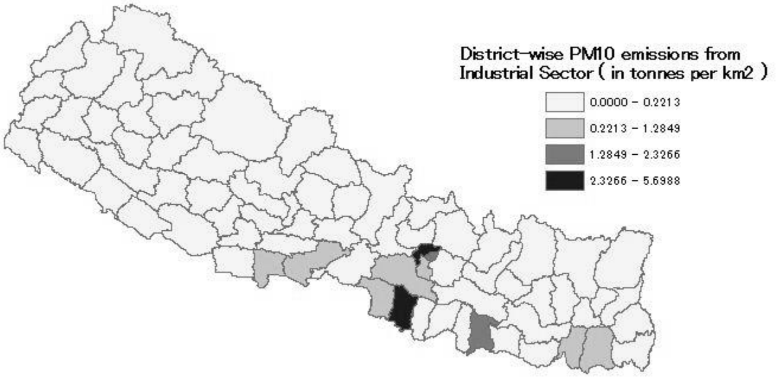
4B: CO Emission Density



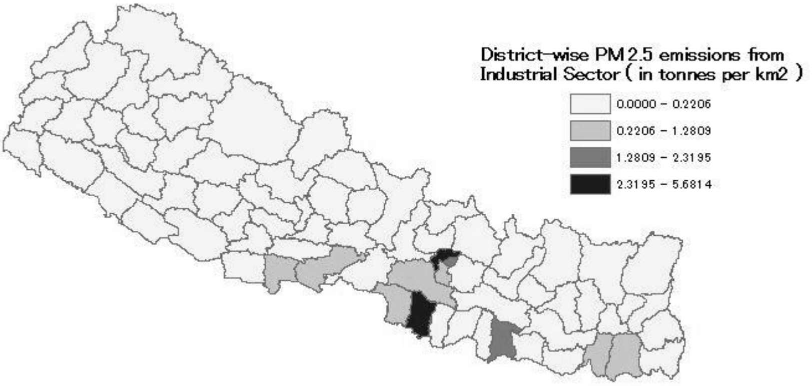
4C: NMVOC Emission Density



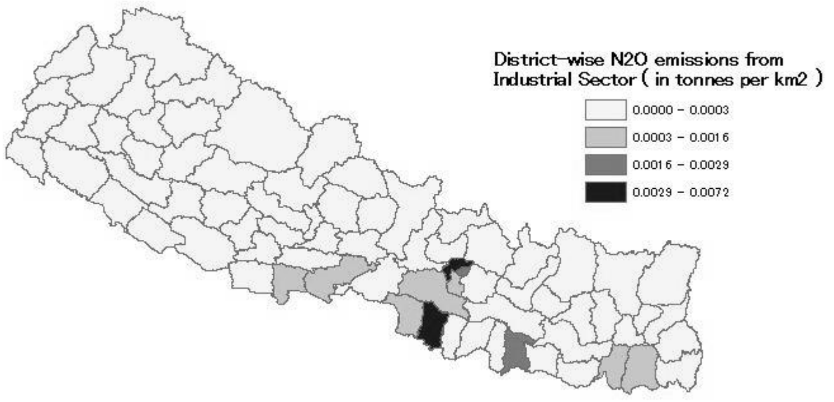
4D: NH_3 Emission Density



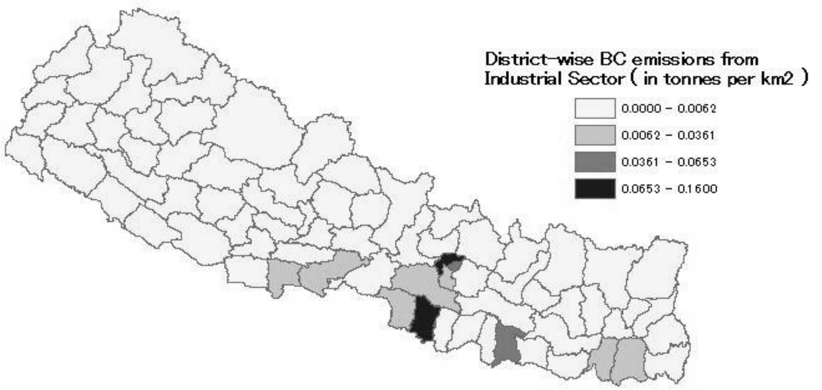
4E: PM_{10} Emission Density



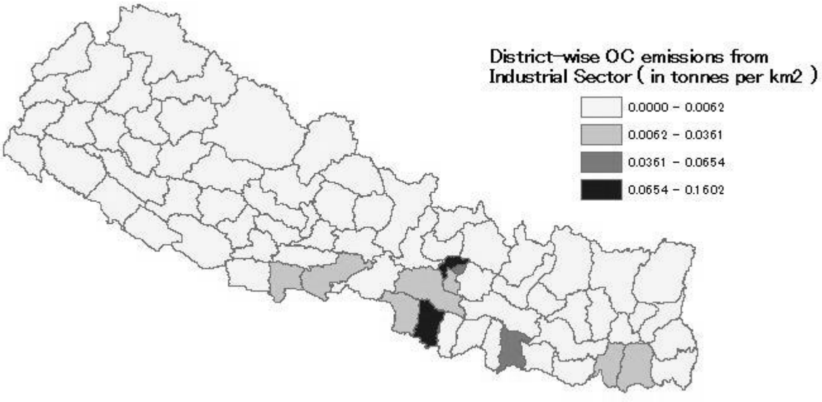
4F: $PM_{2.5}$ Emission Density



4G: N_2O Emission Density



4H: BC Emission Density



4I: OC Emission Density

Annex 5: Total Number of Registered Vehicles in Different Zones of Nepal by Vehicle Type in 2008

According to Zones		According to Vehicle Type	
Zones	Registered Vehicles	Vehicle Type	Registered Vehicles
Mechi	1981	Bus	1419
Koshi	3271	Minibus	1179
Sagarmatha	187	Crane/Dozer/Excavator/Truck	3594
Janakpur	257	Car/Jeep/Van	4741
Narayani	27747	Pick-up	1588
Bagmati	42885	Micro	31
Gandaki	3590	Tempo	18
Dhaulagiri	N.A.	Motorcycle	69666
Lumbini	3633	Tractor	3297
Rapti	137	Others	206
Bheri	571		
Seti	432		
Mahakali	49		
Karnali	N.A.		
Total (in 2008)	**84740**	**Total (in 2008)**	**85739**
Grand Total (as of 2008)	**710914**	**Grand Total (as of 2008)**	**710914**

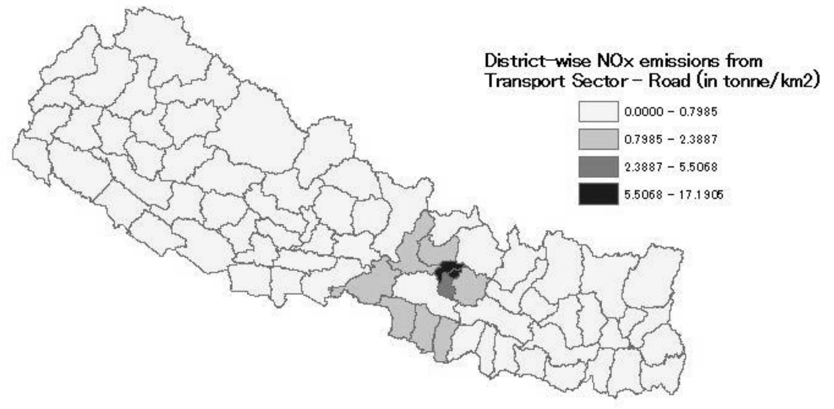
Source: Data obtained from Department of Transport Management

Annex 6: Airportwise Data on Arrivals and Departures

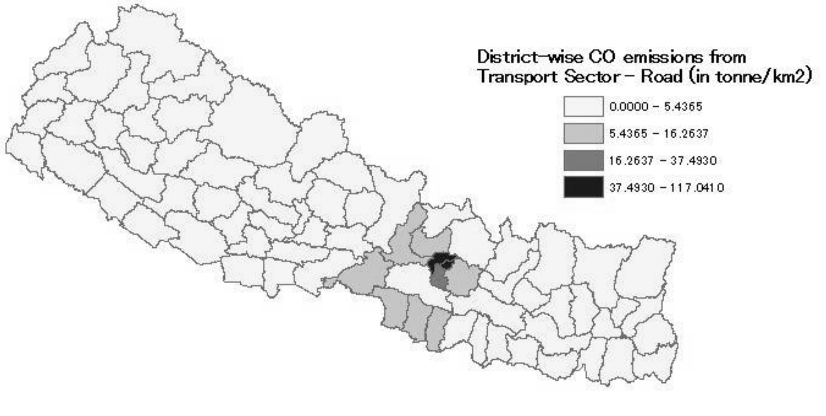
Airports	Arrival	Departure
Bajhang	124	124
Bajura	386	386
Bhadrapur/Chandragadhi	17295	21925
Bhairahawa	2094	2094
Bharatpur	1998	1998
Bhojpur	471	471
Biratnagar	6141	6141
Dang (Tulsipur)	88	88
Dhangadhi	850	850
Dolpa	942	942
Janakpur	9554	11554
Jomsom	1728	1728
Jumla	1820	1820
Kathmandu	41771	41791
Lamidanda	762	762
Lukla	4081	6081
Manang	166	166
Nepalgunj	4842	4875
Phalpu	992	992
Pokhara	19708	
Rukumkot	303	303
Rumjatar	382	382
Simara	2230	2230
Surkhet	4317	4325
Thamkharka	145	145
Tumlingtar	1094	1094

Source: Data Obtained from Civil Aviation Authority Nepal

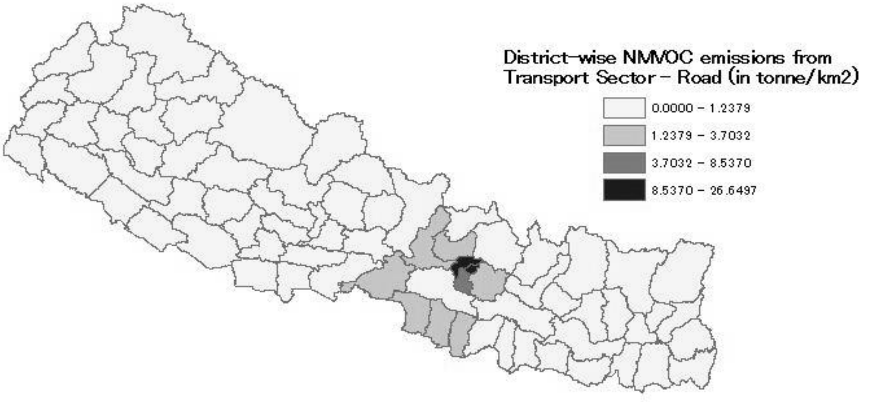
Annex 7: Spatial Variations of Emission Densities from Fuel Combustion in Road Transport Sector



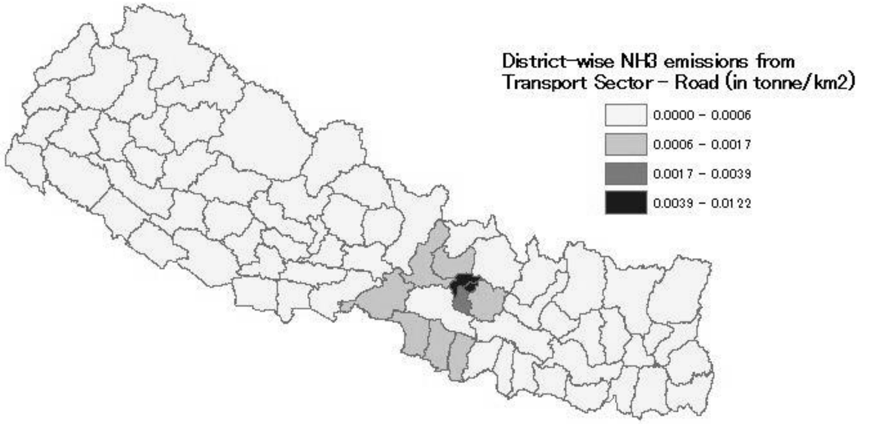
7A: NO_x Emission Density



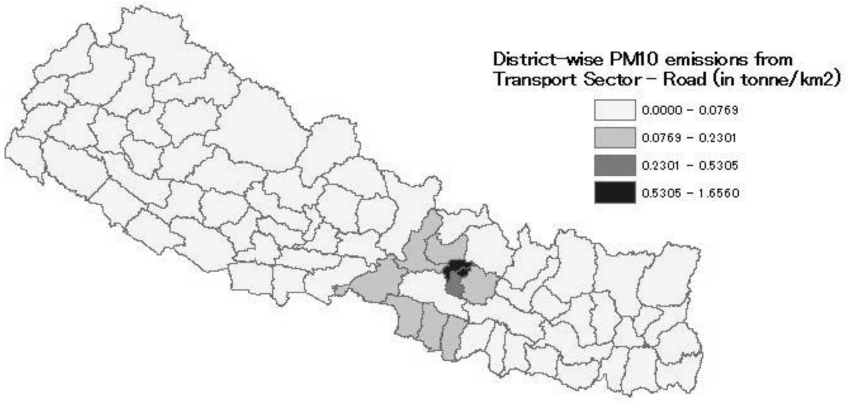
7B: CO Emission Density



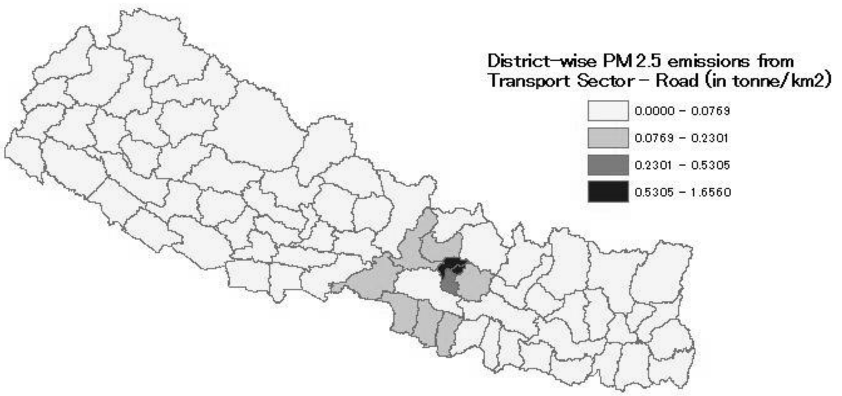
7C: NMVOC Emission Density



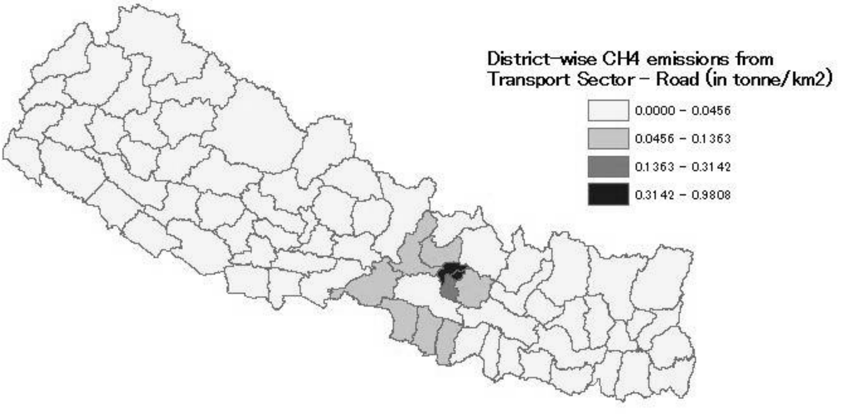
7D: NH_3 Emission Density



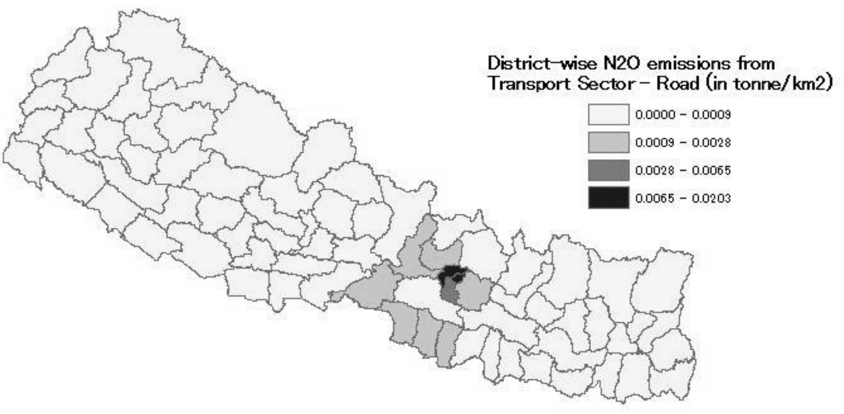
7E: PM_{10} Emission Density



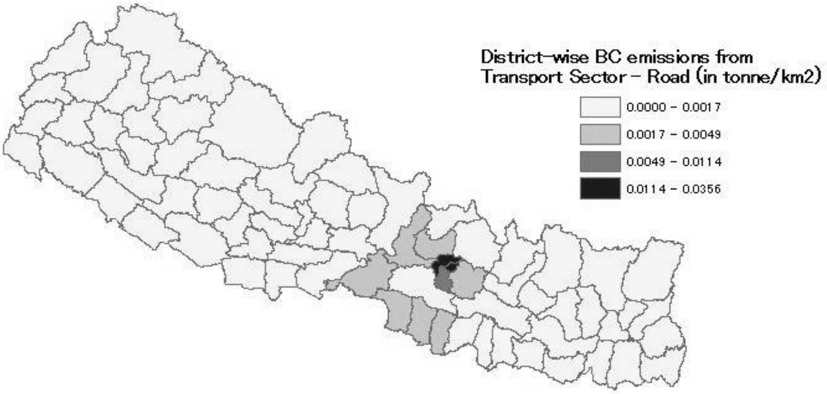
7F: $PM_{2.5}$ Emission Density



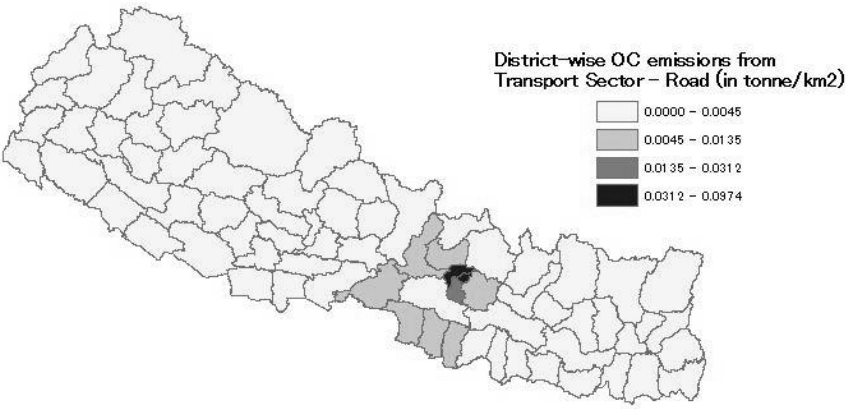
7G: CH_4 Emission Density



7H: N_2O Emission Density

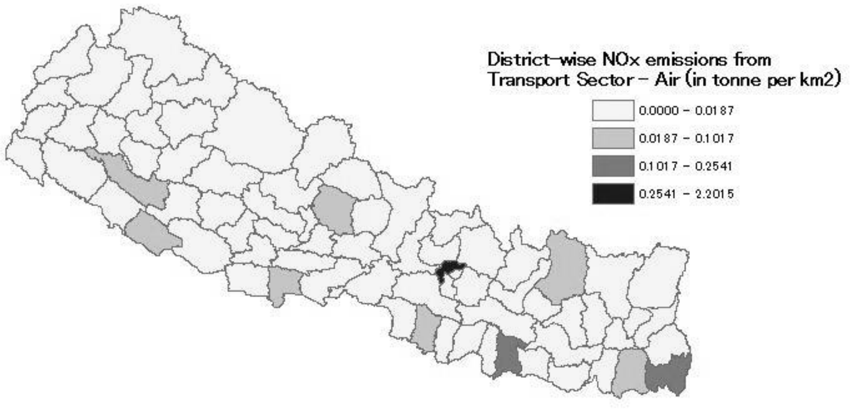


7I: BC Emission Density

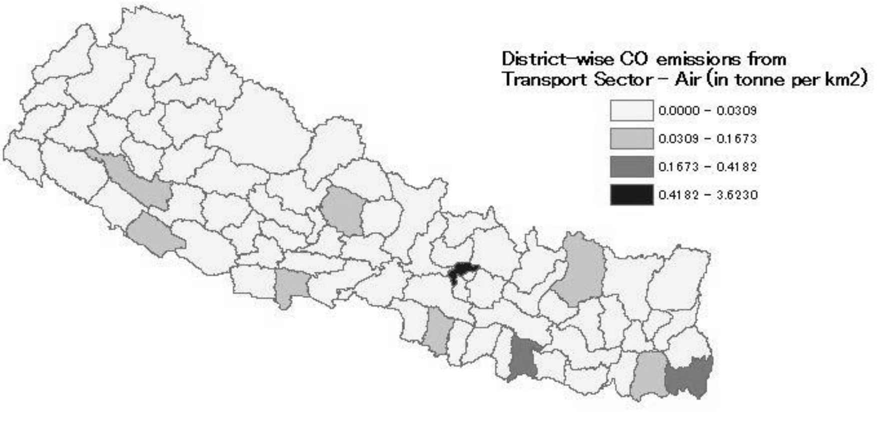


7J: OC Emission Density

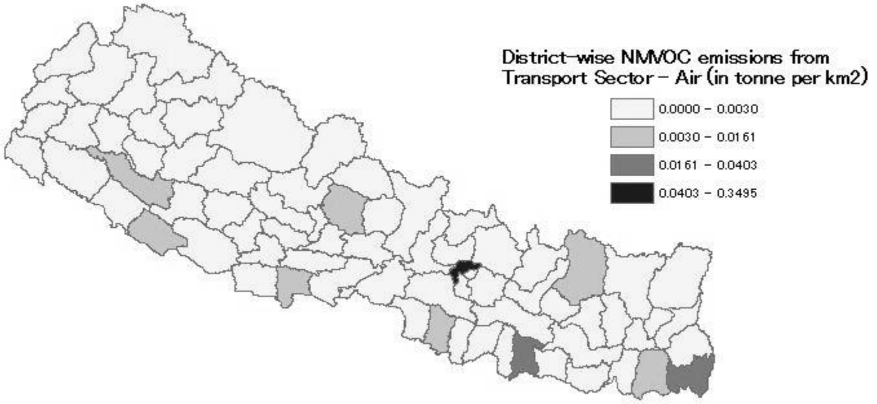
Annex 8: Spatial Variations of Emission Densities from Fuel Combustion in the Air Transport Sector



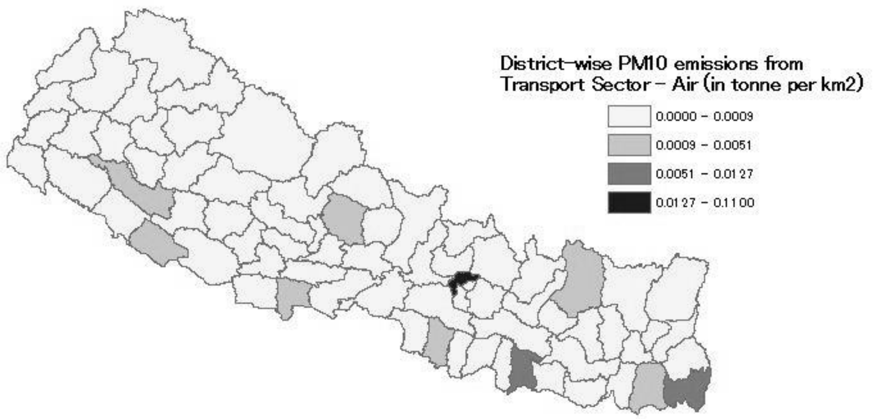
8A: NO_x Emission Density



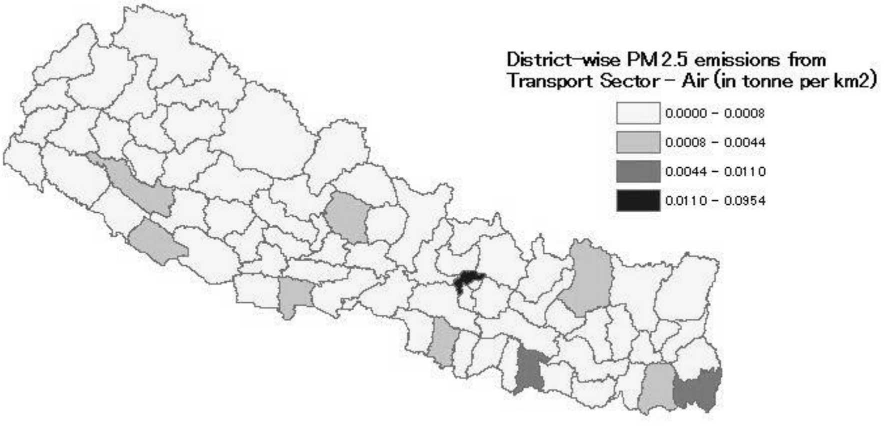
8B: CO Emission Density



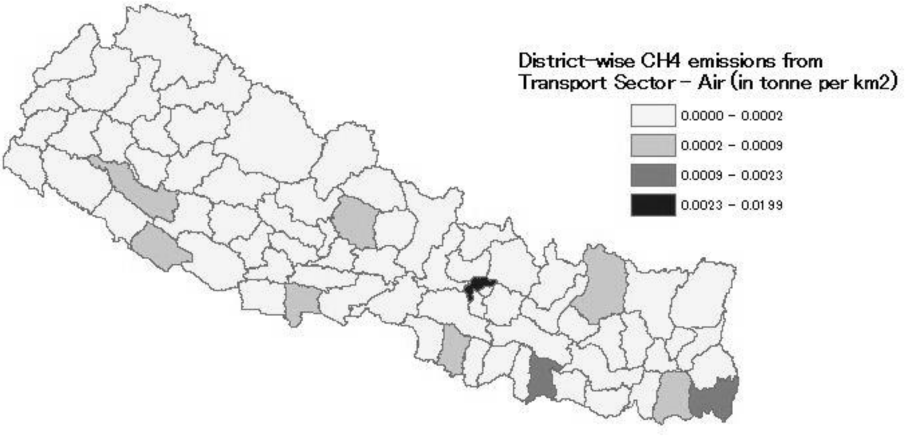
8C: NMVOC Emission Density



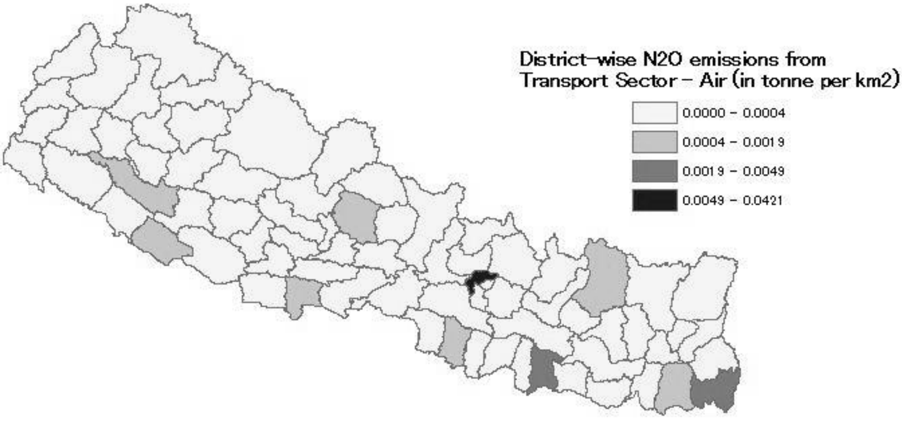
8D: PM_{10} Emission Density



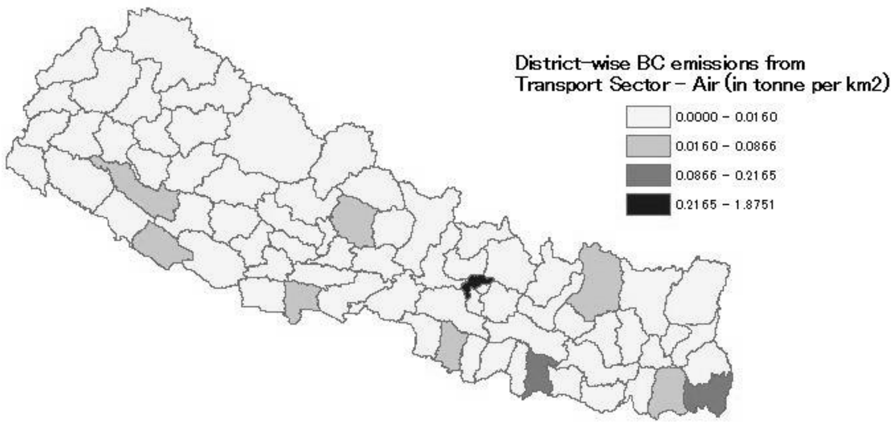
8E: $PM_{2.5}$ Emission Density



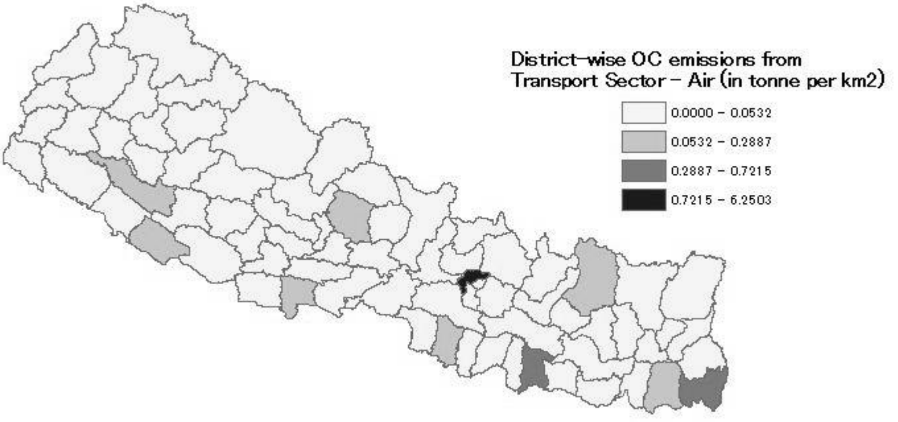
8F: CH_4 Emission Density



8G: N_2O Emission Density



8H: BC Emission Density



8I: OC Emission Density

Annex 9: Distribution of Households by Region and Type of Fuel Used for Cooking, %

Region/ Fueltype	Fuelwood	Animal Waste	Agricultural Residue	LPG	Kerosene	Biogas	Others
Whole country	68.4	10.7	4.3	12.3	1.4	2.4	0.5
Ecological Belt							
Mountain	87.9	1.6	0.3	5.7	2.8	0.4	1.2
Hill	76.2	0.7	0.4	18.1	2.4	1.7	0.5
Terai	58.3	21.3	8.4	7.8	0.3	3.4	0.4
Development Region							
Eastern	68.1	17.6	5.1	6.1	0.4	2.4	0.4
Central	53.3	11.9	7.6	21.5	2.7	2.3	0.8
Western	69.8	10.9	2.3	12.3	0.9	3.2	0.6
Mid-western	91.2	1.8	0.0	4.6	0.5	1.7	0.2
Far-western	90.7	1.1	0.0	3.9	2.1	2.0	0.2
Urban	35.8	2.7	1.6	51.8	4.9	2.3	0.9
Kathmandu Valley	5.9	0.1	1.4	82.9	9.1	0.1	0.4
Rural	75.1	12.4	4.8	4.2	0.7	2.4	0.4

Source: CBS (2009)

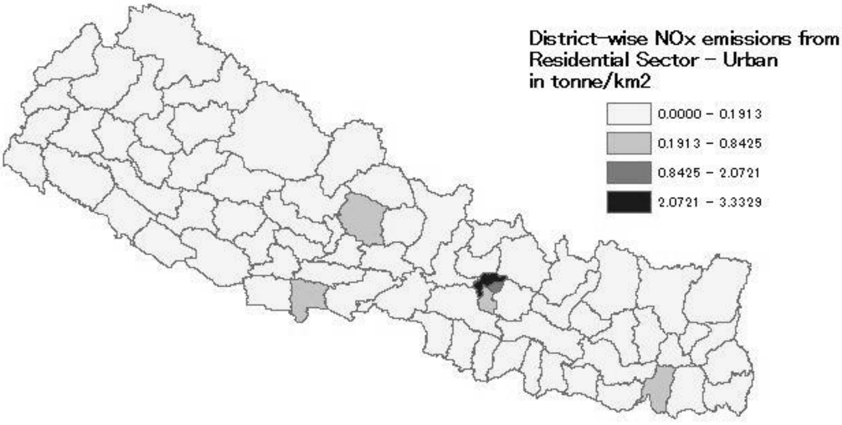
Annex 10: Distribution of Households by Region and Type of Fuel Used for Lighting, %

Region/Fuel Type	Electricity	Kerosene*	Others
Whole country	56.1	33.0	11.0
Ecological Belt			
Mountain	41.3	29.4	29.3
Hill	55.5	27.7	16.8
Terai	58.8	38.4	2.8
Development Region			
Eastern	58.2	39.1	2.6
Central	62.2	33.8	4.0
Western	63.0	31.0	5.9
Mid-western	34.4	18.8	46.8
Far-western	43.7	39.1	17.3
Urban	93.1	6.2	0.8
Kathmandu Valley	99.7	0.3	0.0
Rural	48.5	38.5	13.0

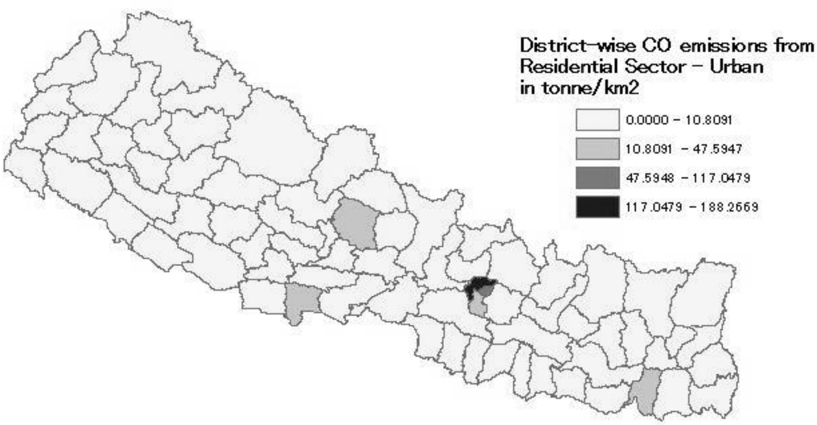
Note: This also includes gas and oil along with kerosene.*

Source: CBS (2009)

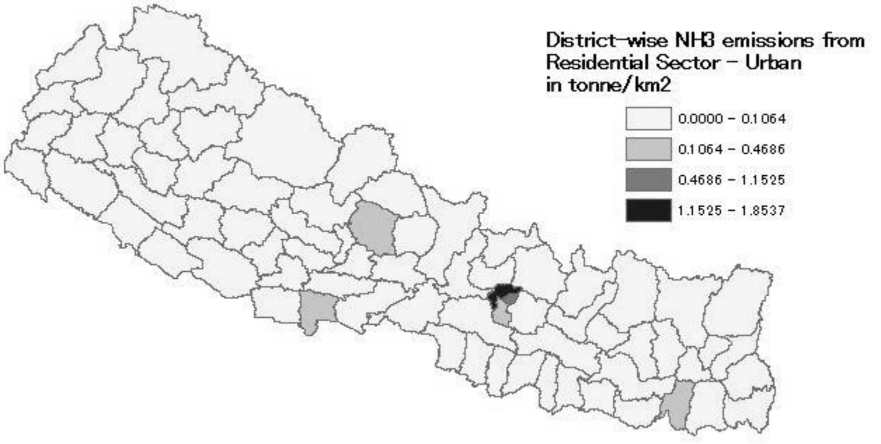
Annex 11: Spatial Variations of Emission Densities from Fuel Combustion in Urban Residential Sector



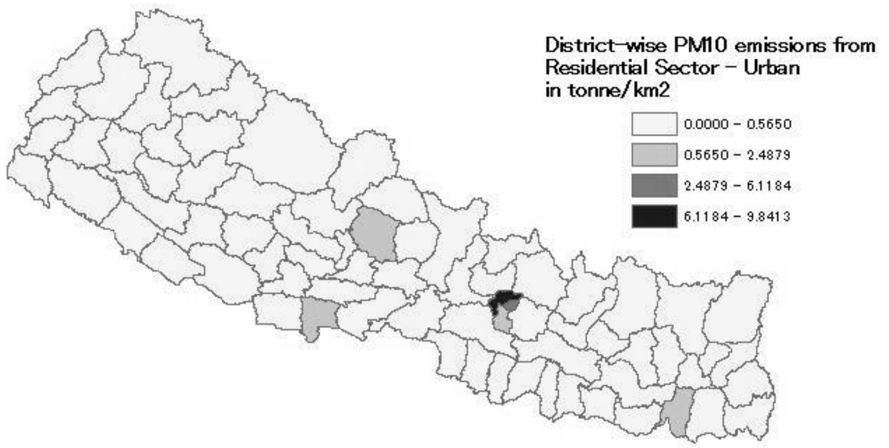
11A: NO_x Emission Density



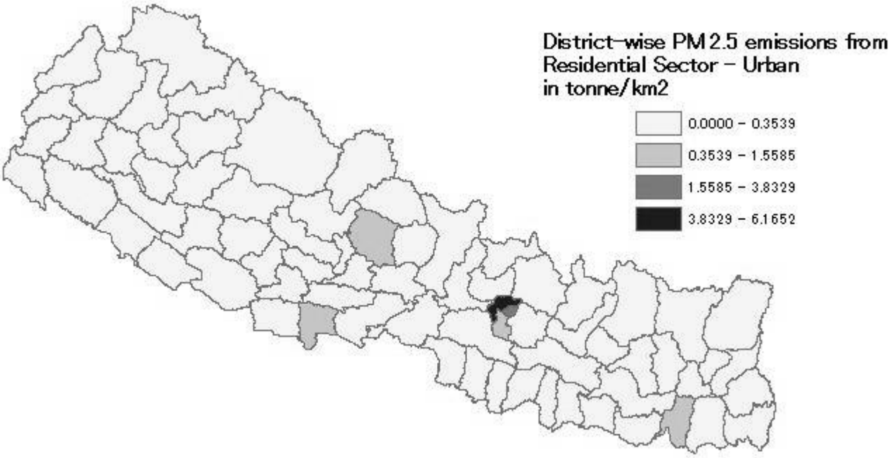
11B: CO Emission Density



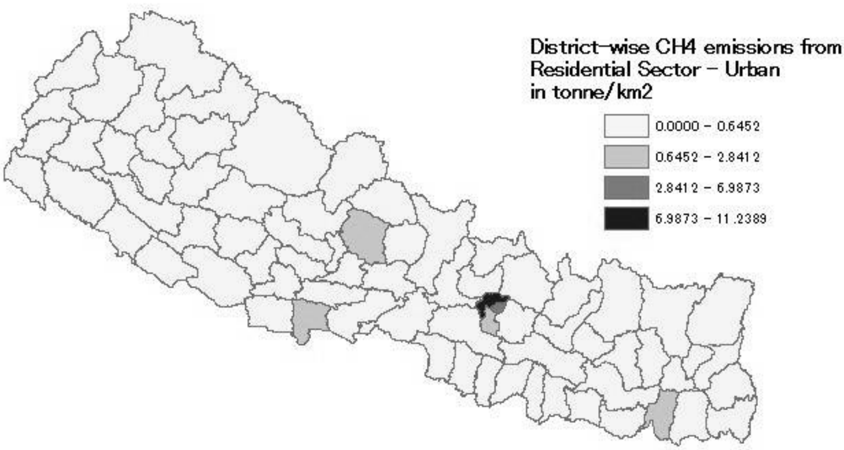
11C: NH_3 Emission Density



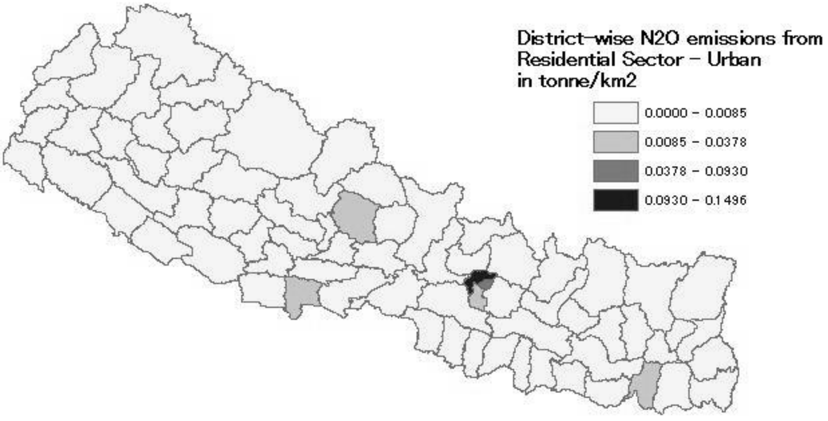
11D: PM_{10} Emission Density



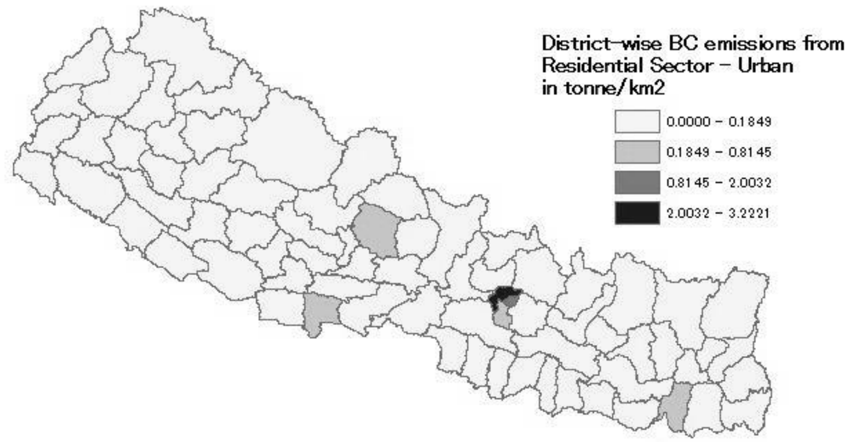
11E: $PM_{2.5}$ Emission Density



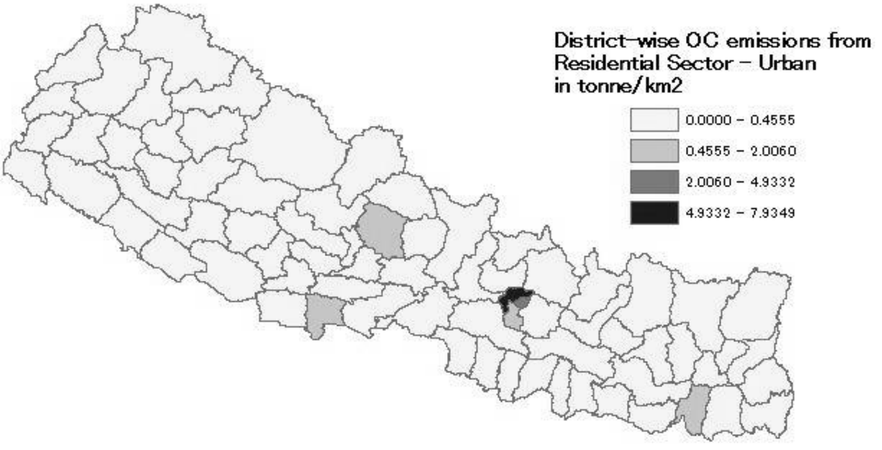
11F: CH_4 Emission Density



11G: N_2O Emission Density

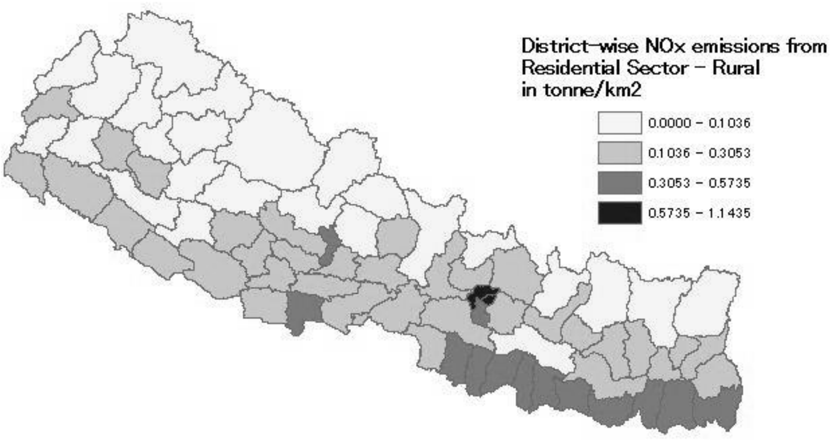


11H: BC Emission Density

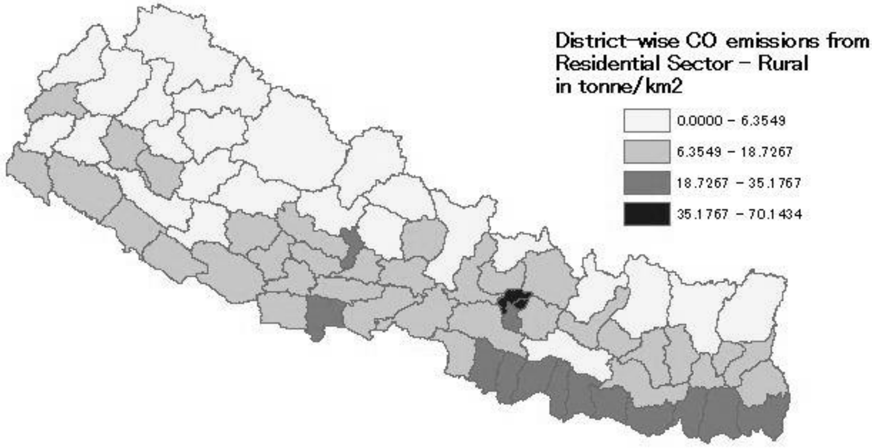


11l: OC Emission Density

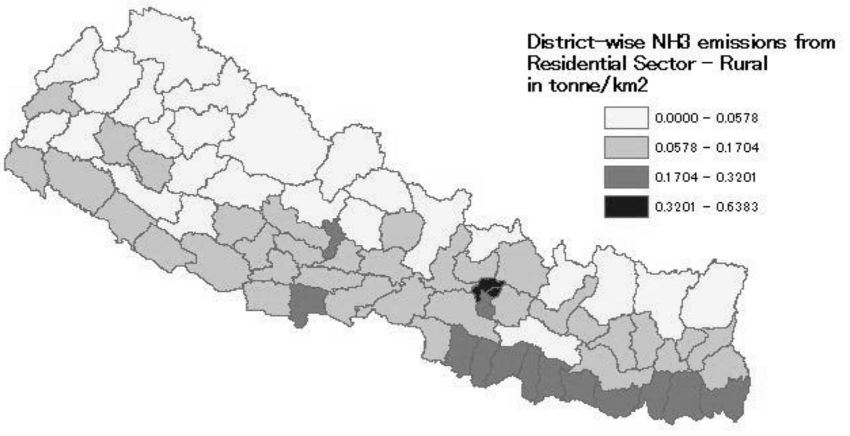
Annex 12: Spatial Variations of Emission Densities from Fuel Combustion in Rural Residential Sector



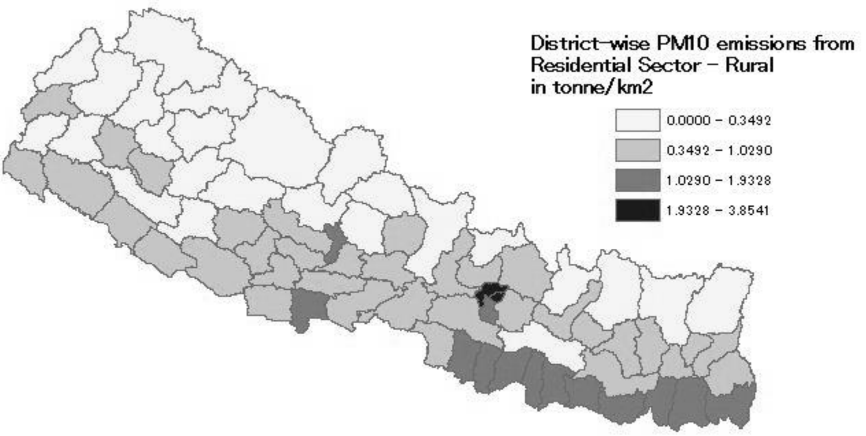
12A : NOx Emission Density



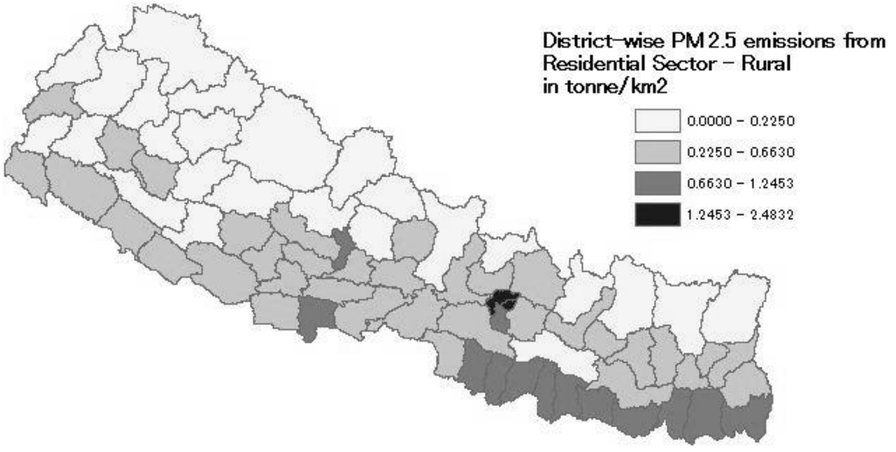
12B: CO Emission Density



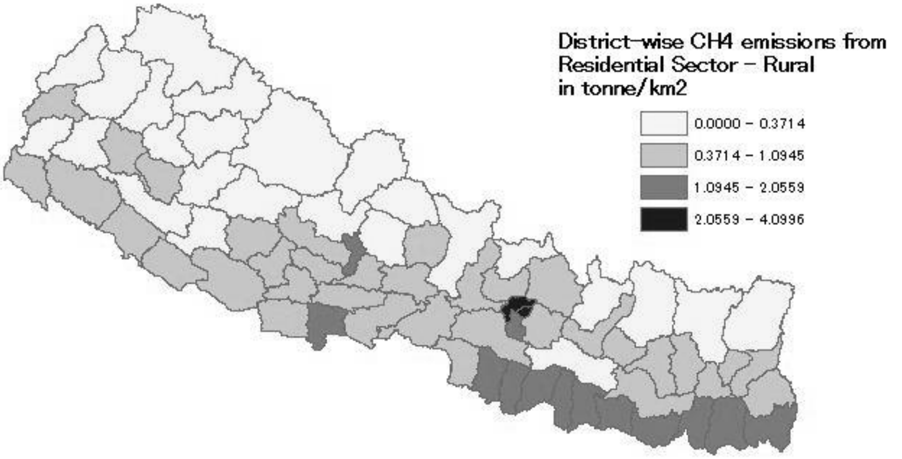
12C: NH_3 Emission Density



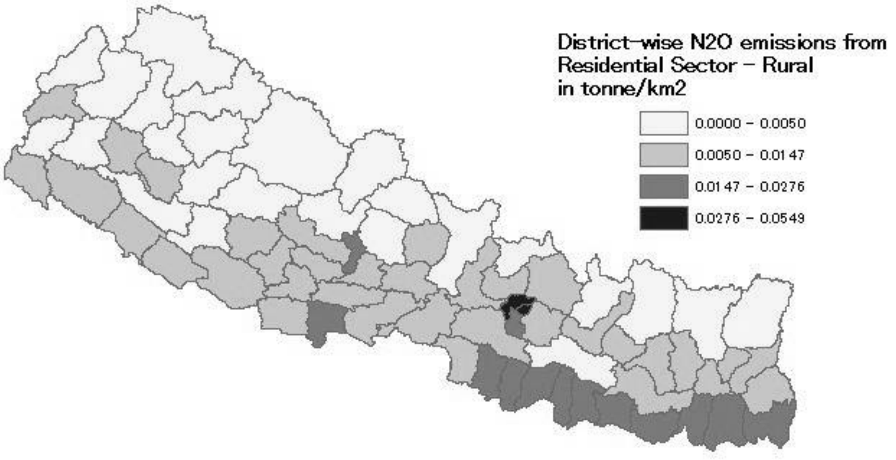
12D: PM_{10} Emission Density



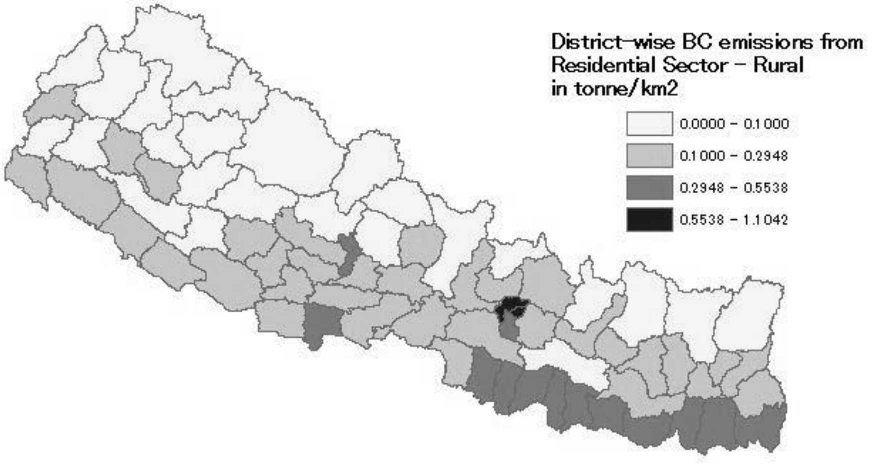
12E: $PM_{2.5}$ Emission Density



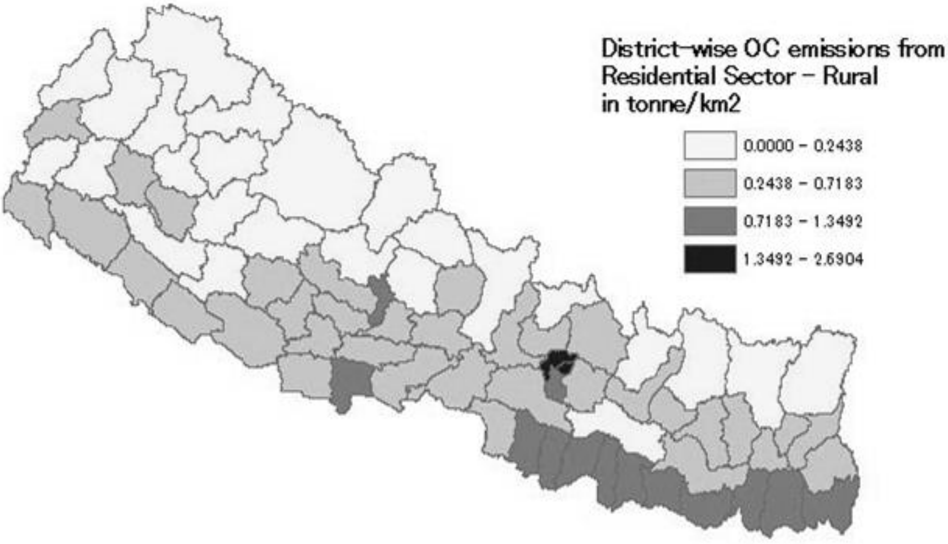
12F: CH_4 Emission Density



12G: N_2O Emission Density

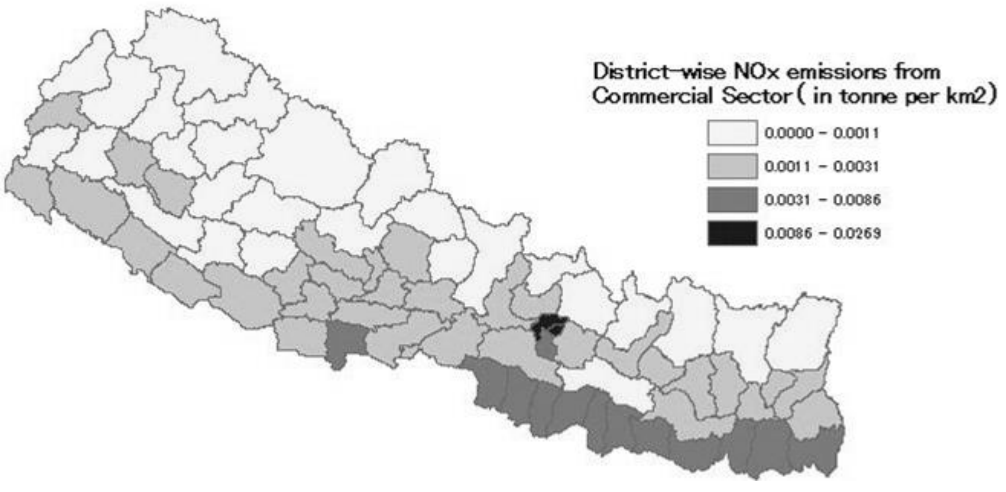


12H: BC Emission Density

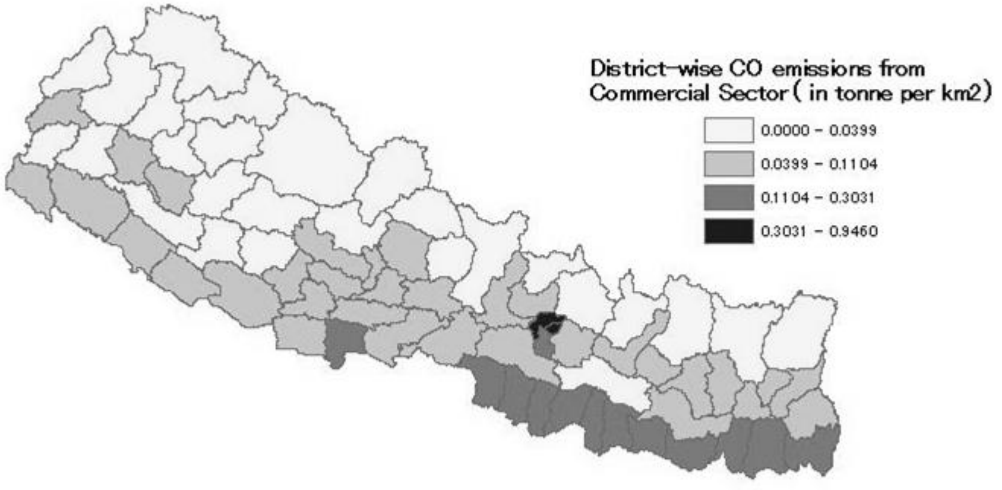


12I: OC Emission Density

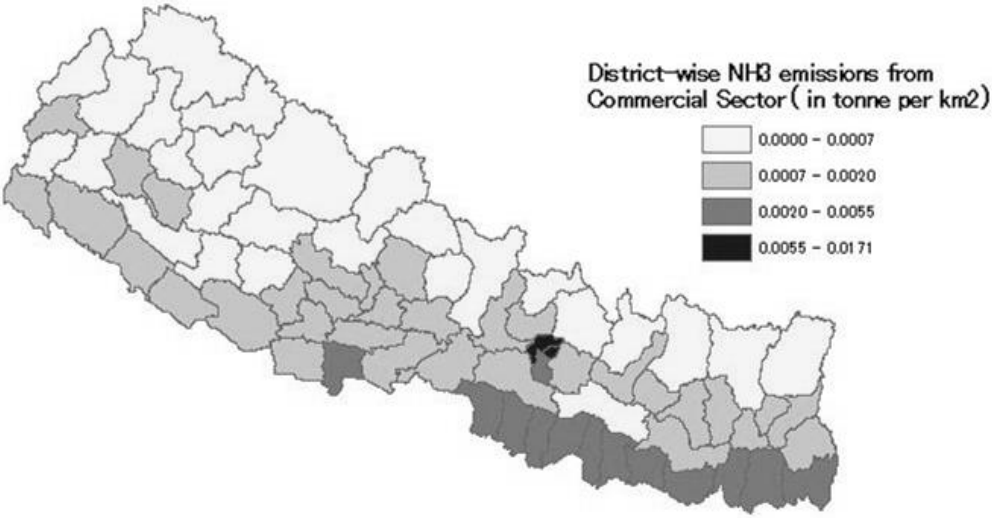
Annex 13: Spatial Variations of Emission Densities from Fuel Combustion in the Commercial Sector



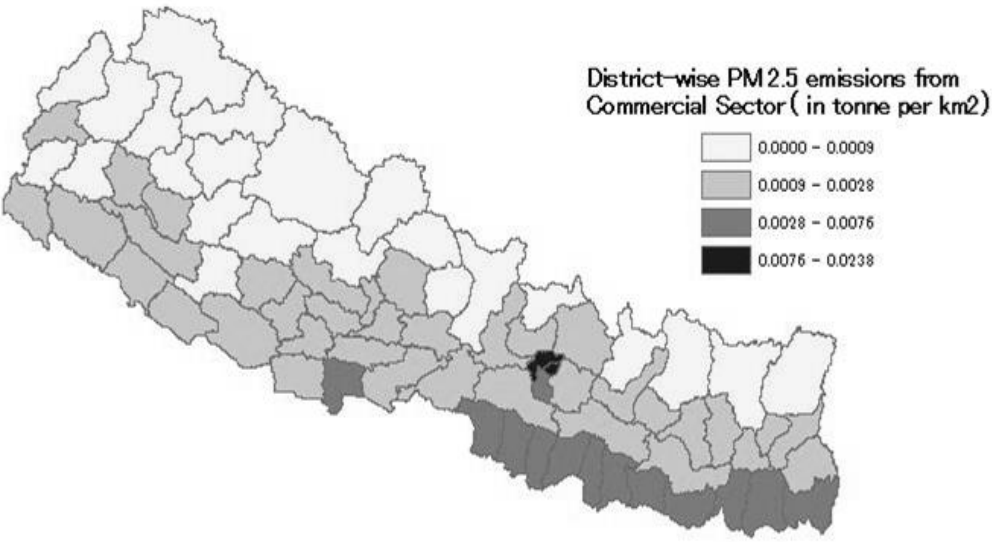
13A: NO_x Emission Density



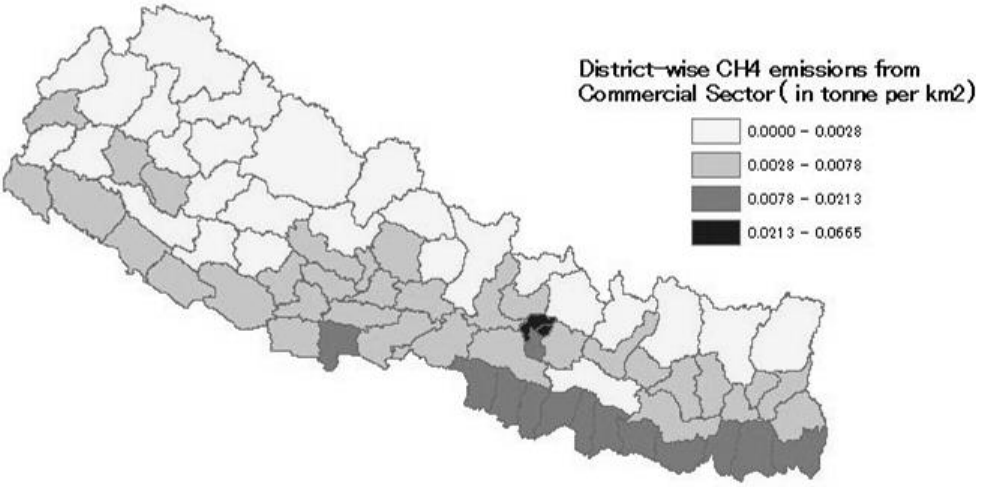
13B: CO Emission Density



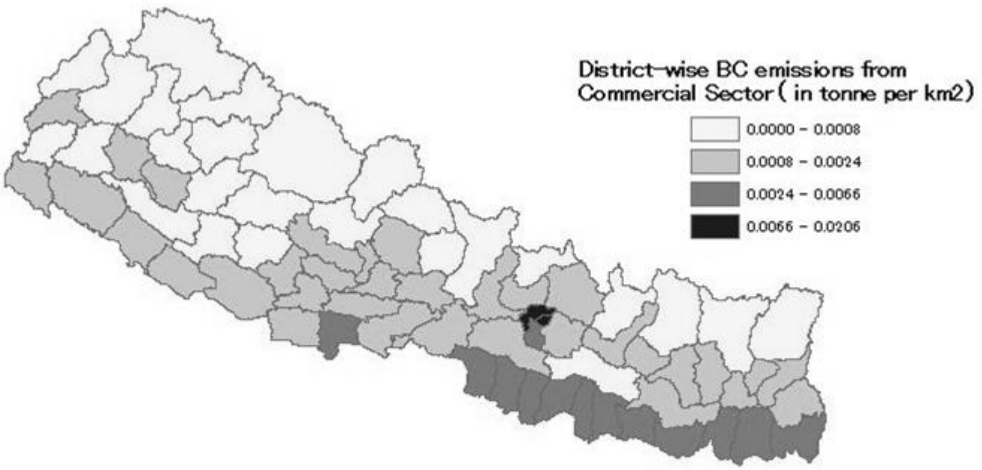
13C: NH_3 Emission Density



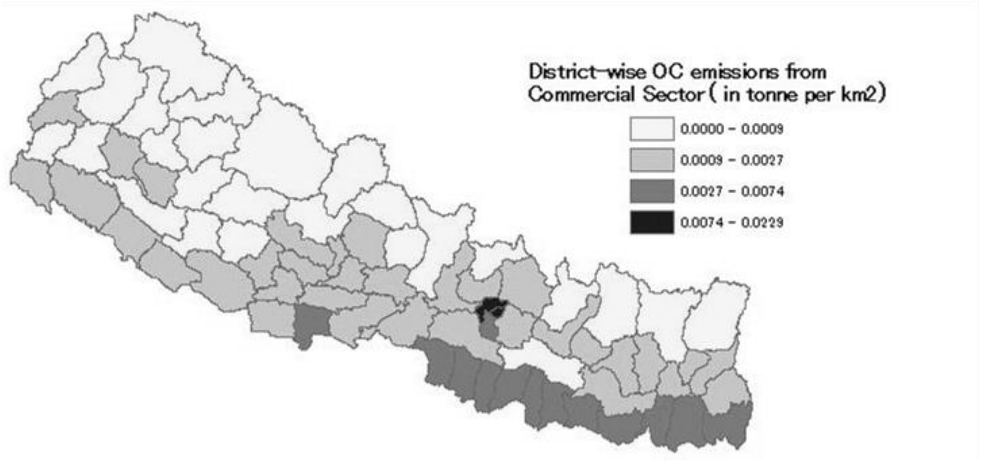
13D: $PM_{2.5}$ Emission Density



13E: CH_4 Emission Density



13F: BC Emission Density



13G: OC Emission Density

Annex 14: Region-wise Cultivated Area, Production and Yield of Cereal Crops in Nepal in 2009/10

Units: Area in thousand ha, Production in thousand metric ton and Yield in kg/thousand ha

District	Paddy			Maize			Millet			Wheat			Barley		
	A	P	Y	A	P	Y	A	P	Y	A	P	Y	A	P	Y
Eastern Region	440.7	1142.1	2.6	236.4	520.1	2.2	70.4	79.5	1.1	119.1	252.7	2.1	1.9	1.8	1.0
Eastern Mountain	23.5	40.3	1.7	39.2	78.3	2.0	15.1	15.2	1.0	7.1	8.4	1.2	0.5	0.5	1.1
Eastern Hills	87.1	201.5	2.3	141.8	308.7	2.2	49.8	58.1	1.2	27.8	47.0	1.7	1.4	1.3	1.0
Eastern Terai	330.0	900.3	2.7	55.5	133.1	2.4	5.5	6.2	1.1	84.2	197.3	2.3	0.0	0.0	0.8
Central Region	408.4	1171.9	2.9	202.2	438.8	2.2	64.0	70.2	1.1	218.8	508.1	2.3	2.6	2.7	1.0
Central Mountain	17.4	37.9	2.2	29.6	62.8	2.1	23.9	27.2	1.1	14.3	18.6	1.3	0.5	0.6	1.1
Central Hills	89.5	274.3	3.1	132.6	280.4	2.1	37.2	39.8	1.1	50.7	94.0	1.9	1.6	1.5	1.0
Central Terai	301.5	859.7	2.9	40.1	95.6	2.4	3.0	3.1	1.1	153.9	395.5	2.6	0.5	0.6	1.1
Western Region	323.6	878.9	2.7	223.2	527.0	2.4	97.0	110.4	1.1	140.2	362.1	2.6	3.9	4.5	1.1
Western Mountain	0.0	0.0	0.0	0.7	1.3	1.8	0.0	0.0	1.0	0.9	1.7	1.9	0.5	0.6	1.3
Western Hills	136.6	338.0	2.5	209.3	493.1	2.4	96.2	109.6	1.1	58.6	113.1	1.9	3.2	3.5	1.1
Western Terai	187.0	540.9	2.9	13.2	32.5	2.5	0.7	0.8	1.1	80.8	247.4	3.1	0.3	0.4	1.2
Mid-Western Region	165.1	492.8	3.0	159.1	278.8	1.8	21.5	23.9	1.1	133.6	241.6	1.8	12.7	13.9	1.1

District	Paddy			Maize			Millet			Wheat			Barley		
	A	P	Y	A	P	Y	A	P	Y	A	P	Y	A	P	Y
Mid-Western Mountain	8.2	15.5	1.9	11.9	21.0	1.8	8.4	8.6	1.0	13.4	15.2	1.1	7.3	8.3	1.1
Mid-Western Hills	47.8	135.7	2.8	107.3	207.5	1.9	12.9	15.1	1.2	72.7	109.7	1.5	5.3	5.6	1.0
Mid-Western Terai	109.1	341.6	3.1	39.9	50.4	1.3	0.2	0.2	1.1	47.5	116.7	2.5	0.1	0.1	0.9
Far-Western Region	143.5	338.1	2.4	54.6	90.5	1.7	15.6	15.5	1.0	119.4	192.1	1.6	5.5	4.7	0.9
Far-Western Mountain	13.1	20.8	1.6	10.0	15.3	1.5	6.2	5.0	0.8	16.3	18.4	1.1	3.8	3.1	0.8
Far-Western Hills	26.5	54.8	2.1	22.1	35.2	1.6	9.0	10.0	1.1	35.9	50.7	1.4	1.2	0.9	0.8
Far-Western Terai	103.9	262.5	2.5	22.5	40.0	1.8	0.5	0.5	1.0	67.3	123.0	1.8	0.6	0.7	1.2
Total Nepal	1481.3	4023.8	2.7	875.7	1855.2	2.1	268.5	299.5	1.1	731.1	1556.5	2.1	26.6	27.6	1.0

Note: A = Area, P = Production, Y = Yield

Source: MOAC (2010)

Annex 15: Region-wise Cultivated Area, Production and Yield of Cash Crops in Nepal in 2009/10

Units: Area in ha, Production in metric ton and Yield in kg/ha

District	Oilseed			Potato			Tobacco			Sugarcane		
	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield
Eastern Region	37436	26348	704	72761	952463	13090	849	820	966	7031	343753	488911
Eastern Mountain	1418	1120	790	16831	222819	13239	0	0	0	70	650	9286
Eastern Hills	9608	6399	666	28945	365091	12613	14	11	791	81	1678	207160
Eastern Terai	26410	18829	713	26985	364553	13509	835	809	969	6880	341425	496257
Central Region	59783	49738	832	56641	853581	15070	1492	1525	1022	30863	1272945	412452
Central Mountain	1277	973	762	9925	122176	12310	0	0	0	5	66	130696
Central Hills	16882	15460	916	27444	411626	14999	0	0	0	399	10611	265886
Central Terai	43215	35214	815	19272	319779	16593	1492	1525	1022	35013	1574275	449628
Western Region	24748	19845	802	22038	263341	11949	30	20	650	13972	623732	446423
Western Mountain	30	25	833	990	12255	12379	0	0	0	0	0	0
Western Hills	7073	6066	858	13798	159175	11536	0	0	0	374	10957	293154
Western Terai	17645	13754	779	7250	91911	12677	30	20	650	13598	612775	450636
Mid-Western Region	46566	37333	802	21111	263401	12477	78	62	806	2536	91138	35945

District	Oilseed			Potato			Tobacco			Sugarcane		
	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield
Mid-Western Mountain	350	191	546	5556	51290	9231	0	0	0	0	0	0
Mid-Western Hills	8812	7366	836	8392	108690	12952	0	0	0	0	0	0
Mid-Western Terai	37404	29776	796	7163	103421	14438	78	62	806	2536	91138	359447
Far-Western Region	30007	21786	726	12791	184910	14456	15	10	671	3909	163530	41834
Far-Western Mountain	613	288	469	2396	26055	10874	0	0	0	107	1822	17017
Far-Western Hills	2862	2273	794	2950	31290	10607	0	0	0	15	319	21724
Far-Western Terai	26532	19225	725	7445	127565	17134	15	10	671	3787	161388	42613
Total Nepal	**198540**	**155050**	**781**	**185342**	**2517696**	**13584**	**2534**	**2491**	**989**	**58310**	**2495098**	**42790**

Source: MOAC (2010)

Annex 16: District-wise Annual Crop Production Data for 2008/09, tonne

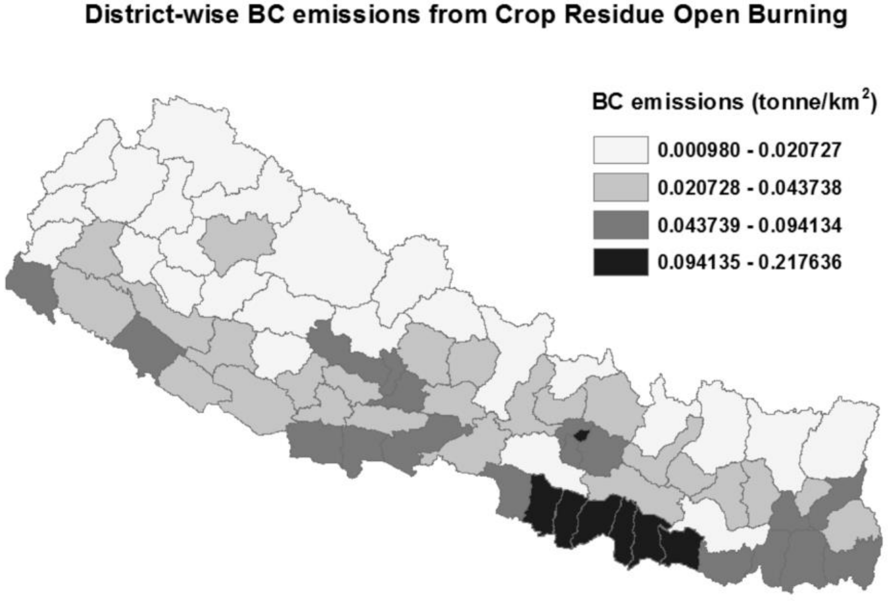
District	Paddy	Wheat	Maize	Millet	Barley	Sugarcane	Oilseed	Tobacco	Potato
Sankhuwasabha	29208	2501	29249	10082	24	616	545	0	37072
Solukhumbu	2970	4461	30173	2599	185	0	222	0	45469
Taplejung	16345	2462	29546	3612	238	0	414	0	46255
Bhojpur	37548	4292	40008	4557	33	0	223	0	34411
Dhankuta	23469	4535	52839	8067	21	758	812	0	31166
Ilam	28823	9086	59648	2921	62	445	642	0	60525
Khotang	34208	5378	55667	14178	323	136	626	0	24722
Okhaldhunga	15220	3540	25364	10228	114	38	351	0	37465
Panchthar	160925	6336	22904	7889	557	0	390	0	61861
Terhathum	20749	3694	16760	2552	96	0	177	0	24879
Udaypur	39419	9952	31888	3383	31	212	3672	10	8055
Jhapa	318308	37193	58715	2127	8	3713	2825	9	166216
Morang	278766	42456	35435	1624	0	79458	5182	57	67239
Saptari	155832	30481	8554	304	0	2368	3259	66	73200
Siraha	159280	29720	5226	810	0	77796	706	598	18525
Sunsari	169236	34884	14672	1369	0	127883	4480	85	59907
Dolakha	6435	6413	11198	3585	190	146	244	0	29808
Rasuwa	3361	1283	4666	1170	357	9	101	0	24511
Sindhupalchowk	33497	15818	48993	19747	0	303	1110	0	45469
Bhaktapur	28771	9557	6679	142	41	0	322	0	23296
Dhading	42777	8099	34735	7712	287	3471	388	0	23015
Kathmandu	43592	15134	17109	881	7	0	55	0	46199
Kavre	36509	18853	57692	3544	612	237	4137	0	105703
Lalitpur	23064	7775	1918	796	232	0	1665	0	20702
Makawanpur	38038	10241	44944	3276	91	2463	1166	0	67138
Nuwakot	58819	10770	39443	7899	2	2842	621	0	27226

District	Paddy	Wheat	Maize	Millet	Barley	Sugarcane	Oilseed	Tobacco	Potato
Ramechhap	16049	7763	47713	6145	163	663	300	0	34164
Sindhuli	11349	9345	40120	11294	45	1705	4798	0	17907
Bara	209518	79502	6128	81	55	74021	3126	90	146709
Chitwan	107657	20178	61858	1833	310	426	5852	0	34242
Dhanusa	164622	55148	2955	405	0	113390	2220	427	28966
Mahaottari	117129	39753	6076	388	41	106096	2573	361	48955
Parsa	172648	62223	13021	81	28	14493	5135	107	22426
Rautahat	115964	32755	5029	57	43	286671	8314	28	46682
Sarlahi	91666	53639	15862	122	41	453180	3027	548	22120
Manang	0	547	378	3	201	0	20	0	8891
Mustang	0	1368	827	4	509	0	25	0	2591
Argakhanchi	14768	11474	29396	861	422	0	1397	0	8207
Baglung	12381	9224	46826	23350	1260	663	712	0	17213
Gorkha	48990	6395	50963	13975	215	727	355	0	31165
Gulmi	24127	12440	41119	3750	446	648	399	0	7101
Kaski	51756	13475	39308	19656	122	4926	370	0	13023
Lamjung	33959	6618	39692	7607	22	477	610	0	21196
Myagdi	9521	5079	26490	3806	517	322	16	0	18143
Palpa	24134	10388	49285	2536	27	743	530	0	9723
Parbat	19764	3916	31908	7058	186	152	233	0	16302
Syangja	48878	12996	89923	20578	91	182	167	0	15965
Tanahu	53645	3411	62088	6279	6	587	375	0	11083
Kapilbastu	157350	58482	2727	142	87	214323	2320	19	28180
Nawalparasi	151996	39758	25818	506	108	298394	3582	9	17379
Rupandehi	221526	83919	2333	91	25	121252	3834	5	64668
Dolpa	481	2351	4050	256	165	0	15	0	5928
Humla	927	829	145	1104	786	0	41	0	5490
Jumla	4934	2673	7103	4456	3242	0	96	0	21343

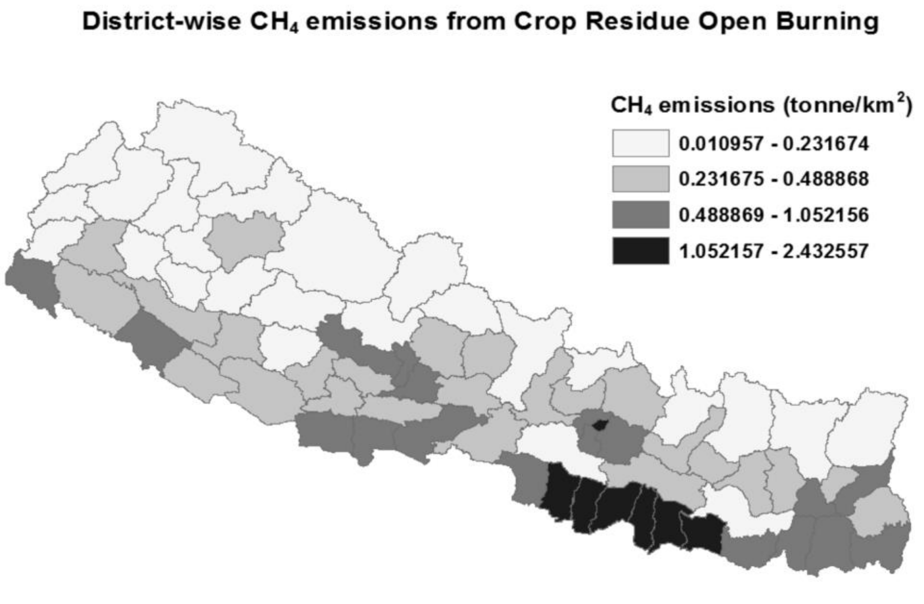
District	Paddy	Wheat	Maize	Millet	Barley	Sugarcane	Oilseed	Tobacco	Potato
Mugu	1818	2223	1037	1570	1098	0	14	0	5434
Kalikot	4685	6626	3059	1382	868	0	78	0	12468
Dailekh	20879	8673	30106	2758	103	0	410	0	8858
Jajarkot	7130	11426	17119	2896	686	0	252	0	8566
Pyuthan	15563	14223	18828	2010	641	0	580	0	9543
Rolpa	9845	12053	18145	1188	457	0	61	0	17419
Rukum	8234	14125	32682	1519	679	0	429	0	28939
Salyan	16915	17357	41720	2320	1034	0	706	0	20742
Surkhet	39152	27873	43881	2759	1023	0	2796	0	12270
Dang	118124	24881	58215	162	25	12788	11996	4	30118
Banke	96860	37321	11406	0	8	1421	3943	38	34972
Bardia	123087	42425	16503	0	8	77298	8979	24	50718
Surkhet	39152	27873	43881	2759	1023	0	2796	0	12270
Dang	118124	24881	58215	162	25	12788	11996	4	30118
Banke	96860	37321	11406	0	8	1421	3943	38	34972
Bardia	123087	42425	16503	0	8	77298	8979	24	50718
Bajhang	9370	7828	6492	2198	1063	426	54	0	8083
Bajura	6216	6094	1720	2684	982	1859	202	0	4637
Darchula	7618	8123	11375	1003	739	469	66	0	7691
Accham	15237	7695	9197	2449	165	0	110	0	5034
Baitadi	9839	5558	17907	962	414	0	177	0	7679
Dadeldhura	14578	10125	6168	322	165	0	356	0	7444
Doti	17869	13731	5205	2642	252	275	368	0	142583
Kailali	152777	40356	35409	203	132	115569	14327	9	44285
Kanchanpur	136990	44588	11328	182	8	147374	4814	0	20770
Total Nepal	4523693	1343862	1930669	292683	23224	2354412	135494	2497	2424048

Source: CBS (2009)

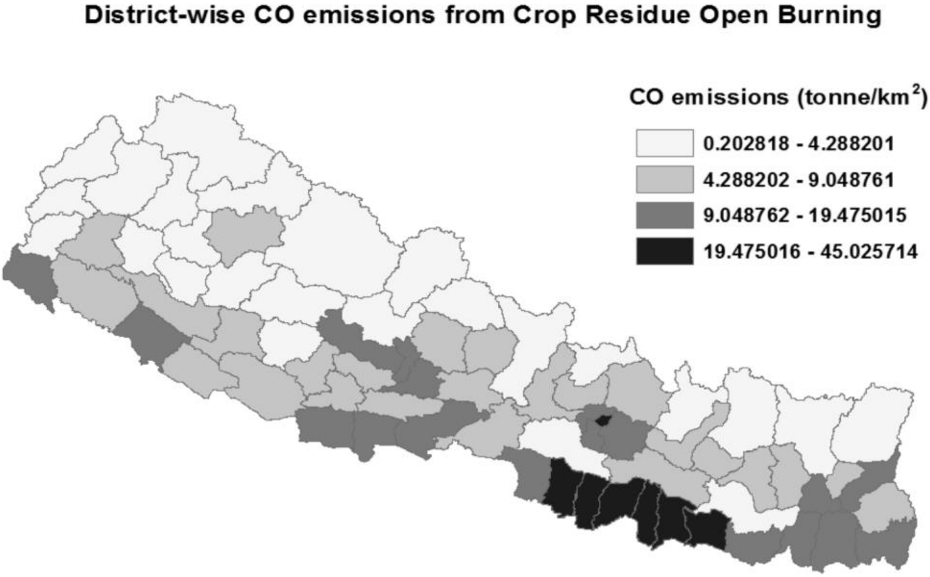
Annex 17: Spatial Variations of Emission Densities from Crop Residue Open Burning



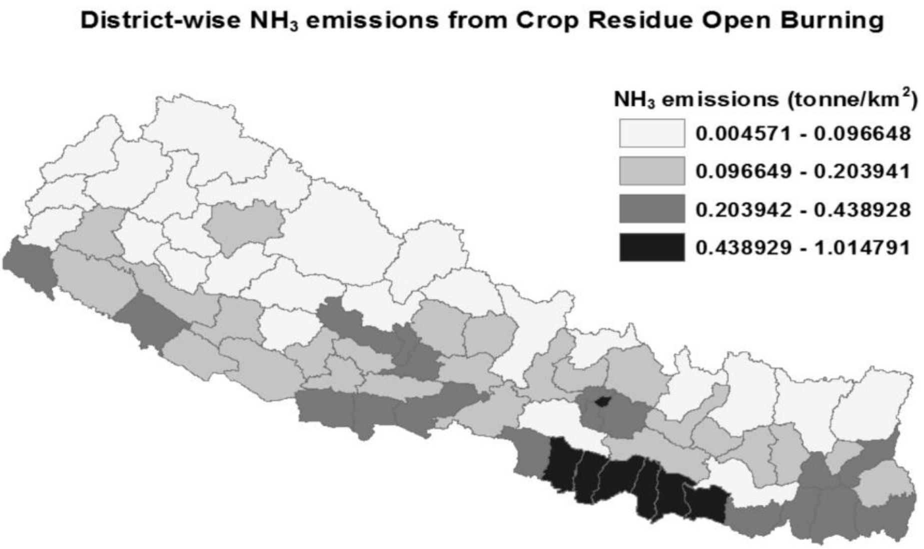
17A: BC Emission Density



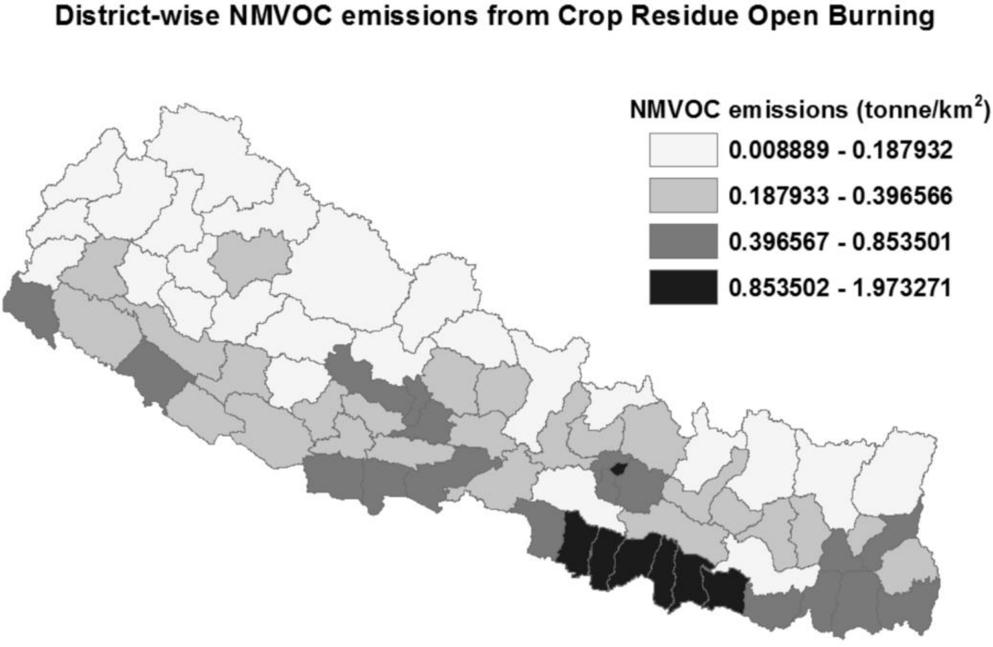
17B: CH_4 Emission Density



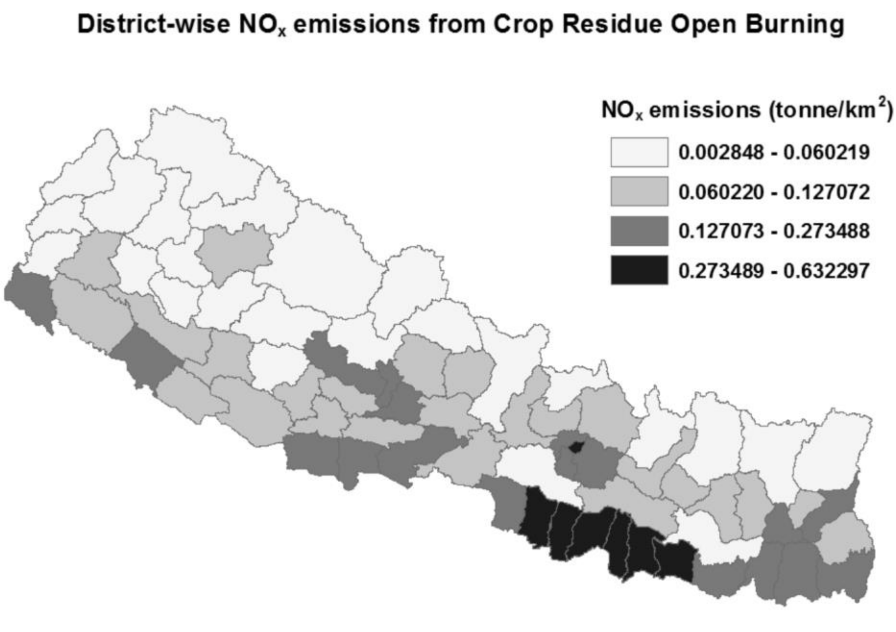
17C: CO Emission Density



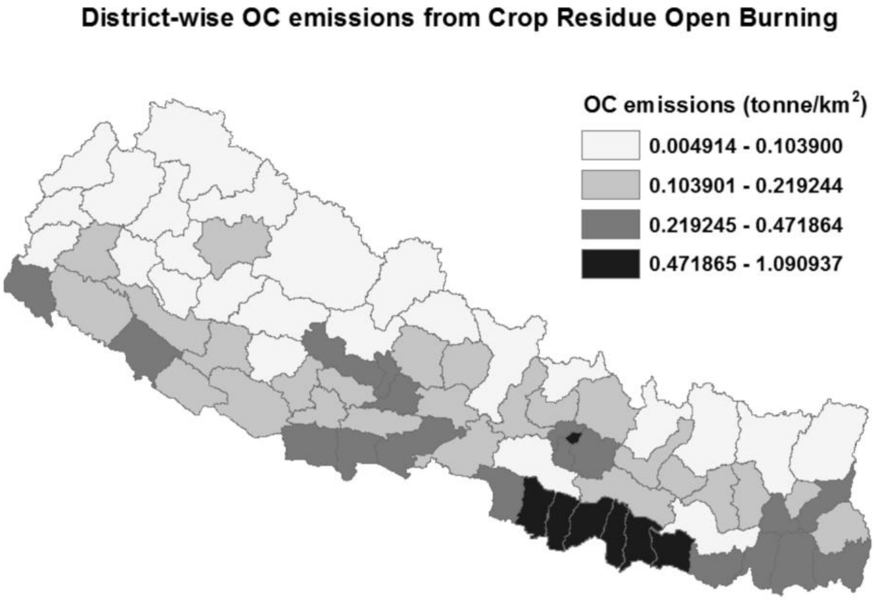
17D: NH_3 Emission Density



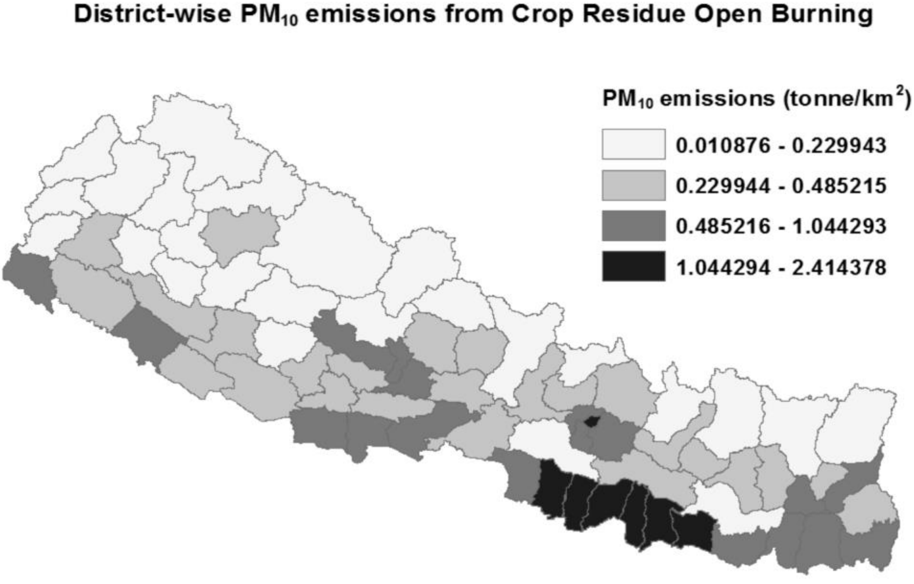
17E: NMVOC Emission Density



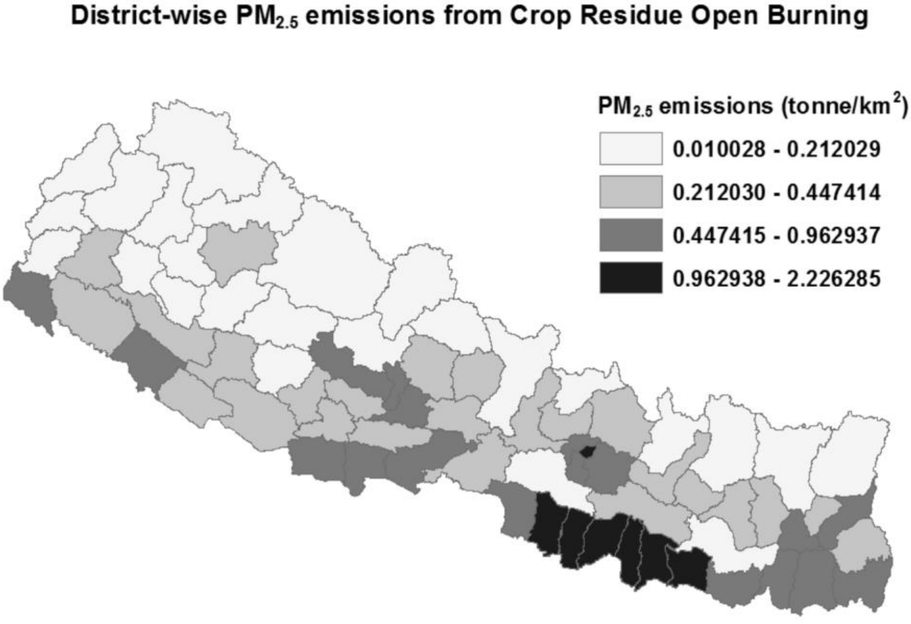
17F: NO_x Emission Density



17G: OC Emission Density

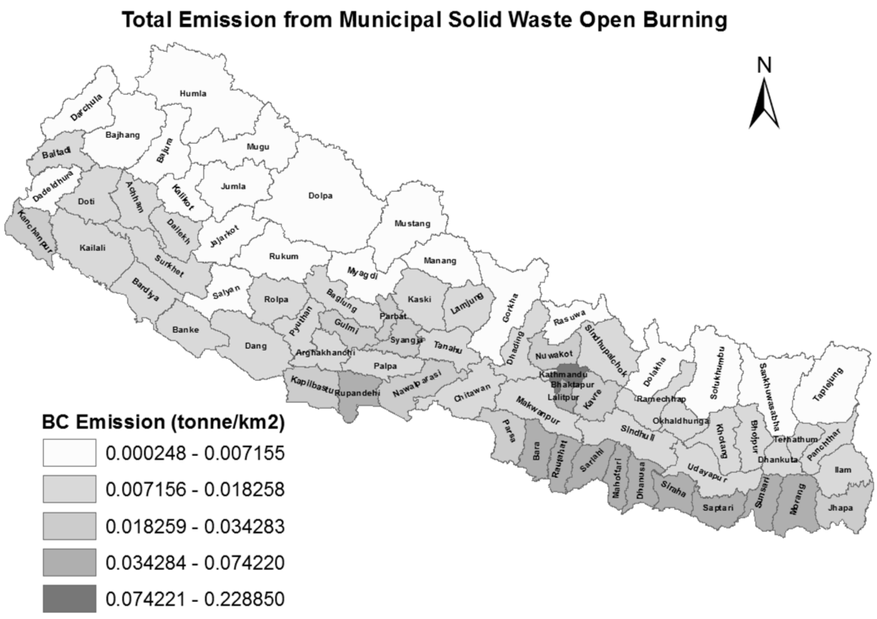


17H: PM_{10} Emission Density

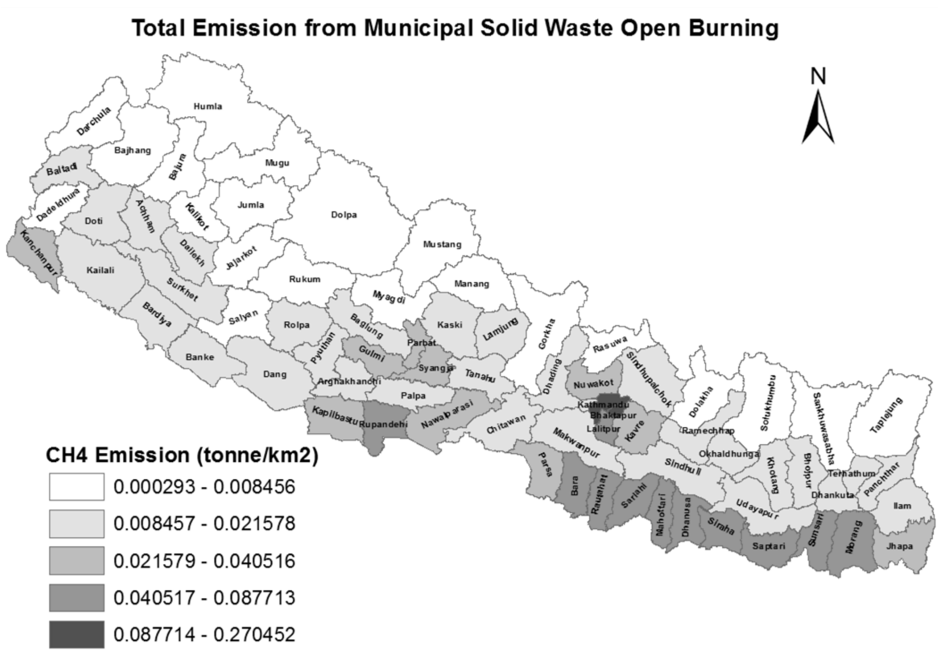


17l: $PM_{2.5}$ Emission Density

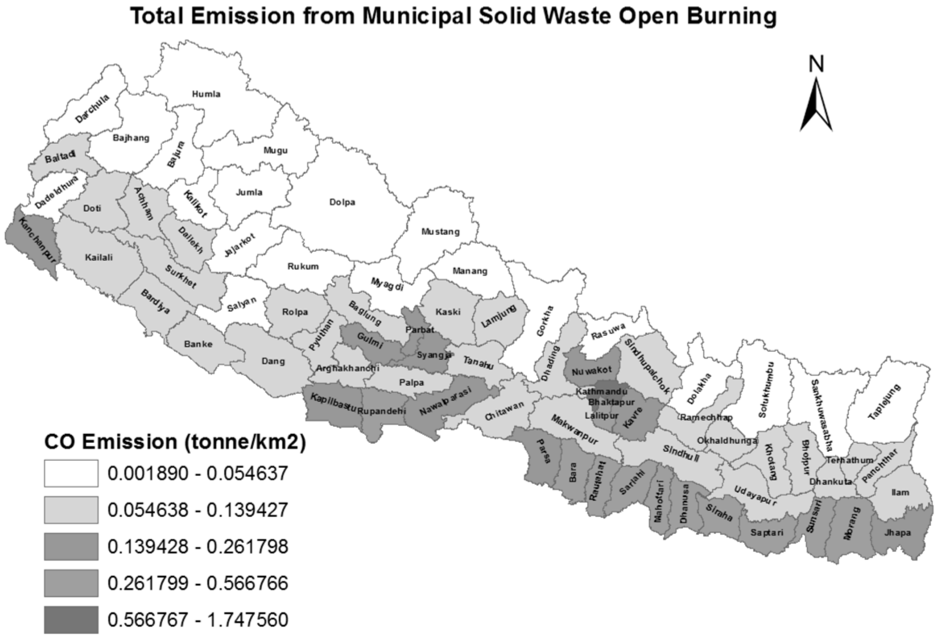
Annex 18: Spatial Variations of Emission Densities from the Municipal Solid Waste Open Burning (both at Source and Disposal Site)



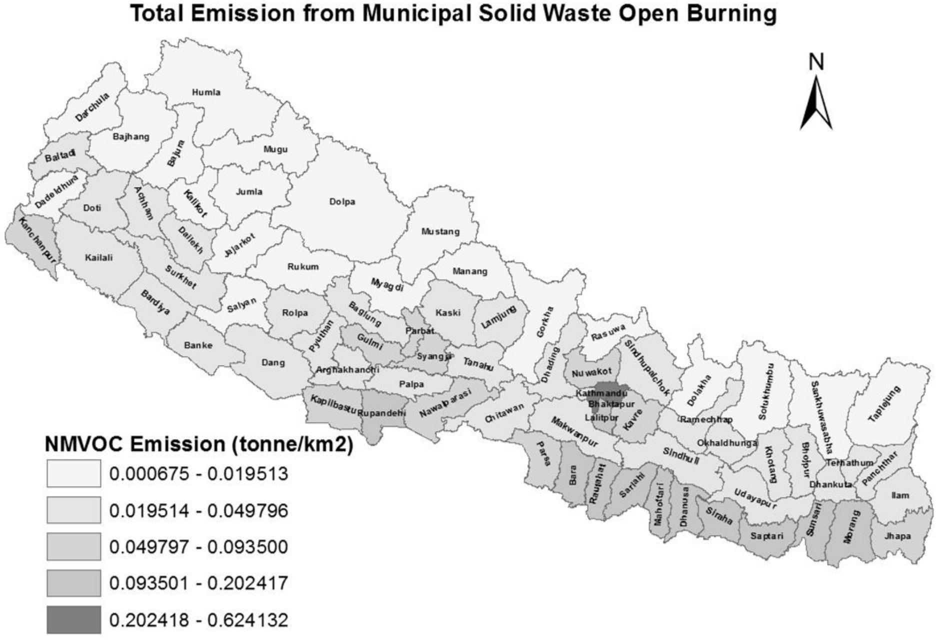
18A: BC Emission Density



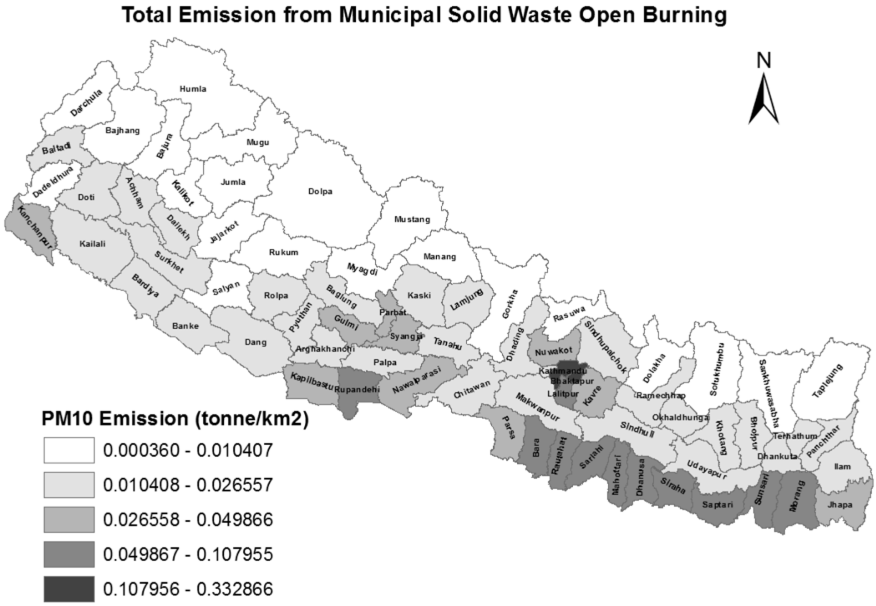
18B: CH_4 Emission Density



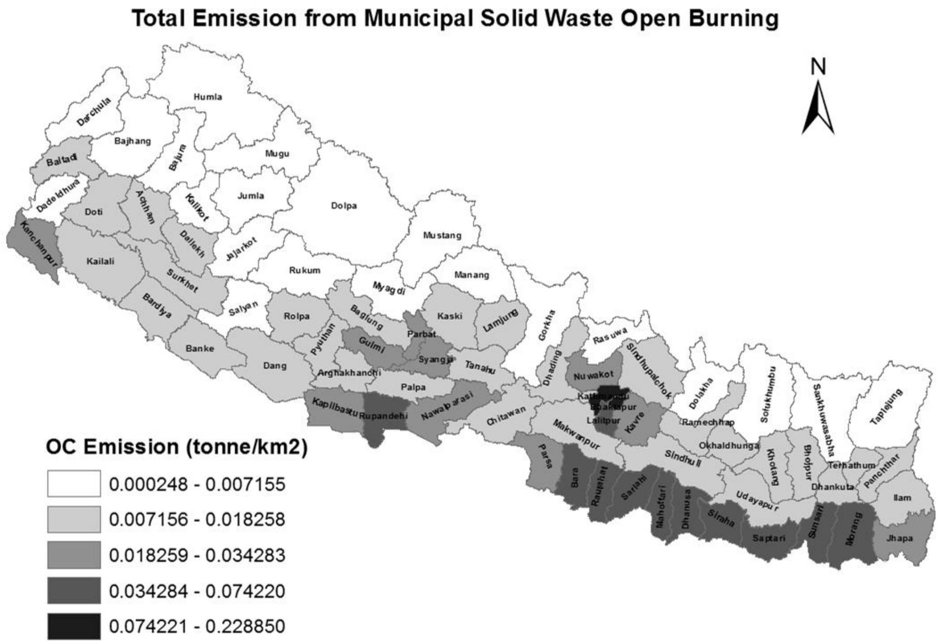
18C: CO Emission Density



18D: NMVOC Emission Density



18E: PM_{10} Emission Density



18F: OC Emission Density

Annex 19: District-wise Methane Emissions from the Solid Waste Disposed at the Landfill Sites, tonne

Districts	CH_4	Districts	CH_4	Districts	CH_4
Sankhuwasabha	2.68	Ramechhap	3.58	Dolpa	0.37
Solukhumbu	1.81	Sindhuli	4.67	Humla	0.68
Taplejung	2.27	Bara	9.42	Jumla	1.17
Bhojpur	3.42	Chitwan	7.95	Mugu	0.53
Dhankuta	2.80	Dhanusa	11.31	Kalikot	0.19
Ilam	4.76	Mahaottari	9.32	Dailekh	3.79
Khotang	3.90	Parsa	8.38	Jajarkot	2.27
Okhaldhunga	2.64	Rautahat	9.18	Pyuthan	3.58
Panchthar	3.40	Sarlahi	10.71	Rolpa	3.54
Terhathum	1.91	Manang	0.16	Rukum	3.17
Udaypur	4.85	Mustang	0.25	Salyan	1.02
Jhapa	10.66	Argakhanchi	3.51	Surkhet	4.55
Morang	14.20	Baglung	4.53	Dang	7.79
Saptari	9.61	Gorkha	4.85	Banke	6.50
Siraha	9.60	Gulmi	5.00	Bardia	6.45
Sunsari	10.54	Kaski	6.41	Bajhang	2.81
Dolakha	2.96	Lamjung	2.98	Bajura	1.70
Rasuwa	0.75	Myagdi	1.93	Darchula	2.06
Sindhupalchowk	4.95	Palpa	4.52	Accham	3.90
Bhaktapur	3.80	Parbat	2.66	Baitadi	3.95
Dhading	5.70	Syangja	5.35	Dadeldhura	2.13
Kathmandu	18.22	Tanahu	5.31	Doti	3.49
Kavre	6.50	Kapilbastu	8.12	Kailali	10.39
Lalitpur	5.69	Nawalparasi	9.48	Kanchanpur	6.37
Makawanpur	6.61	Rupandehi	11.93	Total	383.00

Annex 20: District-wise Annual Emissions from the Solid Waste Incineration Sector, tonne

Districts	Air Pollutants							GHGs	
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	N_2O	CO_2
Sankhuwasabha	9.80	5.66	33.98	5.07	44.53	0.01	0.00	0.03	277.92
Solukhumbu	6.63	3.83	22.98	3.43	30.12	0.01	0.00	0.02	187.99
Taplejung	8.29	4.79	28.75	4.29	37.68	0.01	0.00	0.02	235.14
Bhojpur	12.50	7.21	43.33	6.46	56.79	0.02	0.00	0.04	354.41
Dhankuta	10.25	5.92	35.53	5.30	46.57	0.01	0.00	0.03	290.62
Ilam	17.41	10.05	60.36	9.01	79.11	0.02	0.00	0.05	493.70
Khotang	14.25	8.22	49.39	7.37	64.72	0.02	0.00	0.04	403.93
Okhaldhunga	9.65	5.57	33.45	4.99	43.83	0.01	0.00	0.03	273.56
Panchthar	12.44	7.18	43.13	6.43	56.52	0.02	0.00	0.04	352.73
Terhathum	6.96	4.02	24.14	3.60	31.64	0.01	0.00	0.02	197.46
Udaypur	17.71	10.22	61.40	9.16	80.47	0.03	0.00	0.05	502.22
Jhapa	38.98	22.50	135.12	20.16	177.08	0.06	0.00	0.11	1105.11

Districts	Air Pollutants							GHGs	
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	N_2O	CO_2
Morang	51.92	29.97	179.98	26.85	235.87	0.07	0.00	0.15	1472.01
Saptari	35.11	20.27	121.72	18.16	159.52	0.05	0.00	0.10	995.54
Siraha	35.09	20.25	121.64	18.15	159.41	0.05	0.00	0.10	994.84
Sunsari	38.52	22.23	133.54	19.92	175.00	0.06	0.00	0.11	1092.17
Dolakha	10.83	6.25	37.55	5.60	49.21	0.02	0.00	0.03	307.09
Rasuwa	2.75	1.59	9.55	1.42	12.51	0.00	0.00	0.01	78.09
Sindhupalchowk	18.09	10.44	62.69	9.35	82.16	0.03	0.00	0.05	512.75
Bhaktapur	13.88	8.01	48.12	7.18	63.07	0.02	0.00	0.04	393.59
Dhading	20.85	12.03	72.28	10.78	94.73	0.03	0.00	0.06	591.20
Kathmandu	66.61	38.45	230.91	34.45	302.61	0.10	0.00	0.19	1888.58
Kavre	23.75	13.71	82.32	12.28	107.88	0.03	0.00	0.07	673.27
Lalitpur	20.80	12.00	72.10	10.76	94.49	0.03	0.00	0.06	589.67
Makawanpur	24.17	13.95	83.80	12.50	109.82	0.03	0.00	0.07	685.37

Districts	Air Pollutants							GHGs	
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	N_2O	CO_2
Nuwakot	17.76	10.25	61.57	9.19	80.69	0.03	0.00	0.05	503.60
Ramechhap	13.08	7.55	45.34	6.76	59.41	0.02	0.00	0.04	370.80
Sindhuli	17.07	9.85	59.18	8.83	77.56	0.02	0.00	0.05	484.01
Bara	34.43	19.87	119.34	17.80	156.40	0.05	0.00	0.10	976.09
Chitwan	29.07	16.78	100.75	15.03	132.04	0.04	0.00	0.08	824.06
Dhanusa	41.34	23.86	143.30	21.38	187.79	0.06	0.00	0.12	1172.00
Mahaottari	34.08	19.67	118.14	17.62	154.82	0.05	0.00	0.10	966.22
Parsa	30.62	17.67	106.13	15.83	139.08	0.04	0.00	0.09	868.00
Rautahat	33.57	19.37	116.35	17.36	152.48	0.05	0.00	0.10	951.64
Sarlahi	39.14	22.59	135.68	20.24	177.82	0.06	0.00	0.11	1109.75
Manang	0.59	0.34	2.05	0.31	2.68	0.00	0.00	0.00	16.74
Mustang	0.92	0.53	3.20	0.48	4.19	0.00	0.00	0.00	26.15
Argakhanchi	12.83	7.41	44.48	6.64	58.29	0.02	0.00	0.04	363.79

Districts	Air Pollutants							GHGs	
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	N_2O	CO_2
Baglung	16.56	9.56	57.40	8.56	75.23	0.02	0.00	0.05	469.48
Gorkha	17.74	10.24	61.50	9.17	80.60	0.03	0.00	0.05	503.00
Gulmi	18.27	10.54	63.32	9.45	82.98	0.03	0.00	0.05	517.87
Kaski	23.43	13.52	81.22	12.12	106.44	0.03	0.00	0.07	664.29
Lamjung	10.91	6.30	37.81	5.64	49.55	0.02	0.00	0.03	309.25
Myagdi	7.05	4.07	24.43	3.64	32.01	0.01	0.00	0.02	199.79
Palpa	16.54	9.54	57.32	8.55	75.12	0.02	0.00	0.05	468.82
Parbat	9.72	5.61	33.69	5.03	44.15	0.01	0.00	0.03	275.52
Syangja	19.54	11.28	67.73	10.10	88.76	0.03	0.00	0.06	553.95
Tanahu	19.41	11.20	67.28	10.04	88.18	0.03	0.00	0.06	550.31
Kapilbastu	29.68	17.13	102.87	15.35	134.82	0.04	0.00	0.08	841.39
Nawalparasi	34.66	20.00	120.14	17.92	157.45	0.05	0.00	0.10	982.61
Rupandehi	43.62	25.18	151.21	22.56	198.16	0.06	0.00	0.12	1236.69

Districts	Air Pollutants							GHGs	
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	N_2O	CO_2
Dolpa	1.36	0.78	4.71	0.70	6.17	0.00	0.00	0.00	38.53
Humla	2.50	1.44	8.66	1.29	11.36	0.00	0.00	0.01	70.87
Jumla	4.26	2.46	14.78	2.20	19.36	0.01	0.00	0.01	120.85
Mugu	1.94	1.12	6.72	1.00	8.80	0.00	0.00	0.01	54.93
Kalikot	0.71	0.41	2.46	0.37	3.22	0.00	0.00	0.00	20.09
Dailekh	13.87	8.00	48.07	7.17	62.99	0.02	0.00	0.04	393.13
Jajarkot	8.30	4.79	28.79	4.29	37.73	0.01	0.00	0.02	235.44
Pyuthan	13.08	7.55	45.35	6.77	59.44	0.02	0.00	0.04	370.93
Rolpa	12.93	7.46	44.82	6.69	58.74	0.02	0.00	0.04	366.61
Rukum	11.60	6.70	40.22	6.00	52.71	0.02	0.00	0.03	328.96
Salyan	3.73	2.16	12.94	1.93	16.96	0.01	0.00	0.01	105.86
Surkhet	16.62	9.59	57.60	8.59	75.49	0.02	0.00	0.05	471.11
Dang	28.47	16.43	98.69	14.72	129.34	0.04	0.00	0.08	807.18

Districts	Air Pollutants							GHGs	
	SO_2	NO_X	CO	NMVOC	PM_{10}	BC	OC	N_2O	CO_2
Banke	23.76	13.71	82.35	12.29	107.93	0.03	0.00	0.07	673.56
Bardia	23.56	13.60	81.67	12.18	107.03	0.03	0.00	0.07	667.99
Bajhang	10.28	5.94	35.65	5.32	46.72	0.01	0.00	0.03	291.58
Bajura	6.20	3.58	21.48	3.20	28.15	0.01	0.00	0.02	175.66
Darchula	7.51	4.34	26.04	3.88	34.12	0.01	0.00	0.02	212.97
Accham	14.24	8.22	49.37	7.36	64.70	0.02	0.00	0.04	403.76
Baitadi	14.43	8.33	50.03	7.46	65.57	0.02	0.00	0.04	409.22
Dadeldhura	7.77	4.48	26.93	4.02	35.29	0.01	0.00	0.02	220.24
Doti	12.75	7.36	44.20	6.59	57.92	0.02	0.00	0.04	361.48
Kailali	37.97	21.92	131.63	19.64	172.50	0.05	0.00	0.11	1076.57
Kanchanpur	23.27	13.43	80.66	12.03	105.71	0.03	0.00	0.07	659.70
Total	1400.00	808.00	4853.00	724.00	6360.00	2.00	0.10	4.00	39692.00

Annex 21: Fuel Quality Data

Fuel Type	Net Calorific Value (TJ/ton)[a]	Sulfur Retention in Ash, αs (%)[d]	Sulfur Content, CSfuel (%)[b]	Ash Content in Fuel A (%)[b]
Sub-bituminous coal	0.0251	5	1.27, 2.7-7.8[f]	11.46
Bituminous and Anthracite (Steam/Slack Coal)			1[g]	
Lignite (Assam Coal)			4[g]	
Derived Coal (Breeze/Soft Coal)			0.5[g]	
Natural gas	0.05	0	0.00064	0
Diesel oil	0.043	0	0.54; 1.0[e]	0.03
Heavy fuel oil	0.040	0	2.46	0.03
Woodc	0.015	0	0.04	23
Crude oil	0.0419	0	2.46	0.01
Gasoline	0.045	0	0.011, 0.046[g]	0.001
Kerosene	0.04475	0	0.09, 0.16[g]	0.005
Diesel oil	0.04333	0	0.54, 0.25[g]	0.03
Heavy fuel oil	0.04019	0	2.46, 0.3[g]	0.03

Sources: a. OECD/IEA (1998); b. JICA (1997); c. IPCC (1996); d. US EPA (1995); e. Indian Oil Corporation Ltd. (http://www.iocl.com/Products/LightDieseloil.aspx); f. Barooah and Baruah (1996); g. http://www.rrcap.unep.org/male/baseline/Baseline/Nepal/NEPCH3.htm

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EMISSIONS OF AIR POLLUTANTS AND GREENHOUSE GASES IN NEPAL

AN INTEGRATED INVENTORY

Ram M. Shrestha

Most developing countries are facing the problem of rapidly increasing air pollution and greenhouse gas (GHG) emissions. However, most developing countries lack systematic and comprehensive assessments of the emissions of air pollutants and GHGs. This study has carried out detailed estimation of emissions of air pollutants and GHGs (including both short- and long-lived climate forcers) in Nepal. It presents an integrated inventory of the emissions from energy combustion in different sectors, open burning activities, industrial processes, solid waste management and other sources, and discusses their implications for policymaking on air pollution control and GHG mitigation in Nepal.

The integrated emission inventory in this book should be of significant interest to policy makers, researchers and other stakeholders engaged in environmental management and GHG mitigation in Nepal; it could also be of interest to researchers and organizations involved in the preparation of emission inventories in other developing countries.

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