AIR POLLUTION EMISSION INVENTORY OF PUNJAB, PAKISTAN (1990-2020)

The Urban Unit
Urban Sector Planning & Management Services Unit (Pvt.) Ltd.

SUPARCO

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List of Acronyms

AQI	Air Quality Index
BC	Black Carbon
CAMx	Comprehensive Air Quality Model with Extension
CH_4	Methane
CO	Carbon Monoxide
EDGAR	Emission Database for Global Atmospheric Research
EEA	European Environment Agency
EI	Emission Inventory
EMEP	European Monitoring and Evaluation Program
FAO	Food and Agriculture Organization
GAINS	Greenhouse Gas Air Pollution Interactions and Synergies
GAPF	Global Atmospheric Pollution Forum
IPCC	Intergovernmental Panel on Climate Change
µm	micrometer
NCIP	Non-Combustion Industrial Process
NOx	Oxides of Nitrogen
O_3	Ozone
$PM_{2.5}$	Particulate matter with diameter 2.5 micrometer and smaller
PM_{10}	Particulate matter with diameter 10 micrometer and smaller
REAS	Regional Emission Inventory in Asia
SO_2	Sulfur dioxide
Sq.km	Kilometer square
UN	United Nations
VOC	Volatile Organic Compound
WHO	World Health Organization

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

> Quantifying air pollution and greenhouse gas emissions in the country, particularly in densely populated areas such as Punjab, is an initial step in devising multifaceted, economically feasible and sustainable solutions to deal with the severity of this problem.

It is being recognized in Pakistan, that increasing and unchecked air pollution is causing environmental disasters like smog, melting of glaciers and affecting human health. In the absence of a robust mechanism for continuous monitoring of air pollutants, air emission inventories could be the foundation towards quantifying the emission load of air pollutants, identifying key sources of pollution, and formulating targeted mitigation strategies / policies. The objective of this emission inventory report is to provide the essential estimates of atmospheric load of selected anthropogenic pollutants and their main source contributors in Punjab province of Pakistan. For the first time, a comprehensive emissions inventory from 1990–2020 has been developed for anthropogenic emissions in Punjab by using Greenhouse Gas Air Pollution Interactions and Synergy model (GAINS - South Asia). This emission inventory embodies information on emissions of particulate matter ($PM_{2.5}$ & PM_{10}), and gaseous pollutants (NOx, SO_2, CO, and VOCs) from key sectors including transport, industry, energy, agriculture and others. Due to unavailability of country specific and technology specific emission factors, 'Tier 1' approach is adopted whereas emission estimates of air pollutants are based on Business-as-usual (BAU) scenario in GAINS model.

The cumulative emission load of selected air pollutants ($PM_{2.5}$ & PM_{10}, NOx, SO_2, CO, and VOCs) in the year 2020 is estimated as 7017 kT/Y which is 3.5 times higher than the emissions in 1990. Combustion processes in the energy, industrial, transport and agricultural sectors collectively accounts for 88% of total emissions whereas 12% emission load is estimated from non-combustion industrial processes (NCIP) and miscellaneous sectors including handling, refining, storage of chemicals; mining; wood processing; live stocks; and dairy / poultry etc.). Among four key sectors, transport sector contributes the highest emission load (2763 kT/Y with 39% share), followed by industry (1719 kT/Y, 24%), energy (1103 kT/Y, 16%) and agriculture (739 kT/Y, 11%) in year 2020. Transport sector is estimated as the major contributor of CO, NOx and VOC. The energy sector is noted as potential emitter of SO_2 while industry sector has a major share in PM_{10} and $PM_{2.5}$ emissions. Considering the contribution of individual pollutant in emission estimates, CO (3773 kT/Y) is found to have a largest share followed by PM_{10} (1156 kT/Y), NOx (617 kT/Y), $PM_{2.5}$ (525 kT/Y), VOC (486 kT/Y), and SO_2 (460 kT/Y).

Regarding the contribution of different fuel types, the major source of PM2.5 is biomass burning (387 kT/Y) followed by coal burning (156 kT/Y). In contrary, for PM10, coal burning is found to be the largest emitter (565 kT/Y) followed by biomass burning (400 kT/Y). Liquid fuels (e.g., petrol, diesel) are estimated to have major contribution in emission loads of CO (2072 kT/Y), SO_2 (225 kT/Y) and NOx (400 kT/Y) in year 2020. An overall increasing trend was observed during 1990–2020 for all air pollutants: PM_{10} (245 – 1156 kT/Y), $PM_{2.5}$ (161 – 525 kT/Y), NOx (225 – 617 kT/Y), SO_2 (142 – 460 kT/Y), CO (1008 – 3773 kT/Y), and VOCs (231 – 486 kT/Y).

Overall, the current emissions inventory is valuable for identifying potential sources of anthropogenic emissions. Assessing trends in temporal variation of emission from 1990 to 2020; and timely control measures by policy makers and regulatory bodies. The estimated emissions are also useful to compute ambient concentrations by air quality modeling and further compare with observed ambient air concentrations to assess control measures taken before devising future strategies for pollution management.

ABOUT THE REPORT

CHAPTER 1: ABOUT THE REPORT

1.1. Scope:

The 'Emission Inventory of Anthropogenic Air Pollutants in Punjab Province' reports estimates of emissions of PM10 and PM2.5 as well as gaseous pollutants (NOx, SO2, CO and VOC) from anthropogenic activities. The basis of selecting these pollutants was the severity of their abundance and impacts as reported elsewhere in several air pollution monitoring studies in major cities of Punjab. The estimates of air emissions were calculated for the years 1990, 1995, 2000, 2005, 2010, 2015 and 2020. The report includes emissions from a range of activities, including the energy sector, manufacturing and processing industries, and fuel combustion activities in transportation. Non-combustion activities related to extraction, processing, storage, distribution, and use of fuels. EI also covers crop residue burning in the field or other open areas and non-combustion emissions from the agriculture sector. For convenience all sources / activities are categorized in to six sectors. These include "Industry", "Energy", "Transport", "Agriculture", "Non-Combustion Industrial Processes" (NCIP), and "Others" (with nominal contribution). Table 2.1 lists the type of industries, processes and/or activities covered under these sectors. The data is compiled in simplified tabular and graphical forms. All emissions are reported in kilogram tons per year (kT/Y).

Table 1.1: Sector & sub-sectors focused in this EI report

SECTORS	SUB-SECTORS
ENERGY	Public electricity and heat production
INDUSTRIAL	Petroleum refining
	Manufacture of solid fuels and other energy industries
	Stationary combustion in industry Iron and steel
	Stationary combustion in industry: Chemicals
	Stationary combustion in industry: Food processing, beverages and tobacco and Other
	Stationary combustion in industry: Non-metallic minerals
	Mobile Combustion in industry
TRANSPORT	Road transport: Passenger cars
	Road transport: Light duty vehicles
	Road transport: Heavy duty vehicles and buses
	Road transport: Mopeds and motorcycles
AGRICULTURE	Agriculture/Forestry/Fishing: Stationary
	Agriculture/Forestry/Fishing: Off_road vehicles and other machinery
	Field burning of agricultural residues
NON-COMBUSTION INDUSTRIAL PROCESSES (NCIP)	Quarrying and mining of minerals other than coal
	Storage, handling and transport of mineral products
	Chemical industry: Other

	Storage, handling and transport of chemical products
	Other solvent use
	Fugitive emissions Oil
	Pulp and paper industry
	Wood processing
	Quarrying and mining of minerals other than coal
	Commercial / institutional: stationary
OTHERS	Other / mobile/ land based and recreational boats
	Solid fuel transformation
	Venting and flaring
	Dairy cattle_Manure management
	Laying hens_Manure management
	Other poultry_Manure management

1.2. Objective:

The primary goal of this emission inventory is to estimate the emission load of primary air pollutants, their temporal variations and sectoral contribution to air emissions in Punjab; and to compile the whole data into a single repository for easy referral and informed decision making.

1.3. Study Region:

Punjab (31°N, 72°E) is the most populous province of Pakistan with the area of 205,345 sq.km. According to the 2017 census, the population of the province is about 110 million with average population density of 535 persons per square kilometer.[1] Lahore city is the most populated city and capital of Punjab[2] (Figure 1.1).

[1] Bureau of Statistics (2020). PUNJAB DEVELOPMENT STATISTICS, Planning & Development Board, Government of the Punjab.
[2] Punjab Portal, Government of Punjab, https://punjab.gov.pk/ (Accessed on 01-12-2022)

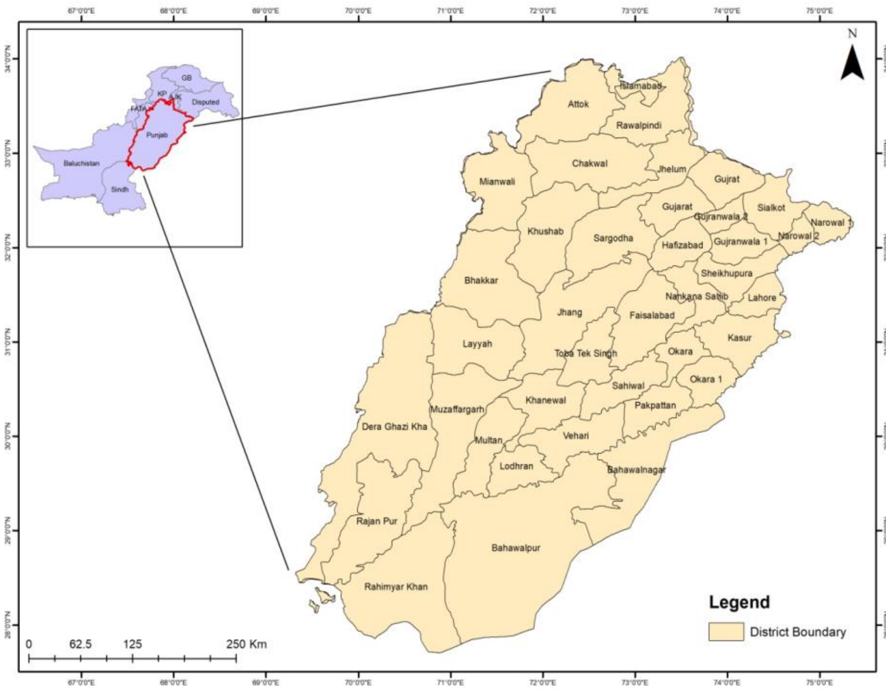

Figure 1.1: District-wise map of Punjab Province (Source: SUPARCO)

The climate of Punjab varies from semi-arid to hyper-arid. Dust storms occur in Punjab from April to June followed by monsoon rains from July to September.[3]. Hottest temperatures are recorded in the months of June and July with mean daily maximum temperature often exceeding 40◦C. The rainy season is followed by the dry months of October and November. Cold weather persists from December to March when the mercury drops to -2◦C on some days. In winter, low temperatures cause occasional fog, which act as a precursor to trap any incoming pollutants resulting in dense smog[4].

In winter, due to lower temperatures foggy conditions occasionally prevail which act as a precursor to trap any incoming pollutants resulting in dense smog.[5] Punjab's economy is primarily agricultural, although industry contributes substantially. It contributes about 68% of the annual food grain production in the country. Cotton, wheat and rice are the major crops. Punjab has also more than 48 thousand industrial units. The small and cottage industries are in abundance. There are 39,033 small and cottage industrial units. Lahore and Gujranwala Districts have the largest concentration of small light engineering units. The district of Sialkot excels in sports goods, surgical instruments and cutlery goods.[6]

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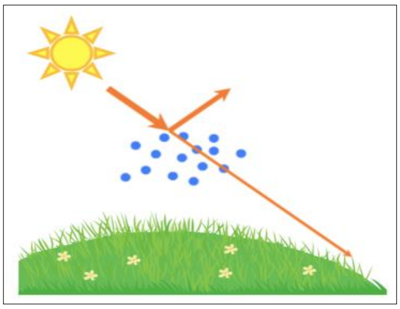
[3] Bureau of Statistics (2020). PUNJAB DEVELOPMENT STATISTICS, Planning & Development Board, Government of the Punjab.
[4] FAO (2018), Remote sensing for spatio-temporal mapping of smog in Punjab and identification of the underlying causes using GIS techniques (R- SMOG).
[5] FAO (2018), Remote sensing for spatio-temporal mapping of smog in Punjab and identification of the underlying causes using GIS techniques (R- SMOG).
[6] Punjab Portal, Government of Punjab, https://punjab.gov.pk/ (Accessed on 01-12-2022)

1.4. About Pollutants in Focus

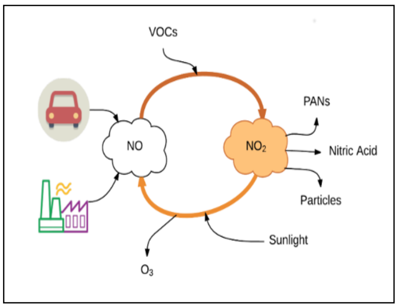
A general overview of key pollutants (i.e., PM_{10}, $PM_{2.5}$, NOx, SO_2, CO & VOC) focused in the emission inventory is presented below:

1.4.1. Particulate Matter (PM)



Particulates in the atmosphere arise from anthropogenic activities like fuel combustion, industrial processes and non-industrial fugitive sources (for example, roadway dust from paved and unpaved roads, wind erosion, and so on) and transportation sources. Biomass burning is also a major source of particulate matter (PM). Particles less than or equal to 2.5 µm in diameter are referred to as "$PM_{2.5}$ or fine" and those greater than less than or equal to 10 µm as "PM_{10} or coarse". Short-term exposures to PM can aggravate lung disease, causing asthma attacks and acute bronchitis. Long-term (months to years) exposure to $PM_{2.5}$ has been linked to premature death, particularly in people who have chronic heart or lung diseases.[7] In addition, aerosols interact both directly and indirectly with the Earth's radiation budget and climate.

1.4.2. Nitrogen Oxides (NOx)

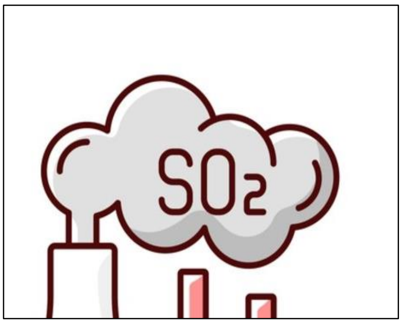


Nitric oxide (NO) and nitrogen dioxide (NO_2), collectively known as NOx, are among the most important molecules in air pollution. NO_2 is also a criteria pollutant. Presence of NOx in troposphere adversely impacts human health and visibility, and contributes to the formation of tropospheric ozone (O_3), fine particle pollution, summer smog and acid rain. Evidences suggest that exposure of mixtures of NO_2 and SO_2 to vegetation and plants may alter their growth and reduce their ability to withstand drought and frost stresses. The main sources of NOx are industrial burning processes, vehicle combustion process, biomass fuel and crop residue burning.[8]

[7] World Health Organization (2013). "Health Effects of Particulate Matter: Policy implications for countries in eastern Europe, Caucasus and central Asia."

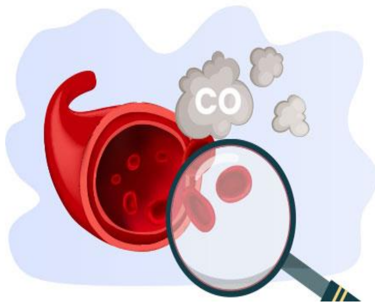
[8] Tariq, S., M. Ali, K. Mahmood, S. A. Batool and A. D. Rana (2014). "A study of tropospheric NO_2 variability over Pakistan using OMI data." Atmospheric Pollution Research **5**(4): 709-720.

1.4.3. Sulfur Dioxide (SO_2)



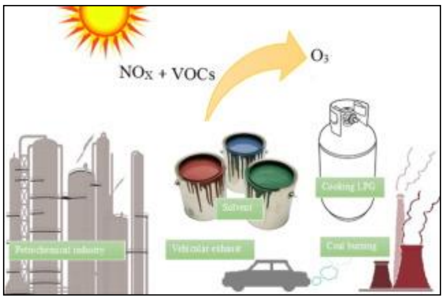
Sulfur Dioxide (SO_2) gas is considered as a criteria air pollutant that is present in the troposphere as a consequence of both natural and manmade activities. Natural sources include volcanic eruptions, sea sprays and biogenic processes whereas anthropogenic releases are contributed by coal power plants, non-ferrous metal smelters, oil & gas industries, biomass burning and wildfires.[9] SO_2 affects the respiratory system, particularly lung function, and can irritate the eyes. It also causes coughing, mucus secretion and aggravates conditions such as asthma and chronic bronchitis.[10]

1.4.4. Carbon Monoxide (CO)



Carbon monoxide (CO) is a trace atmospheric constituent which adversely impacts human life and contributes to climate change at different spatial scales. Locally, it is poisonous to humans and its long-term exposure may result in heart diseases and damage to the nervous system. Carbon monoxide has 210 times greater affinity for hemoglobin than oxygen. If there is too much carbon monoxide in the air, CO builds up in the bloodstream by replacing oxygen which can lead to severe tissue damage, and in the worst case, death. Regionally, it reacts with other pollutants and produces photochemical smog. Globally, it contributes to tropospheric ozone formation in NOx rich environment, leading to global warming. Anthropogenic CO is mainly emitted as a consequence of incomplete combustion from energy production, fossil fuel and biomass burning, industrial plant exhaust, vehicular combustion, waste treatment, and agricultural activity.[11]

1.4.5. Volatile Organic Compound (VOC)



Volatile Organic Compounds (VOCs) are a broad class of organic chemicals that are, in a small number of cases, directly harmful to health, but that more generally act as precursors to the formation of ozone (O_3) and particulate matter (PM). Therefore, the estimation of VOC emissions from domestic fuels

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[9] Jabeen, Z. and M. F. Khokhar (2019). "Extended database of SO2 column densities over Pakistan by exploiting satellite observations." Atmospheric Pollution Research **10**(3): 997-1003.

[10] Ghozikali, M. G., B. Heibati, K. Naddafi, I. Kloog, G. O. Conti, R. Polosa and M. Ferrante (2016). "Evaluation of chronic obstructive pulmonary disease (COPD) attributed to atmospheric O3, NO2, and SO2 using Air Q Model (2011–2012 year)." Environmental research **144**: 99-105.

[11] Blumenthal I. Carbon monoxide poisoning. J R Soc Med. 2001 Jun;94(6):270-2. doi: 10.1177/014107680109400604. PMID: 11387414; PMCID: PMC1281520.

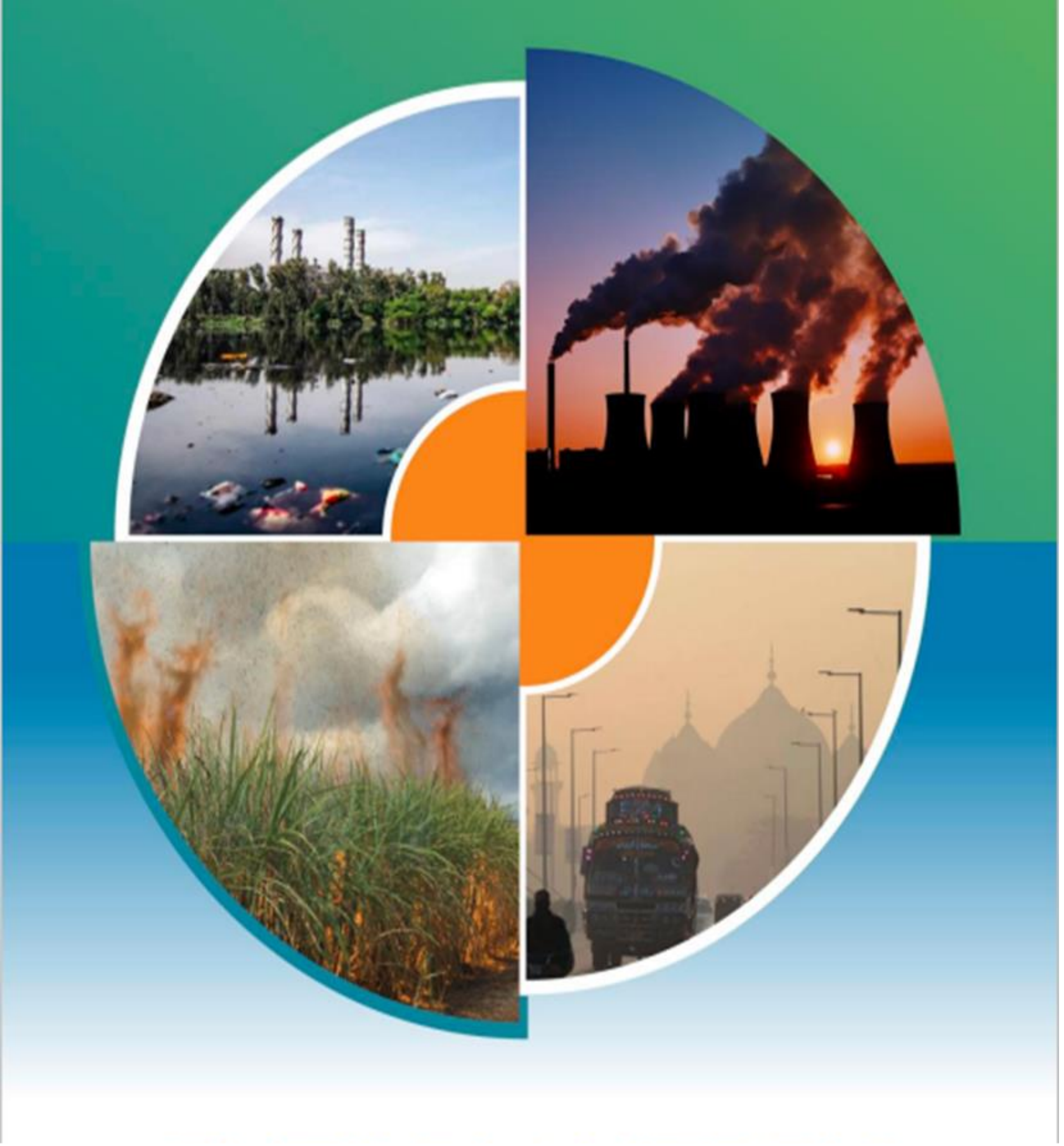
is vital due to their significant role in the photochemistry and ozone formation in the lower troposphere. The major anthropogenic sources of VOC emissions are industrial activities, as for example, industrial coating process, industrial solvent use, dry cleaning, large point sources (oil refineries, large combustion plants, chemical manufacture and production processes), transport sector (motor vehicles), waste water treatment plants, and other combustion sources, such as residential biomass burning.[12]

1.5. Structure of the Report

The structure of the report is as follows;

- Chapter 1 describes the scope and objective of this report.
- Chapter 2 describes the background of air pollution and need of the emission inventory.
- Chapter 3 includes methodology of developing the present emission inventory.
- Chapter 4 covers the emission estimates of air pollutants. Results are mentioned in three ways
  (i) sector wise emissions
  (ii) pollutant wise estimates
  (iii) emissions by fuel / activity type.
- Chapter 5 discusses the outcomes of the emission inventory and comparison with economic growth indicators of Punjab as well as recommendations for future work.

[12] Lewis, A., D. Carslaw and S. J. Moller (2020). "Non-methane Volatile Organic Compounds in the UK."



INTRODUCTION

CHAPTER 2: INTRODUCTION

2.1. Background

Air pollution is one of the most serious global environmental threats affecting human health, agriculture, natural ecosystems and climate patterns among many others. These impacts are projected to become much more severe in the coming decades. Air pollutants (aerosols and gases) are of particular concern because air masses flow freely across borders, leaving the geographic and political jurisdiction of the country of origin, and becoming the burden of another region or country where they have never been produced or used. These pollutants play an important role in disturbing Earth's energy budget which affects rainfall patterns and unexpected temperature changes (e.g., heat waves). In addition to affecting rain patterns, there have been several investigations worldwide which revealed that deposition of atmospheric aerosols e.g., black carbon, dust etc., on snow reduce the snow albedo which ultimately enhance the absorption of solar radiation and foster the melting rates of High Asia glaciers in Tibetan Plateau, Himalayas, Karakoram. On the other hand, presence of air pollutants (e.g. CO, SO_2, O_3) in atmosphere is pose potential threats to human health. According to World Health Organization (WHO) fact sheets released in September 2021, more than 80% of people living in world are exposed to air quality levels that exceed the WHO safe limits. The consequences are air pollution causes death of over three million people worldwide in a year. Addressing air pollution, therefore, features high on the global agenda; and policies to address air pollution generate co-benefits of climate, environment, socio-economic development.

Pakistan is not the exception as air pollution is reportedly causing adverse impacts on human health, agriculture, and eco-system.[13,14] The WHO has ranked Pakistan as fourth country in the world with the most air pollution (Figure 2.1) after China, India and Nigeria. According to the report, one of the major causes of death in Pakistan is air pollution with the number of deaths reportedly rising to 59,000 each year. The situation is likely to be aggravated with the ongoing urbanization and industrialization (WHO Report 2016).[15]

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[13] U. Mehmood, A. Azhar, F. Qayyum, H. Nawaz and S. Tariq (2021). "Air pollution and hospitalization in megacities: empirical evidence from Pakistan." Environmental Science and Pollution Research 28(37): 51384-51390.

[14] S. Ullah (2017). "Climate Change Impact on Agriculture of Pakistan- A Leading Agent to Food Security." Int J Environ Sci Nat Res 6(3).

[15] Ambient air pollution: A global assessment of exposure and burden of disease, World Health Organization, Publication date: 2016, ISBN: 9789241511353

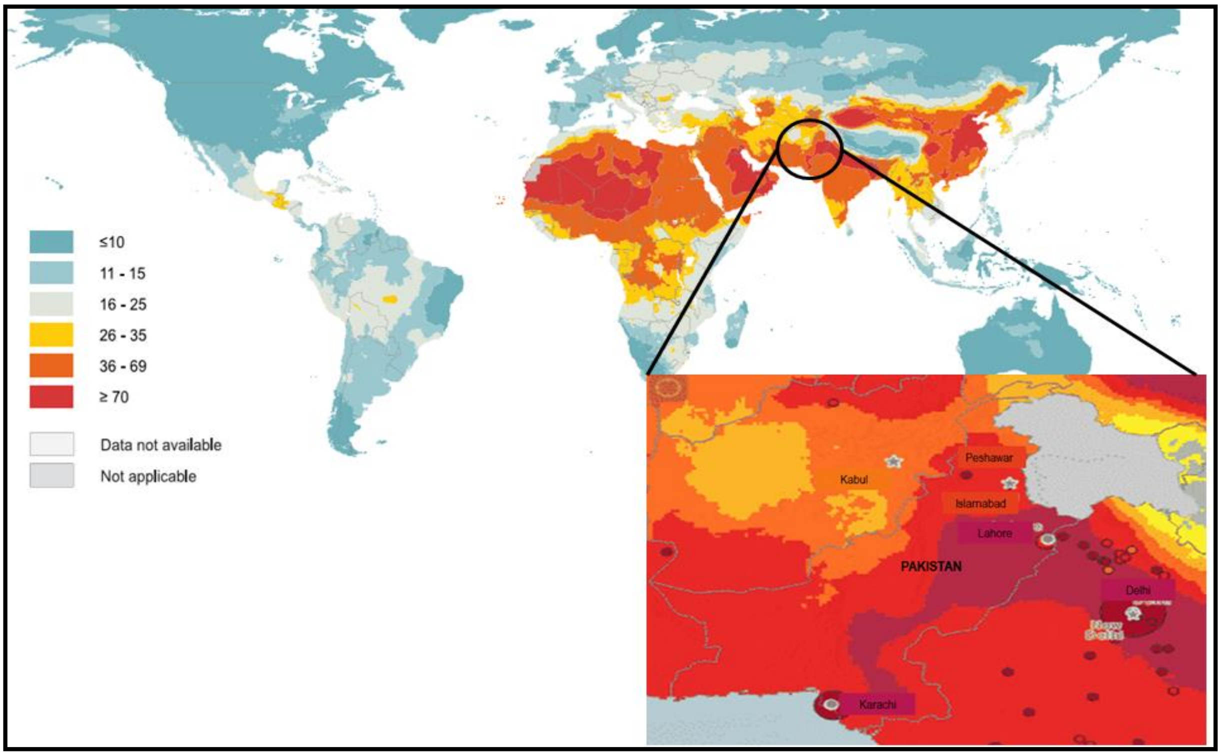

Figure 2.1: Interactive map by WHO showing levels of pollution over Pakistan(Source: WHO Report 2016)

In Pakistan, two-thirds of its population lives in Punjab province. Punjab is the most dynamic province of the country contributing about 60% to the annual growth of industrial goods and services. The anthropogenic emissions are mainly contributed from industrial and vehicular emissions and biomass burning activities.[16] In Punjab, three of the most populated cities are Lahore, Faisalabad and Gujranwala. Besides over-population, another unfortunate resemblance between these three megacities is their abysmal air quality. The Air Quality Index (AQI) in certain areas of Lahore has frequently exceeded 400 $\mu g/m^3$ in the month of November 2021 while the safe AQI value is considered below 50 $\mu g/m^3$. The major reason for this deteriorated air quality in winter months is smog.

Crop burning, rampant industrialization and urbanization, with increasing number of vehicles on the roads and poor fuel quality, brick kilns and deforestation are among the leading causes of air pollution in Punjab. Smog is responsible for many serious health issues including respiratory problems such as asthma exacerbation, coughing, burning throat and chest irritation and chronic bronchitis. In addition to these respiratory problems, smog can also cause eye, cardiovascular and skin symptoms..[17]

[16] FAO (2018). Remote sensing for spatio-temporal mapping of smog in Punjab and identification of the underlying causes using GIS techniques (R- SMOG).[http://www.gcisc.org.pk/R-SMOG-Report.pdf; Accessed on 01-12-22]

[17] Ashraf, M. F., R. U. Ahmad and H. K. Tareen (2022). "Worsening situation of smog in Pakistan: A tale of three cities." Annals of Medicine and Surgery: 103947.

2.2. Significance of Air Quality Measurements

An effective air quality management strategy consists of three main components: I) Identification and quantification of major sources; II) Regulatory and non-regulatory approaches to reduce source contributions; and III) Measurement and monitoring of air quality to support source identification and to evaluate progress in achieving ambient air quality targets. Measurements play a key role in identifying sources and hotspots of greatest concern, benchmarking against national or international standards, and in evaluating effectiveness of actions to reduce emissions and tracking overall progress. These measurements provide critical support for more advanced tools such as chemical transport models which are combined with emissions inventories and meteorological information to simulate the source to ambient concentration relationship. Further, these models can be used for air quality forecasting or evaluation of control or development scenarios.

Conventionally, ambient air quality measurement has focused on establishing a number of fixed-location monitors situated to provide information on regional or urban background concentrations, and/or locations targeted to assess impacts of specific sources such as vehicles, industrial sources or power plants. These monitoring stations typically incorporate robust, high-quality devices to provide a combination of real-time or integrated average measurements of common air pollutants (SO2, CO, NOx, O3, PM10/PM2.5 etc). Many international and national organizations are carrying continuous monitoring of air pollutants by establishing the networks of ground-based observatories. Some prominent examples are Global Atmospheric Watch (GAW) observatories under World Meteorological Organization (WMO), NASA's ground-based Global Aerosol Robotic Network (AERONET) consists of over 800 sun photometers worldwide, European Aerosol Research Lidar Network (EARLINET), China Atmosphere Watch Network (CAWNET), SAFAR (System of air quality and weather forecasting for research) is an initiative to monitor and forecast air quality in four Indian cities, and MAPAN (Modeling Air Pollution and Networking) is also being operated to conducts monitoring in 11 Indian cities.

Despite the significant increase in air pollution and its devastating effects on climate and ecosystems, there is no permanent network of environmental observatories in any of Pakistan. One of the several reasons for absence of atmospheric observatories in the country could be the high principal cost of air monitoring analyzers as well as highly skilled staff for their calibration and maintenance. Consequently, there is a dearth of knowledge about composition, seasonal / temporal variations and sources of atmospheric pollutants across the country. Hence, there is an imperative need of continuous monitoring of atmospheric pollutants not only for insight into the current situation of atmospheric composition over urban and remote regions but also to support satellite data, forecast atmospheric changes and to design management / abatement strategies.

2.3. Emission Inventory

Emission inventories are databases that specify the amount of air pollutants and greenhouse gases released into the atmosphere by various pollutant sources for a given period of time. They are usually developed for variety of spatial and temporal scales based on usage purposes.[18] Emission inventories can also be used as a major foundation for air quality modeling in order to understand the fate of pollution emitted from different sources, spatial distribution of pollutant concentrations, and identify the emission reduction opportunities. Spatially and temporally emission inventories are used as primary inputs for atmospheric dispersion models like AERMOD and CALPUFF, Trajectory models such as LAGRANTO, and coupled chemical-atmospheric air quality models like CAMx. An updated emission inventory can help governments for air quality policymaking to control pollution sources. Different kinds of emission inventories have been developed. Some inventories are related to specific sources of pollution or individual pollutants. Additionally, some of them are continental, national, regional, or urban.[19]

2.4. Global and Regional Emission Inventories

Global inventories like EDGAR (Emission Database for Global Atmospheric Research) give emissions at 0.1° resolution for CO, SO_2 and NOx. EDGAR emissions are calculated at country level for different sectors relevant to that country. These parameter data are based on evaluation of scientific literature, inventory guidance, inventory reports, industry reports, dataset documentation. Emissions by country and grid are allocated on a spatial grid to provide gridded emissions dataset for atmospheric modeling. The emissions are then spatially allocated using grid maps with 0.1° x 0.1° resolution based on data such as location of energy and manufacturing facilities, road networks, shipping routes, human and animal population density and agricultural land use. Similarly, REAS (Regional Emission Inventory in Asia) emissions use country region specific emission factors for several emission species from subdivided source sectors to estimate emissions on state or and country levels. These emissions are divided into a 0.5 × 0.5 grid by using index databases, i.e., population data; information on the positions of large point sources; land cover data sets; and land area data sets. GAINS-Asia emission inventories are calculated at country and sub-region level for China and South Asia.[20] For Pakistan, Khan et al., has utilized GAINS model to analyze the source-based anthropogenic emissions of air pollutants (NH_3 and SO_2), volatile organic compounds (VOCs), and greenhouse gases (CH_4 and CO_2), their impacts and abatement cost, for the duration of 1990–2030, in the Khyber Pakhtunkhwa and Baluchistan regions of Pakistan.[21]

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[18] Gioli, B., Gualtieri, G., Busillo, C., Calastrini, F., Zaldei, A., Toscano, P., 2015. Improving high resolution emission inventories with local proxies and urban eddy covariance flux measurements. Atmos. Environ. 115, 246–256

[19] Shahbazi, H., S. Taghvaee, V. Hosseini and H. Afshin (2016). "A GIS based emission inventory development for Tehran." Urban Climate 17: 216-229.

[20] Mohan, M., S. Bhati, P. Gunwani and P. Marappu (2012). Emission inventory of air pollutants and trend analysis based on various regulatory measures over megacity Delhi, IntechOpen.

[21] Khan, A. and S. S. Ahmad (2018). "Application of GAINS model for assessing selected air pollutants in Khyber Pakhtunkhwa and Balochistan, Pakistan." Arabian Journal of Geosciences 11(9): 1-10.

2.5. Emission Sources and Sectors

Normally, air emission sources are divided into three main categories: area source, point source, and line source. Each source includes many subcategories based on its distributed characteristic as shown in Figure 2.2.

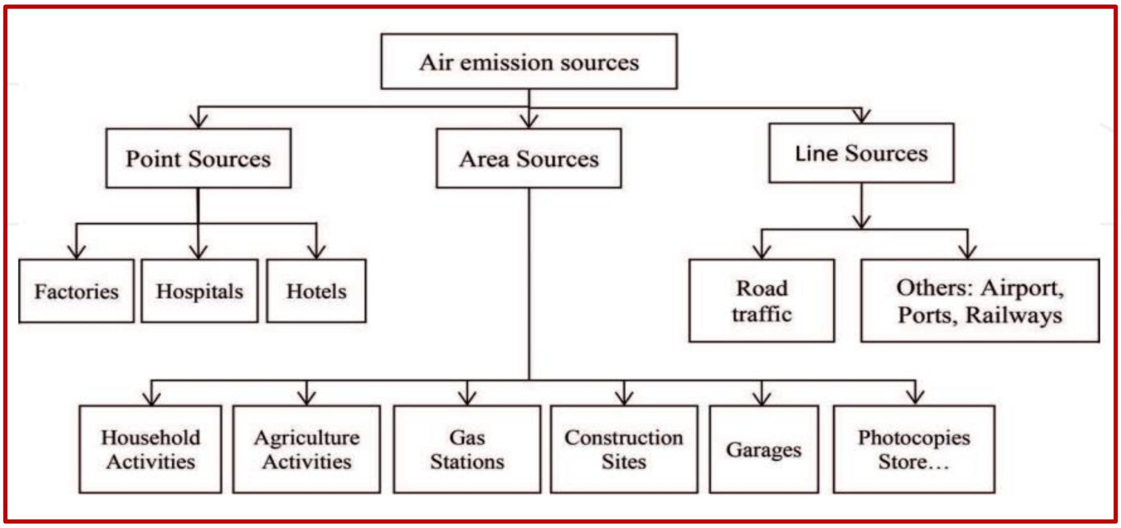

Figure 2.2: Air Emission Sources

Point Sources

Point sources are stationary sources that are typically large manufacturing or production plants that include confined, chimney or stack emission points. Within a given point source, there may be several units of combustion, such as several boilers. The point sources can be hospital incinerators, hospital boilers, hotel boilers, and industries.

Area Sources

Area sources are defined as sources that are too small and/or too numerous to be considered as point sources. In aggregate, these sources may contribute a significant proportion of the total airshed emissions. Area sources include a wide range of sources, such as rice straw/biomass burning, gas stations, construction activities, printing facilities, auto repair facilities, paint spraying facilities, and so on.

Line Sources (Mobile Sources)

Line sources, also considered as mobile sources, are vehicles, engines, and equipment that generate air pollution and that move or can be moved from place to place. Mobile sources are classified under two smaller sources: on-road and non-road sources. On-road sources include vehicles used on roads for transportation of passengers or freight, such as passenger cars, trucks, and motorcycles that may be fueled with gasoline, diesel fuel, or alternative fuels, such as alcohol or natural gas. Non-road sources include gasoline and diesel-powered vehicles, engines, and equipment used for construction, agriculture, transportation, recreation, and many other purposes.[22]

[22] Bang, H. Q. and V. H. N. Khue (2018). Air emission inventory. Air Pollution-Monitoring, Quantification and Removal of Gases and Particles, IntechOpen.

DEVELOPMENT OF EMISSION INVENTORY

CHAPTER 3: DEVELOPMENT OF EMISSION INVENTORY

3.1. Emission Inventory Development Approaches

An emission inventory is an accounting of all air pollution emissions and associated data from sources within a specified area and over a specific time interval. The development of information for an emissions inventory can be carried out in one of two methods.[23] One method is often referred to as the **'Top-down Approach'**, and the other as a **'Bottom-up Approach'**.

Top-Down Approach:

It uses generalized factors such as total fuel use, total population, total activity data as indicators of emissions. Emission factors predict emissions per unit of a process or fuel mass or per person or such. The product of the emission factor with the relevant emissions indicator provides an estimate of total emissions. These emissions can be disaggregated sector wise. Furthermore, national or regional level emission estimates can be scaled down to a smaller inventory domain based on surrogate data (geographic, demographic, economic data, and so on). They are typically used when local data are not available and the cost of gathering local information is high. This approach requires minimum resources, but the emissions generally have ample uncertainty in emission estimates. This approach is also known as **'Tier 1'** approach and serves as an excellent tool for preliminary estimation of pollution generation, to serve in decision-making.

Bottom-Up Approach:

The region of interest is divided into sectors of interest and specific information is developed for each sector, in this approach. Emission estimation for individual sources (and source categories) is summed up to obtain a domain-level inventory. It is typically used when source/category-specific activity or emission data are available. It produces a better spatial distribution of emissions but requires resources to collect site-specific information.[24] This approach falls under the category of Tier 2 or Tier 3 approach. Tier 2 employs country specific emission factors instead of Tier 1 defaults and requires highly stratified activity data to correspond with country-specific emission factors for a specific region. Similarly, Tier 3 method uses detailed emission models to address national circumstances. In general, these methods provide greater certainty in estimates as compared to lower tiers though at the cost of detailed information and measurement complexity.[25]

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[23] Mohan, M., S. Bhati, P. Gunwani and P. Marappu (2012). Emission inventory of air pollutants and trend analysis based on various regulatory measures over megacity Delhi, IntechOpen.

[24] Shrestha, R. M., Kim Oanh, N. T., Shrestha, R. P., Rupakheti, M., Rajbhandari, S., Permadi, D. A., ... & Iyngararasan, M. (2013). Atmospheric Brown Clouds: Emission Inventory Manual.

[25] FAO (2018). Remote sensing for spatio-temporal mapping of smog in Punjab and identification of the underlying causes using GIS techniques (R- SMOG).[http://www.gcisc.org.pk/R-SMOG-Report.pdf; Accessed on 01-12-22]

3.2. Estimation of Emissions

In general, emissions from source "*s*" in the region "*i*" and year "*t*" are calculated as the activity data (A_{its}) times an emission factor (EF_{ism}). If emissions are controlled through the implementation of technology *m*, the fraction of the activity controlled is specified by ($Appl_{itsm}$),[26] i.e.,

$$\boldsymbol{E_{its} = \sum_{m} [A_{its} \times EF_{ism} \times Appl_{itsm}]},$$

where,

A_{its} = Activity (amount of fuel consumed)

EF_{ism} = Emission factor for activity control by technology *m*

$Appl_{itsm}$ = Rate of technology *m* to activity *s*

3.3. Emission Factor

An **emissions factor** is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with 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 mega gram {Mg} of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution.[27]

In case of lack of activity-based emission data from sources, emission factors are generally adopted from internationally recognized emission manuals / datasets, such as:

- ***EMEP/EEA Emission Inventory Guidebook (CORINAIR)***: contains emission factors for many pollutants, as well as information on emissions from natural and organic sources.
- ***United States Environmental Protection Agency - Compilation of Air Pollutant Emission Factors (US EPA—AP 42):*** allows the user to search for the latest and best emission factors for most point and area source categories, including a rating on the quality of the particular emission factor.
- ***Intergovernmental Panel on Climate Change (IPCC) 2006 - Greenhouse Gases Emission Inventory Guidebook:*** to estimate greenhouse gas (GHG) emissions and emission factors from other combustion activities.

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[26] Höglund-Isaksson, L., Winiwarter, W., Purohit, P., & Gomez-Sanabria, A. (2016). Non-CO2 greenhouse gas emissions in the EU-28 from 2005 to 2050: GAINS model methodology.

[27] https://www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification (Accessed on 12-12-22)

3.4. Methodology

In present study, the emissions of particulate matter (PM_{10} and $PM_{2.5}$), and gaseous pollutants (NOx, SO_2, CO, and VOCs) from key sectors in Punjab were quantified by using the Greenhouse gas and Air Pollution Interactions and Synergies (GAINS) model. The model was developed by the International Institute for Applied Systems Analysis (IIASA).[28] The GAINS model estimates air pollutants emission along with an outline of scenarios from different sources.[29] The present emission inventory includes estimates of historic anthropogenic emissions of air pollutants by source category starting from 1990 to 2020. The detailed activities from key contributing sectors are included in this study such as agriculture, transport, industry, power, construction, waste, and domestic (commercial and residential activity). The 'Tier 1' approach for developing the emission inventory due to unavailability of activity specific emission data in Punjab. This tool integrates several default emission factors (EF) obtained from IPCC and AP-42 and also fulfills all the requirements of internationally accepted methods.[30] The UNFCCC-CRF sectors classification is used for emission estimates of air pollutants under the business-as-usual (BAU) scenario. The BAU scenario considers all policies, legislation, and declared and current regulations affecting emissions of air pollutants applicable to Punjab, Pakistan as shown in Figure 3.1.

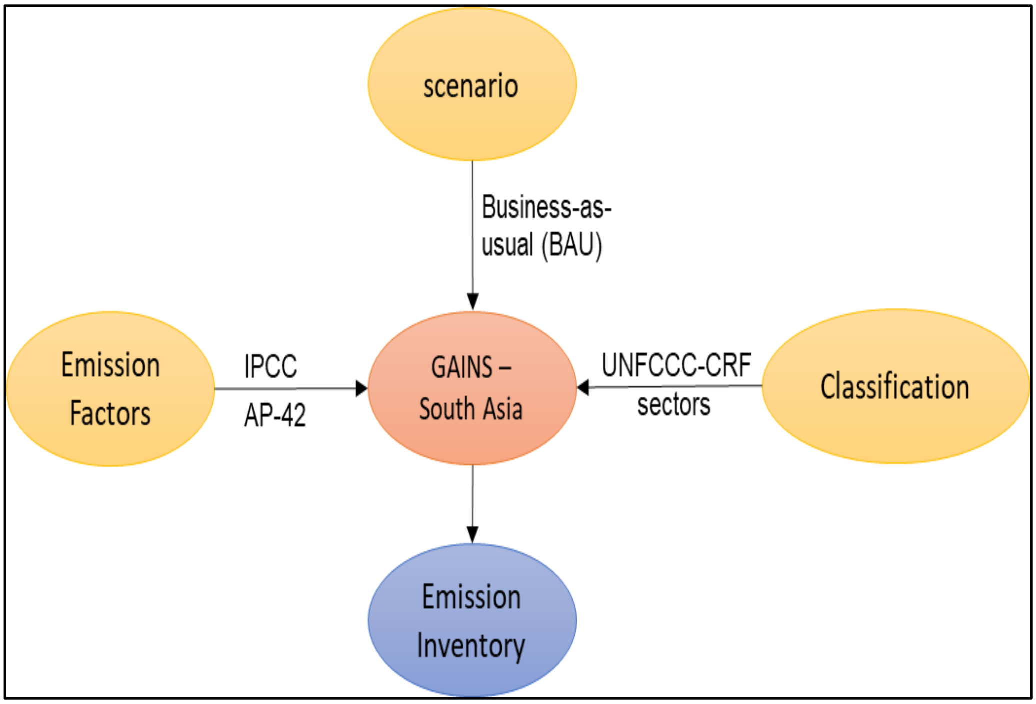


Figure 3.1: Work flow of Study

[28] Liu, F., Klimont, Z., Zhang, Q., Cofala, J., Zhao, L., Huo, H., ... & Heyes, C. (2013). Integrating mitigation of air pollutants and greenhouse gases in Chinese cities: development of GAINS-City model for Beijing. *Journal of Cleaner Production*, *58*, 25-33.

[29] Amann, M., Kejun, J., Jiming, H. A. O., Wang, S., Xing, Z., Xiang, D. Y., ... & Winiwarter, W. (2008). GAINS Asia. Scenarios for cost-effective control of air pollution and greenhouse gases in China.

[30] Vallack, H. W., Olawoyin, O. O., Hicks, W. K., Kuylenstierna, J. C., & Emberson, L. D. (2020). The Global Atmospheric Pollution Forum (GAPF) emission inventory preparation tool and its application to Côte d'Ivoire. *Atmospheric Pollution Research*, *11*(9), 1500-1512.

ESTIMATES OF AIR POLLUTION EMISSIONS

CHAPTER 4: ESTIMATES OF AIR POLLUTION EMISSIONS

4.1. Sector-wise Estimates

In 2020, the cumulative emissions from all sectors under study were 7,017 kT/year. The contribution of each sector to the total emissions is given in Figure 4.1.

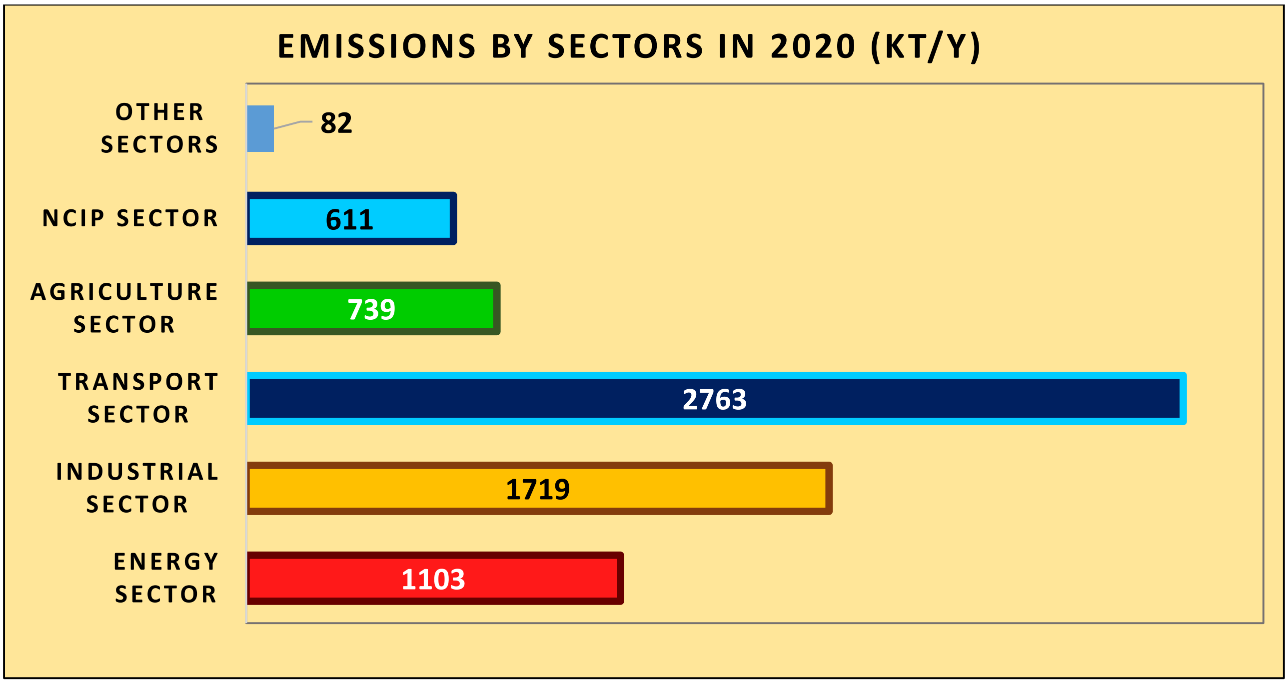


Figure 4.1: Contribution by sectors in air pollution during the year 2020

The percentage contribution of each sector represented in Figure 4.2 indicates that transport sector is the major polluter in Punjab province, followed by industrial and energy sectors.

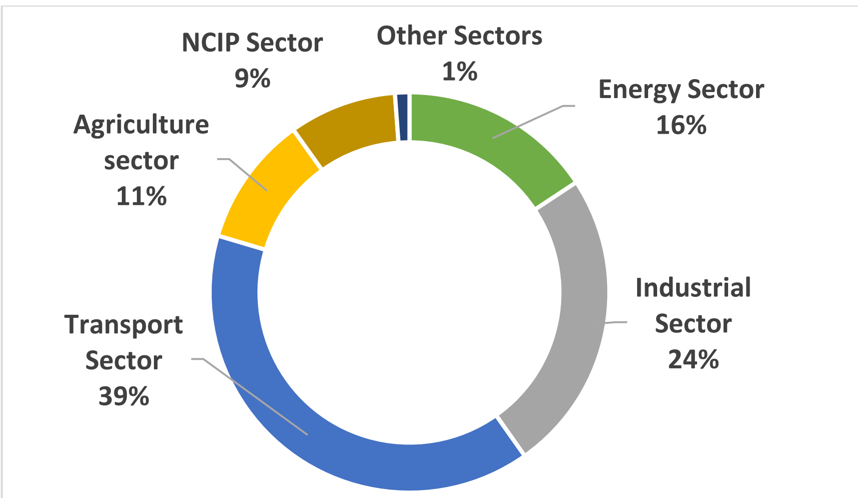


Figure 4.2: Percentage of contribution of air emissions by sectors in 2020

Cumulative emissions over temporal range of 1990-2020, with a five-year interval, to estimate the trend of emissions in Punjab province. The results represent that the emissions have increased considerably, indicating high air pollution. The increase in emissions between 1990-1995, 1995-2000, 2000-2005, 2005-2010, 2010-2015, 2015-2020 is 33%, 16%, 9%, 31%, 30%, and 22%, respectively.

Table 4.1: Emission (kT/Y) of air pollutants from different sectors (1990 – 2020)

SECTOR	1990	1995	2000	2005	2010	2015	2020
ENERGY	150	268	379	297	458	946	1103
INDUSTRIAL	468	559	650	847	1188	1423	1719
TRANSPORT	715	924	1055	1077	1541	2042	2763
AGRICULTURE	382	551	571	637	658	697	739
NCIP	235	296	352	419	454	553	611
OTHERS	62	70	80	88	106	71	82
TOTAL	**2012**	**2668**	**3087**	**3366**	**4405**	**5731**	**7017**

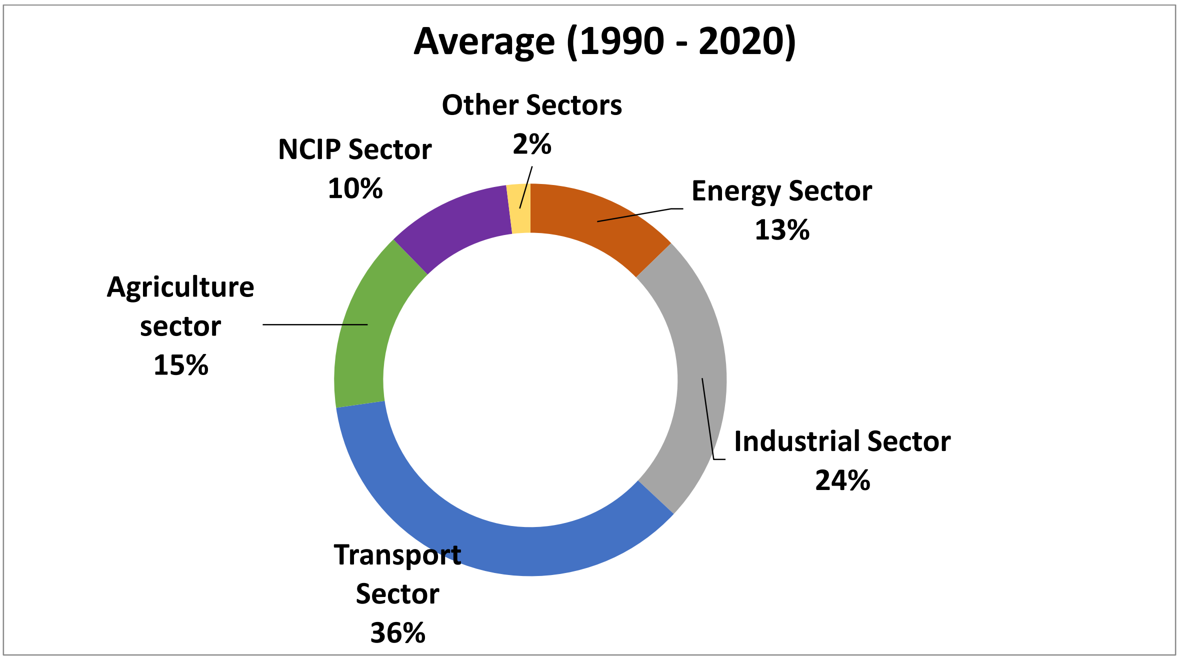


Figure 4.3: Percentage of contribution of air emissions by sectors (1990 – 2020)

4.2. Pollutant-wise Estimates

Emissions of six criteria air pollutants have been estimated in this report from different sectors. The total emissions of each pollutant is given in Table 4.2, and % contributions is given in Figure 4.4.

Table 4.2: Emission estimates of selected air pollutants in year 2020

Air Pollutants	Emission (kT/Y)
PM_{10}	1,156
$PM_{2.5}$	525
SO_2	460
NOx	617
CO	3,773
VOC	486

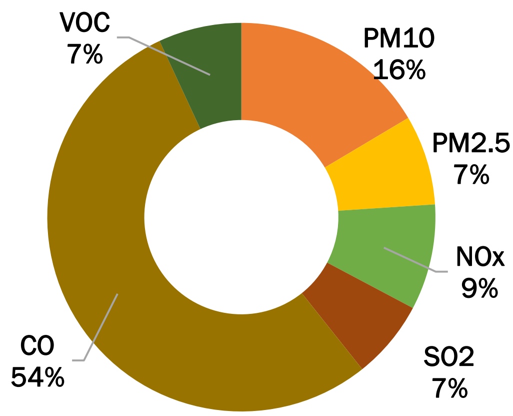


Figure 4.4: Contribution of emissions of selected air pollutants (2020)

The temporal trend of all pollutants from 1990-2020 represents a considerable increase, except Sulfur Dioxide that decreased between 2015-2020. The highest increased was observed in the concentration of Carbon Monoxide and $PM_{2.5}$, in Punjab.

Table 4.3: Temporal emissions of air pollutants in Kilogram tons per year

	1990	1995	2000	2005	2010	2015	2020
PM_{10}	245	309	361	419	502	741	1,156
$PM_{2.5}$	161	207	238	270	312	395	525
NOx	225	324	386	396	416	573	617
SO_2	142	249	359	284	440	501	460
CO	1,008	1,316	1,482	1,709	2,377	3,112	3,773
VOC	231	264	260	289	358	409	486
Total	**2,012**	**2,668**	**3,087**	**3,366**	**4,405**	**5,731**	**7,017**

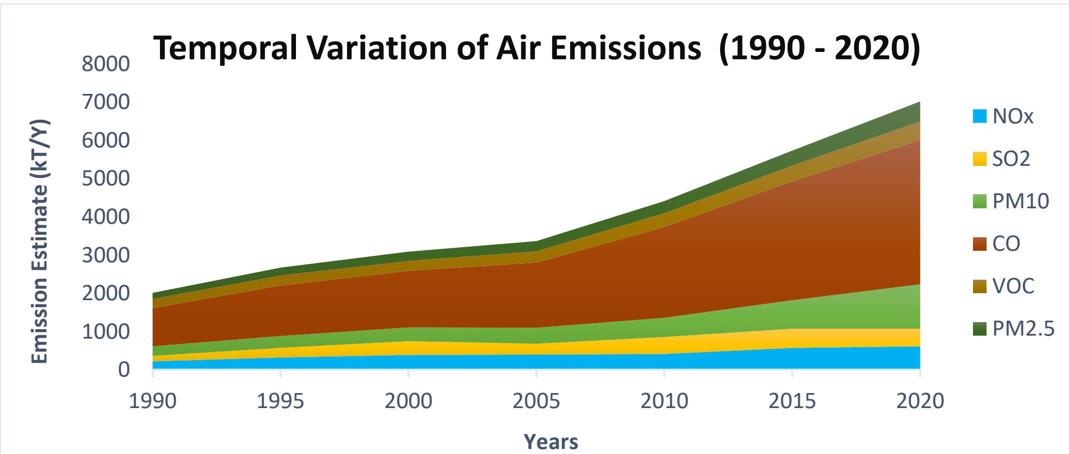


Figure 4.5: Temporal variation of selected air pollutants (1990 – 2020)

Energy sector has contributed to a total of 1,103 kT emissions in 2020. The emissions of PM10, and PM2.5 have increased exponentially over the years, whereas, a decrease has been observed in emissions of SO_2, NOx, CO, and VOC between 2015-2020. The trend is represented in Figure 4.6.

Table 4.1: Emission of air pollutants by energy sector from 1990 to 2020 (Unit in kT/Y)

	1990	1995	2000	2005	2010	2015	2020
PM_{10}	3	5	10	9	9	13	302
$PM_{2.5}$	3	4	6	6	6	11	83
SO_2	80	163	256	179	333	318	224
NOx	46	69	75	71	77	154	105
CO	14	20	23	25	24	423	373
VOC	5	7	8	8	8	26	16
Total	**150**	**268**	**378**	**297**	**457**	**945**	**1,103**

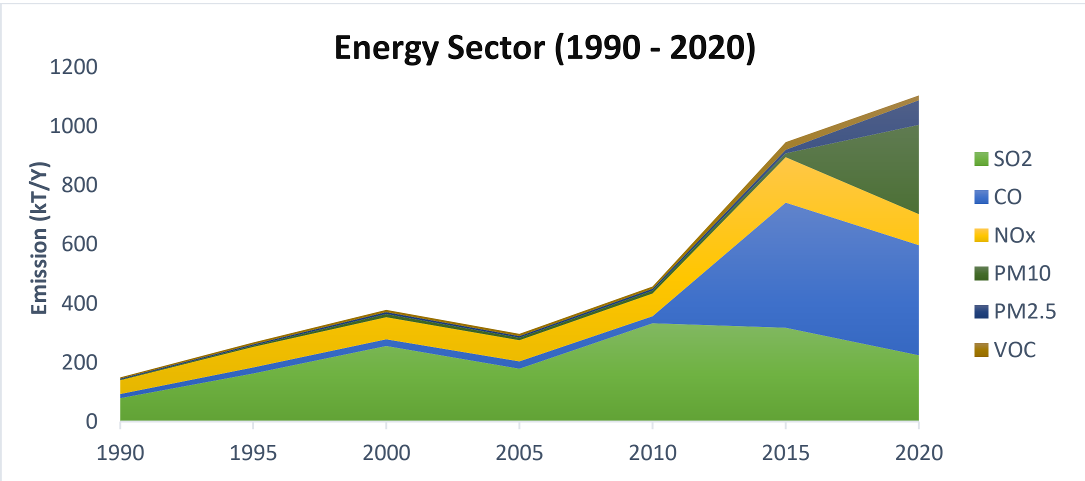


Figure 4.6: Temporal contribution of air pollutants by energy sector

Industrial Sector contributed to a total of 1,719 kT emissions in 2020. The concentrations of pollutants emitted from this sector increased significantly. The highest emissions in this sector are constituted by Carbon Monoxide. The trend of Industrial emissions between 1990-2020 is given in Figure 4.7.

Table 4.2: Emission of air pollutants by industrial sector from 1990 to 2020 (Unit in kT/Y)

	1990	1995	2000	2005	2010	2015	2020
PM_{10}	73	83	96	126	195	362	450
$PM_{2.5}$	46	53	62	77	111	147	180
NOx	24	29	32	44	57	48	60
SO_2	33	43	48	51	59	138	174
CO	286	342	404	538	753	719	845
VOC	7	8	9	12	13	9	11
Total	**468**	**559**	**650**	**847**	**1188**	**1423**	**1719**

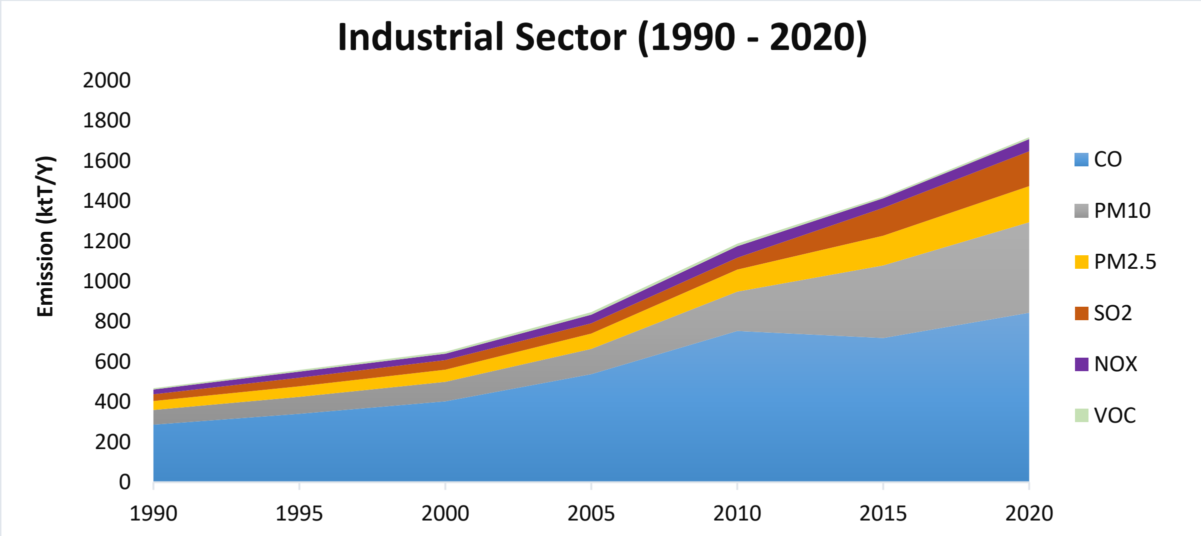


Figure 4.7: Temporal contribution of air pollutants by industrial sector

Transport Sector contributed to about 2,763 kT emissions in 2020. Most of these emissions consisted of Carbon Monoxide. A drastic increase has been observed in the increase in emission from transport sector during 1990-2020, mainly because of the increase in number of vehicles.

Table 4.3: Emission of air pollutants by transport sector from 1990 to 2020 (Unit in kT/Y)

	1990	1995	2000	2005	2010	2015	2020
PM_{10}	23	26	26	22	22	35	44
$PM_{2.5}$	21	24	25	20	20	29	37
NOx	96	150	197	186	187	268	339
SO_2	21	31	40	38	45	41	54
CO	441	577	663	708	1,111	1,498	2,057
VOC	114	116	104	103	157	171	232
Total	**715**	**924**	**1,055**	**1,077**	**1,541**	**2,042**	**2,763**

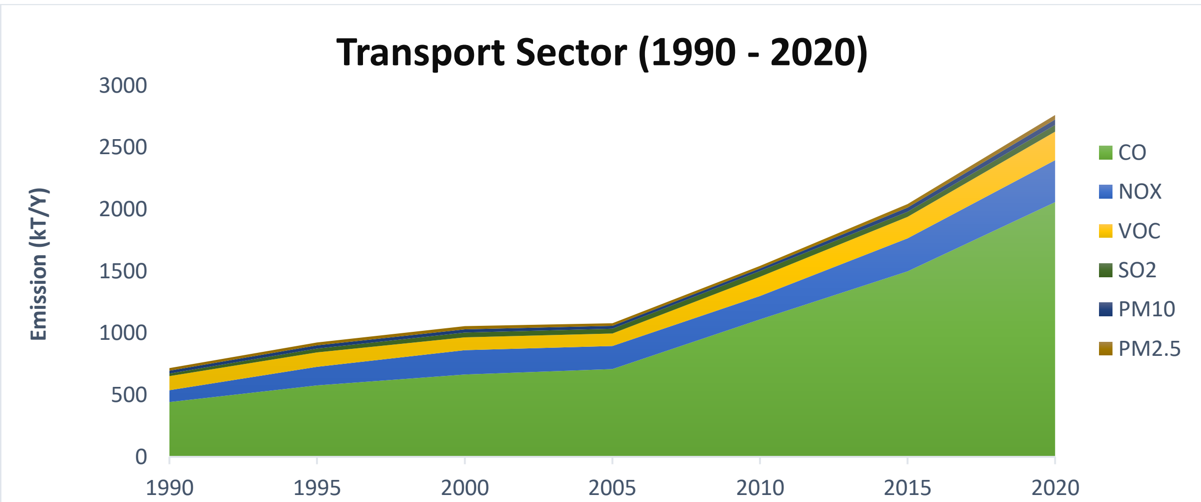


Figure 4.8: Temporal contribution of air pollutants by transport sector

Agriculture Sector contributed to 739 kT emissions in 2020, a considerable increase since 1990. Carbon Monoxide is the major pollutant contributing to these emissions.

Table 4.4: Emission of air pollutants by agriculture sector from 1990 to 2020 (Unit in kT/Y)

	1990	1995	2000	2005	2010	2015	2020
PM_{10}	36	53	54	59	62	66	69
$PM_{2.5}$	32	47	48	53	55	58	61
NOx	39	54	58	67	71	77	85
SO_2	2	2	2	2	2	2	4
CO	229	333	344	385	394	415	438
VOC	43	63	65	71	74	78	82
Total	**382**	**551**	**571**	**637**	**658**	**697**	**739**

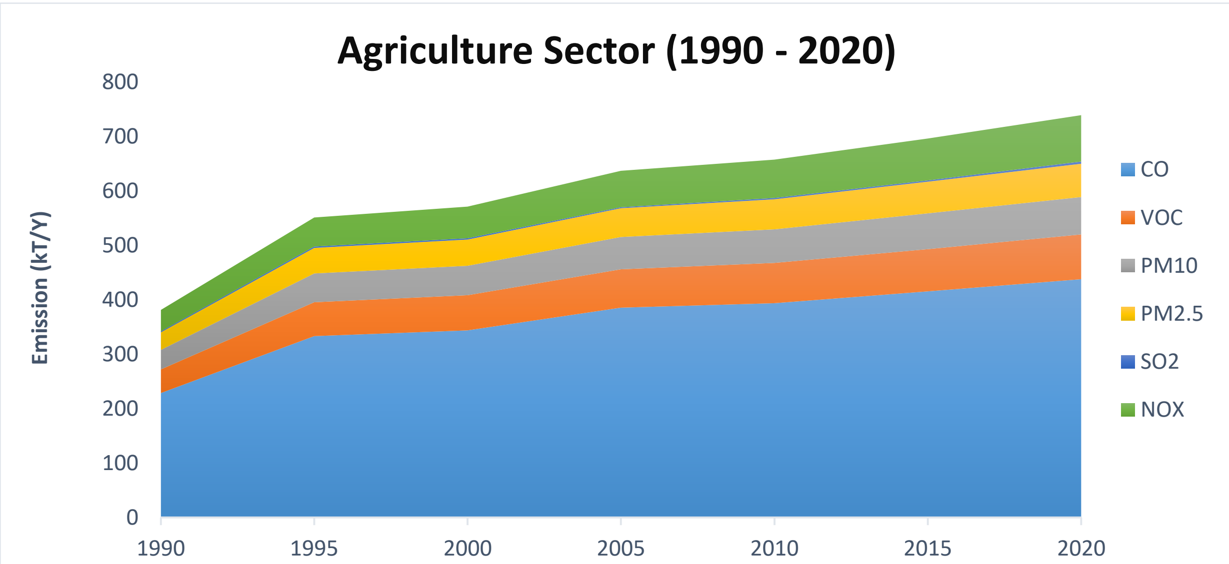


Figure 4.9: Temporal contribution of air pollutants by agriculture sector

The emissions from Industrial processes which do not involve combustion of fuel have been estimated at 611 kT in 2020. PM_{10} is the major pollutant emitted from this sector.

Table 4.9: Emission of air pollutants by NCIP from 1990 to 2020 (Unit in kT/Y)*

	1990	1995	2000	2005	2010	2015	2020
PM_{10}	90	121	152	179	191	241	265
$PM_{2.5}$	54	73	92	108	116	144	159
NOx	0.36	0.37	0.39	0.44	0.41	0.26	0.29
SO_2	1	1	0	0	0	0	0
CO	36	40	45	50	51	56	61
VOC	54	60	63	82	96	111	127
Total	**235**	**296**	**352**	**419**	**454**	**553**	**611**

* NCIP: Non-Combustion Industrial Processes

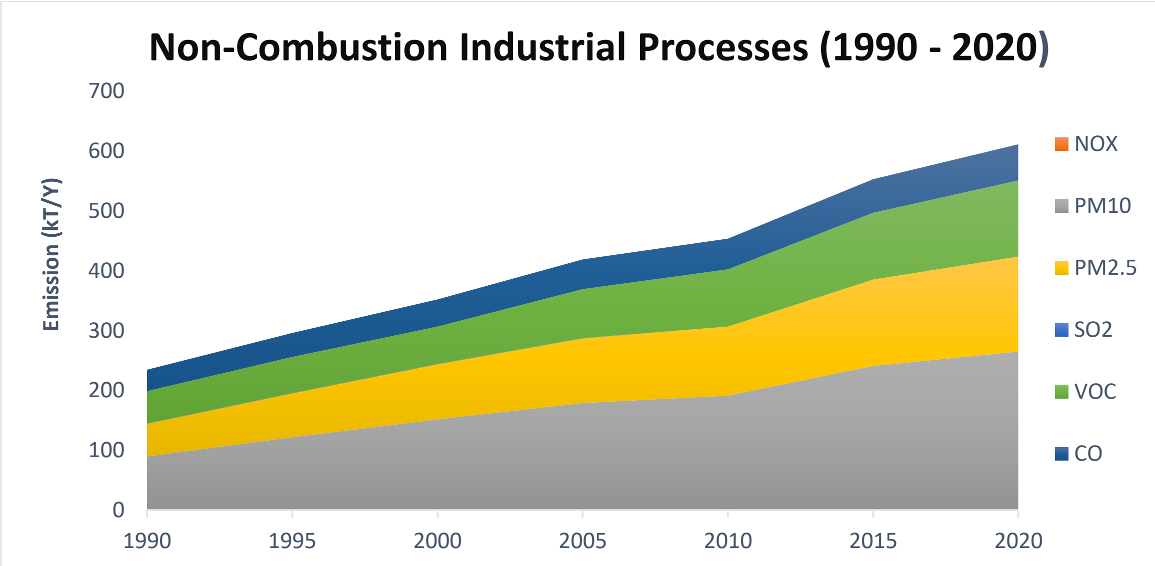


Figure 4.10: Temporal contribution of air pollutants by NCIP

Other Sectors emitted 82 kT of emissions in 2020, a decrease by 29% since 2010. Other sectors include domestic and commercial sectors.

Table 4.10: Emission of air pollutants by other sectors from 1990 to 2020 (Unit in kT/Y)

	1990	1995	2000	2005	2010	2015	2020
PM_{10}	20	22	23	24	23	24	25
$PM_{2.5}$	6	6	6	7	5	5	6
NOx	19	21	24	27	23	26	28
SO_2	6	8	13	14	1	2	3
CO	3	3	3	3	44	1	1
VOC	8	9	11	13	10	13	18
Total	**62**	**70**	**80**	**88**	**106**	**71**	**82**

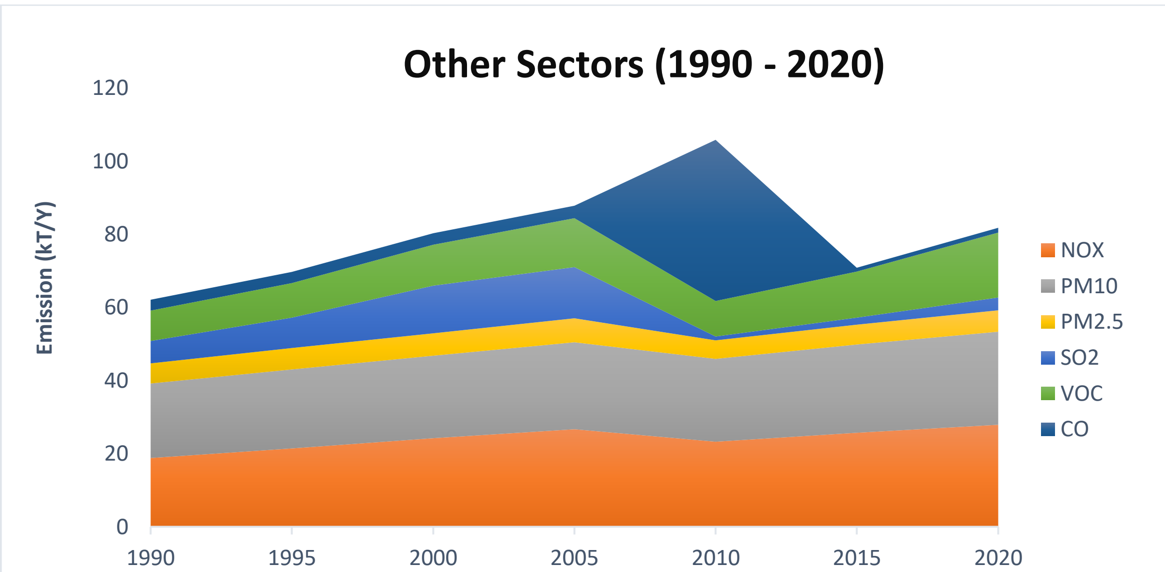


Figure 4.11: Temporal contribution of air pollutants by other sectors

The concentration of emissions and their percentage contribution with respect to each sector is given as Tables and also presented as charts below;

Table 4.11: Emissions of PM_{10} from different sectors in Punjab in 2020

Sectors	Emission (kT/Y)
Energy	302
Industry	450
Transport	44
Agriculture	69
NCIP	265
Others	25

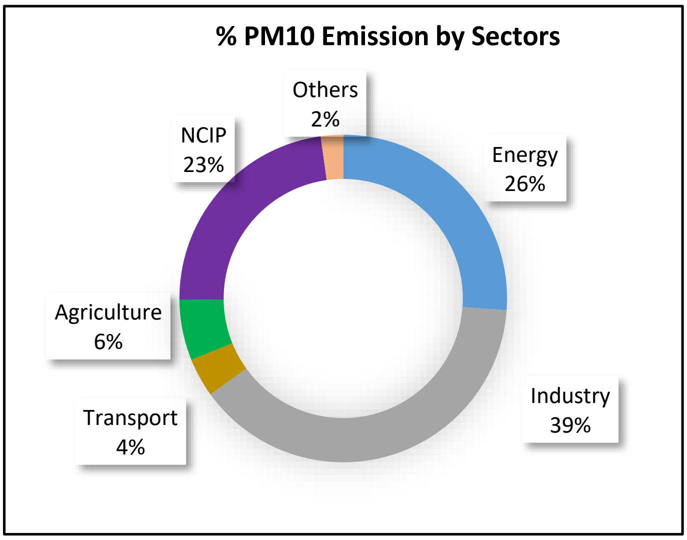


Figure 4.12 Sectoral contribution in PM_{10} in Punjab during 2020

Table 4.12: Emissions of $PM_{2.5}$ from different sectors in Punjab in 2020

Sectors	Emission (kT/Y)
Energy	83
Industry	180
Transport	37
Agriculture	61
NCIP	159
Others	6

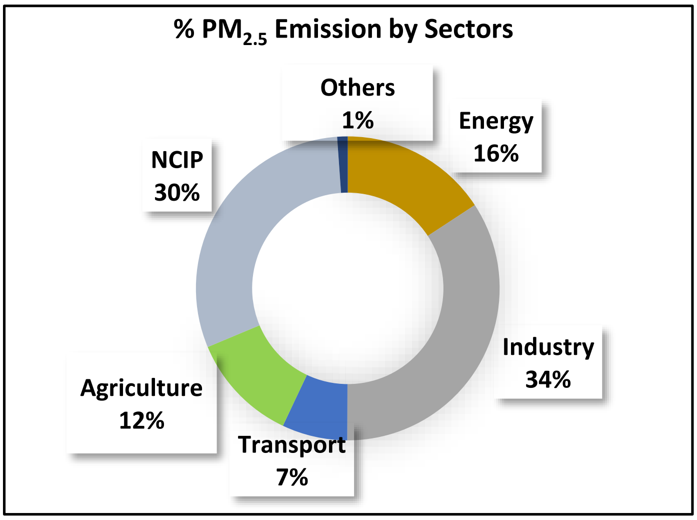


Figure 4.13: Sectoral contribution in $PM_{2.5}$ in Punjab during 2020

Table 4.13: Emissions of NOx from different sectors in Punjab in 2020

Sectors	Emission (kT/Y)
Energy	105
Industry	60
Transport	339
Agriculture	85
NCIP	0
Others	28

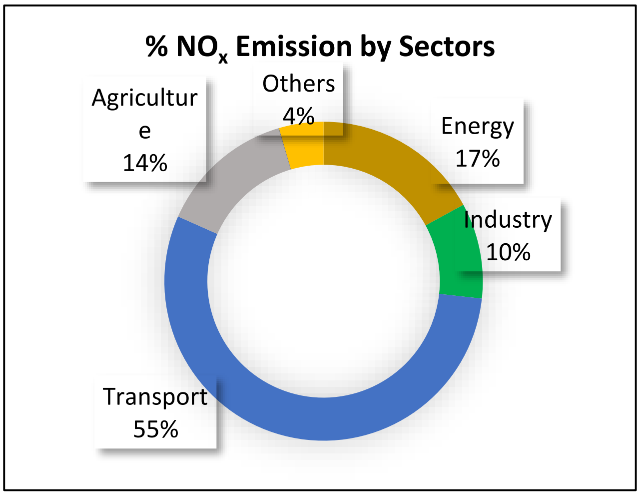


Figure 4.14: Sectoral contribution in NOx in Punjab during 2020

Table 4.14: Emissions of SO_2 from different sectors in Punjab in 2020

Sectors	Emission (kT/Y)
Energy	224
Industry	174
Transport	54
Agriculture	4
NCIP	0
Others	3

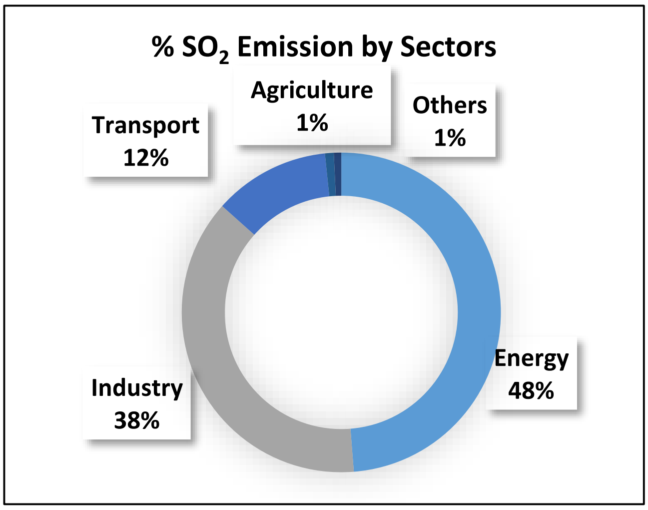


Figure 4.15: Sectoral contribution in SO_2 in Punjab during 2020

Table 4.15: Emissions of CO from different sectors in Punjab in 2020

Sectors	Emission (kT/Y)
Energy	373
Industry	845
Transport	2057
Agriculture	438
NCIP	61
Others	1

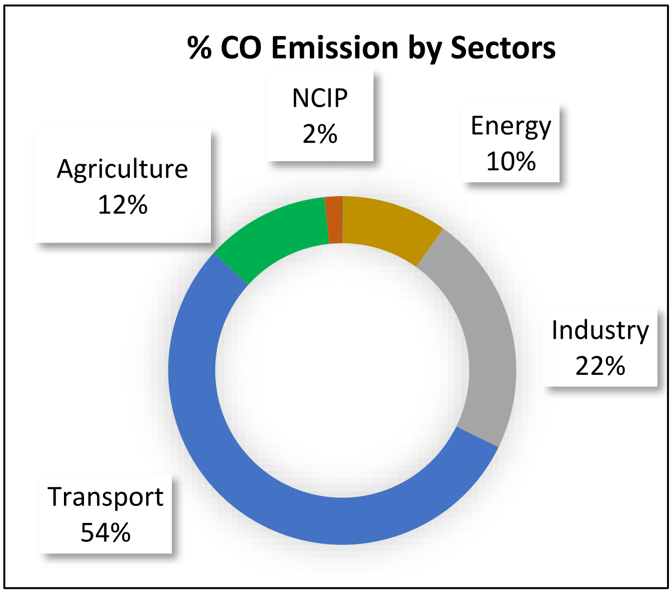


Figure 4.3: Sectoral contribution in CO in Punjab during 2020

Table 4.16: Emissions of VOC from different sectors in Punjab in 2020

Sectors	Emission (kT/Y)
Energy	16
Industry	11
Transport	232
Agriculture	82
NCIP	127
Others	18

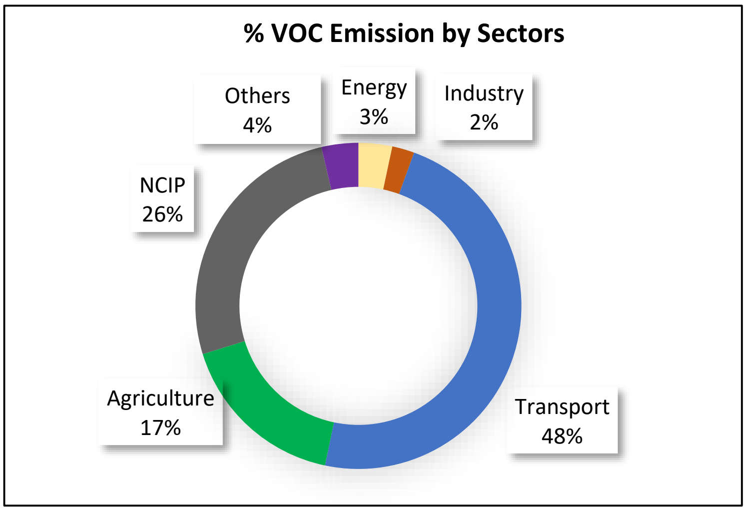


Figure 4.4: Sectoral contribution in VOC in Punjab during 2020

4.3. Fuel / activity wise Estimates of Emissions

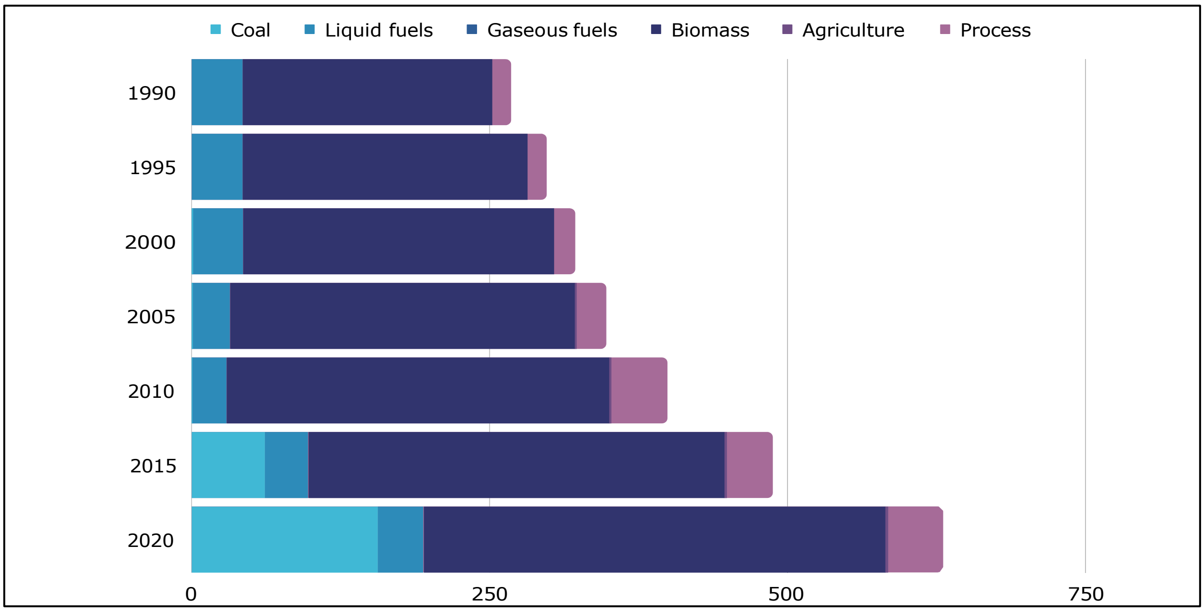
4.3.1. Particulate Matter ($PM_{2.5}$)

In terms of $PM_{2.5}$, it is also showing an increasing trend in the last two decades. For instance, it is observed that biomass burning has the highest contribution followed by agriculture and other activities from 1990 to 2020 as shown in Table 4.17. However, from 2015 onward a significant contribution of $PM_{2.5}$ emissions from coal burning is widely observed in the Punjab province. Moreover, contributions from liquid fuel, biomass burning non- exhaust, and agriculture are also playing a significant role as shown in Figure 4.18.

Table 4.17. Emissions of $PM_{2.5}$ from various key fuel types/ activities of Punjab province (Units in kT/Y)

$PM_{2.5}$	1990	1995	2000	2005	2010	2015	2020
Coal	n.a	n.a	1.2	1.0	0.7	61.4	156.2
Liquid fuels	42.6	42.6	41.8	31.1	28.5	36.2	38.2
Gaseous fuels	0.1	0.1	0.2	0.2	0.2	0.4	0.4
Biomass	209.0	238.6	260.7	289.0	320.8	348.9	387.2
Agriculture	1.2	1.4	1.6	1.8	2.0	2.3	2.6
NCIP*	14.6	14.7	16.2	24.7	46.9	38.4	46.0

(* NCIP: Non-Combustion Industrial Process)



* **Process** means Non-Combustion Industrial Process (NCIP)

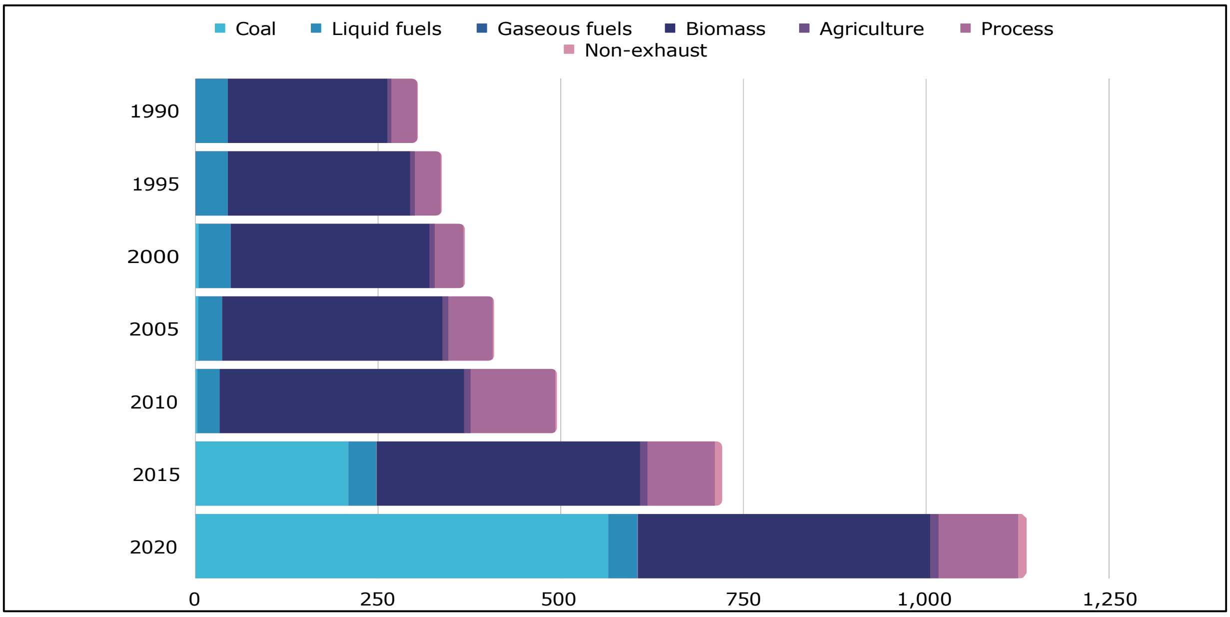
Figure 4.18. $PM_{2.5}$ Emission by key fuel types (Unit in kT/Y)

4.3.2. Particulate Matter (PM_{10})

In the present study, emissions of air pollutants from various key fuel types/ activities of Punjab province from 1990 to 2020 are given in Table 4.18. The results revealed that Biomass fuel is one of the major sources of PM_{10} emissions from 1990 to 2015. However, from 2015 to 2020 it is observed that the emission of PM_{10} from coal burning is contributing a significant role in the overall emission as shown in figure 4.19. This could be mainly due to the increasing number of coal-based power plants and bricks kiln in the Punjab province.

Table 4.18. Emissions of PM_{10} from various key fuel types/ activities of Punjab province (Units in kT/Y)

PM_{10}	1990	1995	2000	2005	2010	2015	2020
Coal	n.a	n.a	4.5	3.9	2.7	209.2	564.8
Liquid fuels	43.9	44.1	43.5	32.4	30.2	38.1	39.9
Gaseous fuels	0.1	0.1	0.2	0.2	0.2	0.4	0.4
Biomass	217.6	248.5	271.5	301.0	334.1	360.3	399.7
Agriculture	5.3	6.4	7.2	7.9	8.8	10.1	11.5
Process	35.3	35.4	39.3	60.8	115.9	92.2	109.1
Non-exhaust	0.9	1.4	1.9	1.9	2.2	9.9	11.5



* **Process** means Non-Combustion Industrial Process (NCIP)

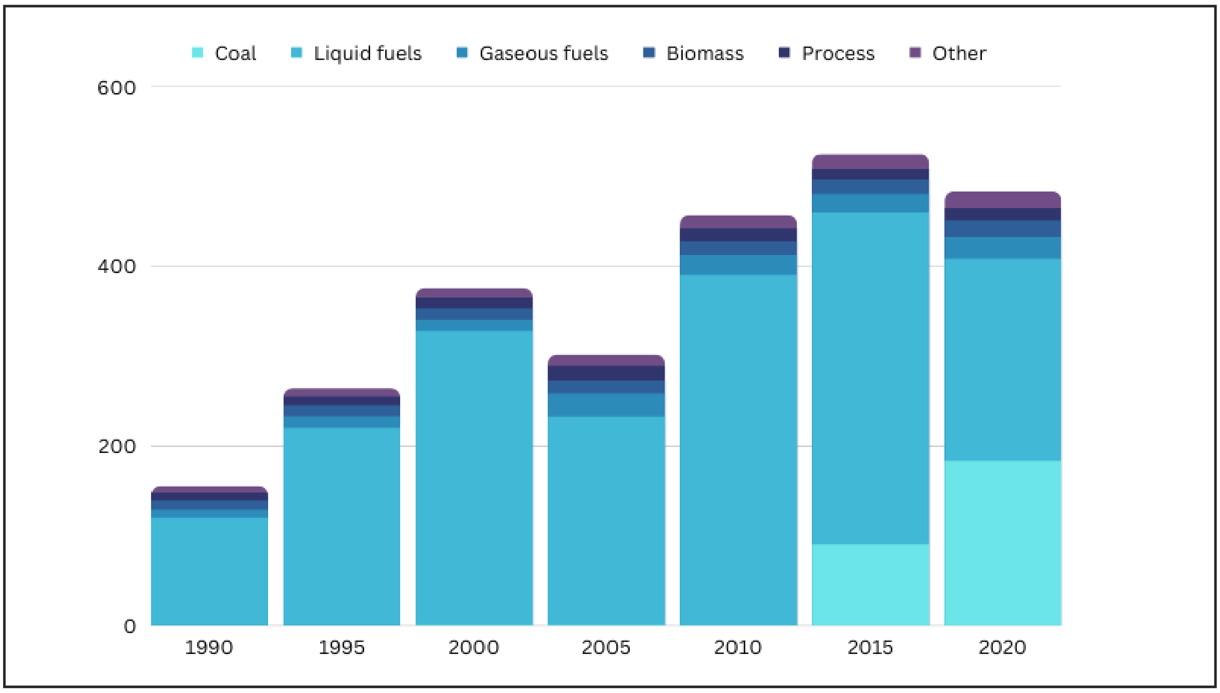
Figure 4.19. PM_{10} Emission by key fuel types (Unit in kT/Y)

4.3.3. Sulphur Dioxide (SO_2)

In terms of Sulphur dioxide emission by key fuel/ activity, it was observed that the highest contribution is associated with liquid fuel from 1992 to 2020. However, from 2015 onward it was noted that other fuel/ activity is also playing a substantial role in SO_2 emissions. For instance, in 2015 and 2020, other fuel/ activity is almost contributing approximately, 16.26 kT and 18.6 kT, whereas liquid fuel is contributing 368.37 kT and 224.93 kT of SO_2 emissions. So, it is quite evident that the emission from liquid fuel is decreasing however, other fuel types are contributing towards higher SO_2 emissions as shown in Table 4.19 and figure 4.20.

Table 4.19. Emissions of SO2 from various key fuel types/ activities of Punjab province (Units in kT/Y)

SO_2	1990	1995	2000	2005	2010	2015	2020
Coal	n.a	n.a	1.2	1.05	0.7	90.7	183.1
Liquid fuels	119.5	219.5	326.3	231.7	389.1	368.4	224.9
Gaseous fuels	9.1	13.1	12.7	25.5	22.1	21.0	24.4
Biomass	10.1	11.6	12.7	14.1	15.6	16.0	17.8
Process	8.5	9.8	12.0	16.6	14.5	11.8	14.0
Other	7.1	9.2	10.7	12.4	14.2	16.3	18.6



* **Process** means Non-Combustion Industrial Process (NCIP)

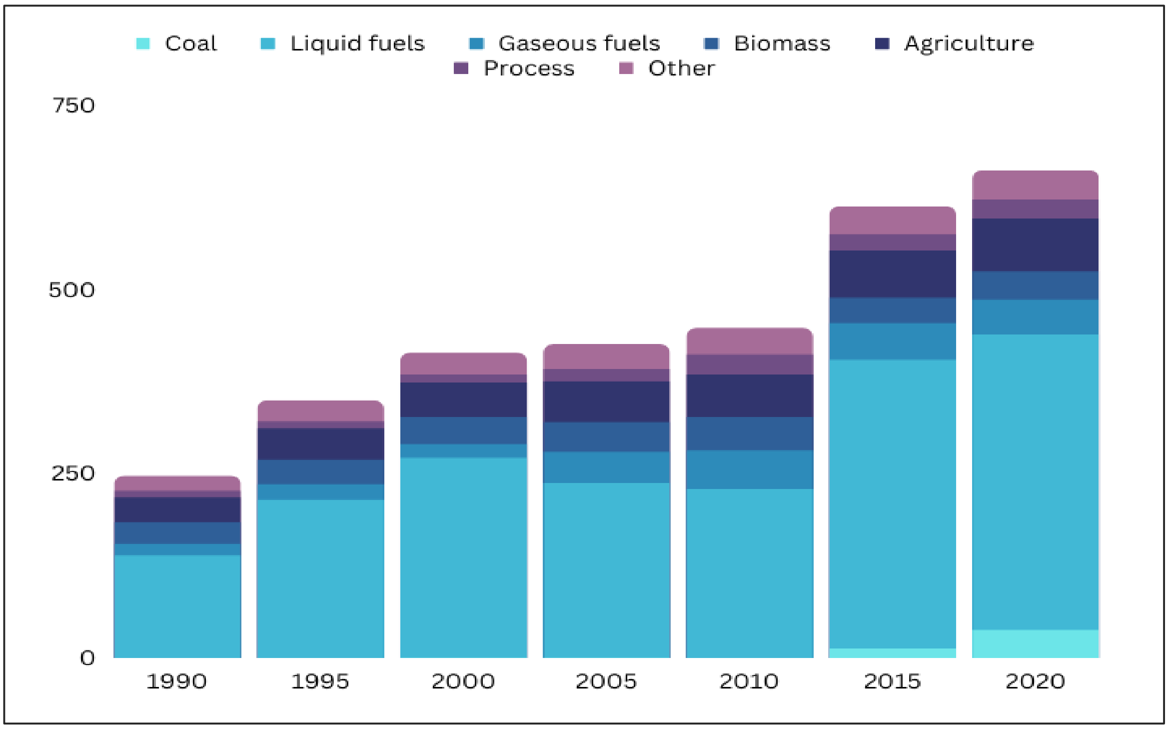
Figure 4.20. Sulphur Dioxide Emission by key fuel types (Unit in kT/Y)

4.3.4. Nitrogen Oxides (NO_x)

The total emission from various fuel types / activities for NOx was also calculated in the present study. It was found that agriculture burning is the key source of NOx emissions. During the study, it was observed that liquid fuels roughly contribute 400kT in 2020, whereas, 138kT in 1990 as shown in Table 4.20. Moreover, besides, liquid fuels, agriculture, and gaseous fuels are also contributing to NOx emissions whilst, the overall contribution is less than 30% of the total emission as shown in Figure 4.21.

Table 4.20. Emissions of NOx from various key fuel types/ activities of Punjab province (Units in kT/Y)

NOx	1990	1995	2000	2005	2010	2015	2020
Coal	-	-	0.3	0.3	0.2	13.0	38.6
Liquid fuels	138.9	214.6	271.0	236.6	229.1	391.4	400.0
Gaseous fuels	15.8	20.6	18.4	42.2	51.8	49.8	47.4
Biomass	28.8	33.2	36.5	40.4	44.9	34.5	38.4
Agriculture	33.4	41.8	46.5	55.5	57.8	64.1	71.3
Process	9.1	9.6	11.1	16.6	27.1	21.9	26.1
Other	20.3	28.6	29.7	33.5	35.8	37.7	39.7



* **Process** means Non-Combustion Industrial Process (NCIP)

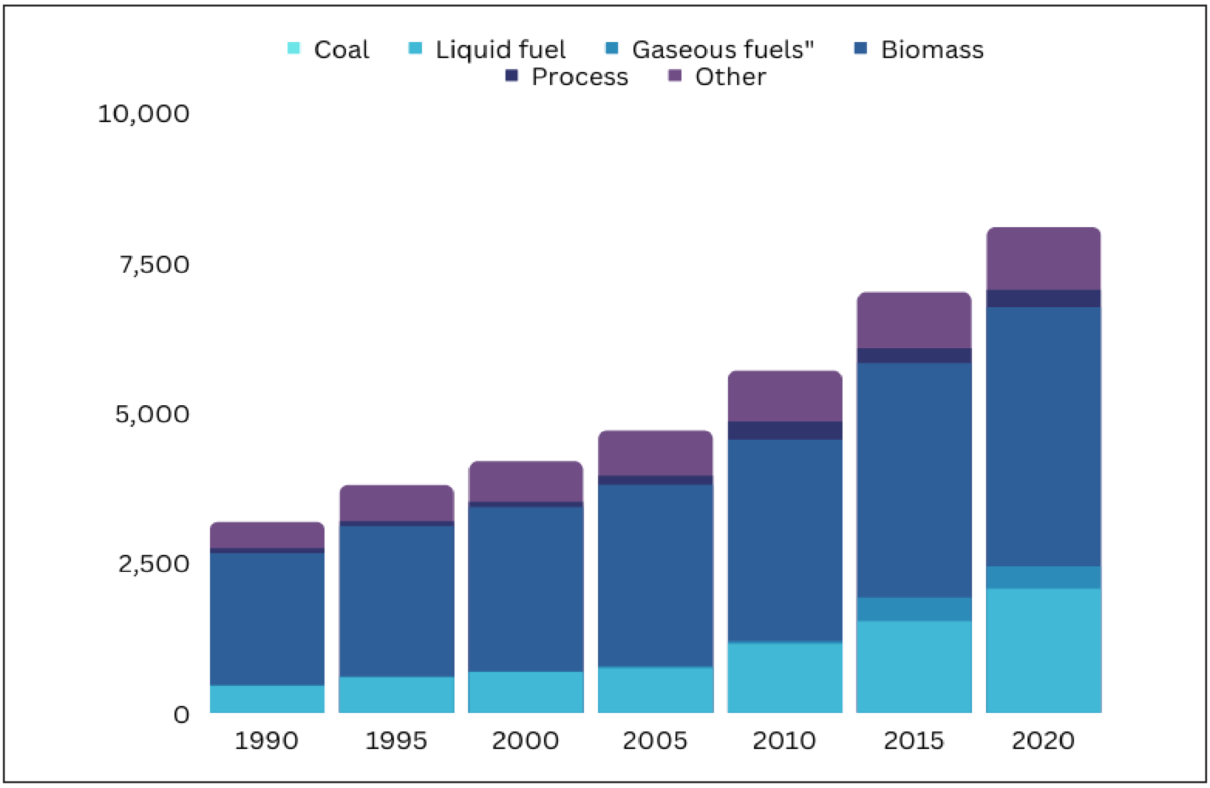
Figure 4.21. Nitrogen Dioxide Emission by key fuel types (Unit in kT/Y)

4.3.5. Carbon Monoxide (CO)

Moreover, the results of carbon monoxide depict that the overall trend of CO emissions from various fuel types is significantly increasing over the last two decades. In the present research, it was found that biomass burning (4,317 kT) and liquid fuels (2,071 kT) are the major contributors to CO emissions. However, other fuel types including coal, gaseous fuels, and process fuels are contributing less than 30%, as shown in Table 4.21 and Figure 4.22.

Table 4.21. Emissions of CO from various key fuel types/ activities of Punjab province (Units in kT/Y)

CO	1990	1995	2000	2005	2010	2015	2020
Coal	-	-	0.01	0.01	0.01	3.0	4.8
Liquid fuels	458.9	601.4	687.8	751.0	1157.5	1531.9	2071.9
Gaseous fuels	4.1	6.3	8.9	29.4	43.4	400.0	370.4
Biomass	2193	2499	2727	3023	3356	3892	4317
Process	83.3	83.4	92.6	144.3	294.7	242.8	291.6
Other	442.2	600.4	665.9	752.6	844.9	936.3	1036.9



* **Process** means Non-Combustion Industrial Process (NCIP)

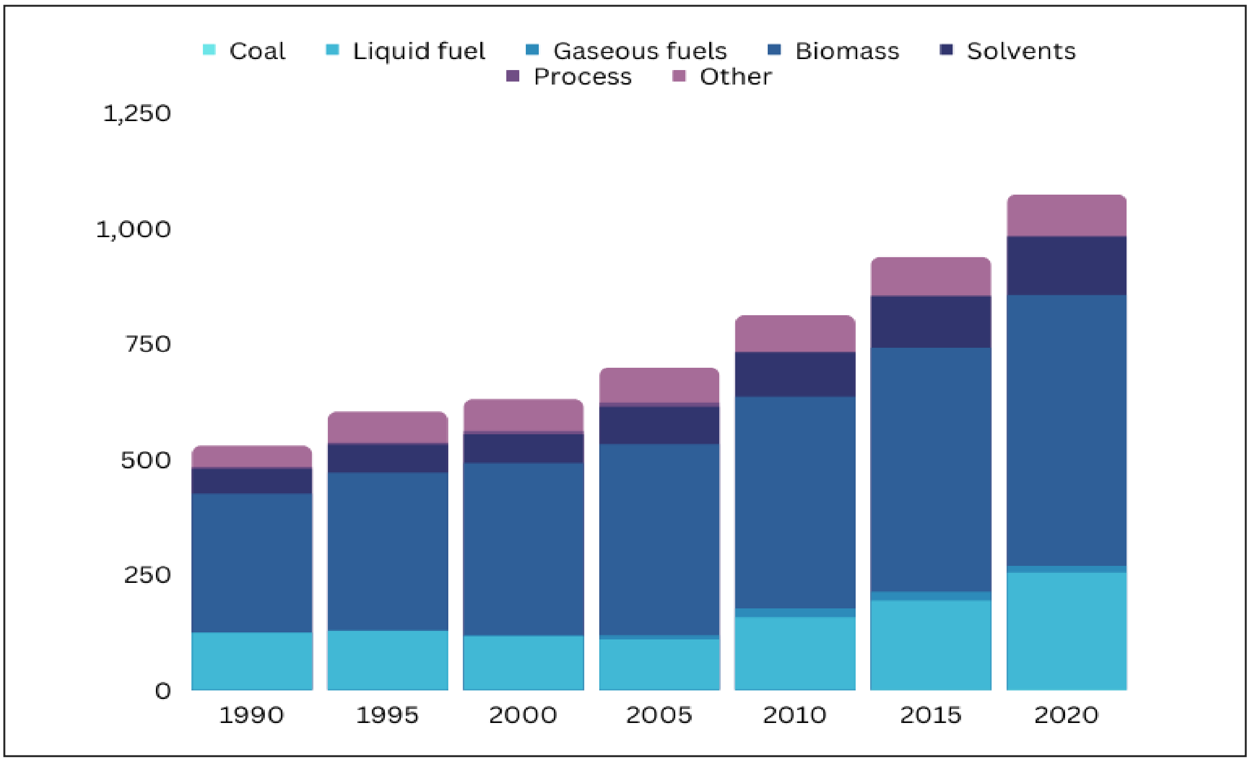
Figure 4.22. Carbon Monoxide Emission by key fuel types (Unit in kT/Y)

4.3.6. Volatile Organic Compound (VOC)

In terms of Volatile Organic Compounds, it is found that VOC is mainly emitted as a result of biomass burning (585.6 kT) followed by liquid fuels (252.4 kT) and solvents (127 kT) during 2020 (Table 4.22). In addition, there is a significant increase in the emission of VOC from biomass and liquid fuel during the study period, in Punjab as shown in Figure 4.23.

Table 4.22. Emissions of VOC from various key fuel types/ activities of Punjab province (Unit in kT/Y)

VOC	1990	1995	2000	2005	2010	2015	2020
Coal	-	-	-	-	-	0.99	1.43
Liquid fuels	123.5	127.6	115.7	108.7	157.0	192.8	252.4
Gaseous fuels	0.3	0.5	1.6	8.9	19.0	18.3	14.4
Biomass	299.0	340.8	371.8	412.1	457.5	527.9	585.6
Solvents	54.0	60.1	62.6	81.7	95.7	111.3	127.0
Process	4.2	5.5	7.2	9.2	0.0	0.0	0.0
Other	45.3	65.7	68.5	75.4	80.0	85.0	90.3



* **Process** means Non-Combustion Industrial Process (NCIP)

Figure 4.23. VOC Emissions by key fuel types (Unit in kT/Y)

DISCUSSION AND RECOMMENDATIONS

CHAPTER 5: DISCUSSION AND RECOMMENDATIONS

The GAINS model is one of the most comprehensive tools, that enable estimations of air pollutants and greenhouse gases, defined by the Kyoto Protocol. This study uses this model to analyze the source-based anthropogenic emissions of air pollutants including particulate matter ($PM_{2.5}$ & PM_{10}), and gaseous pollutants (NOx, SO_2, CO, and VOCs) from key sectors in Punjab including transport, industry, energy, agriculture and others for the duration of 1990–2020. In general, the combustion processes in energy, industrial, transport and agricultural sectors collectively account for 88% of total emissions whereas 12% emissions are estimated from non-combustion industrial processes (NCIP) and other sectors *(e.g., refining, storage of chemicals; mining; wood processing; livestock and poultry etc.).*

On average, from 1990 to 2020, the transport sector was found major contributor of anthropogenic emissions with 36% share followed by industry (24%), agriculture (15%), energy (13%), NCIP (10%) and others (2%). In 2020, the contribution from different sectors is quantified as; transport (39%), industry (24%), energy (16%), agriculture (11%), NCIP (9%) and others (1%). The overall emission load of six air pollutants in year 2020 is estimated as 7,017 kT/Y which is 3.5 times higher than the emissions in 1990.

In year 2020, CO (3,773 kT/Y) is found as major contributor followed by PM_{10} (1,156 kT/Y), NOx (617 kT/Y), $PM_{2.5}$ (525 kT/Y), VOC (486 kT/Y), and SO_2 (460 kT/Y). Transport sector is the major contributor of CO, NOx and VOC. The energy sector is noted as major emitter of SO_2 whereas industry sector has major share in PM_{10} and $PM_{2.5}$ emissions.

Concerning the release of pollutants from different fuel types / activities, biomass burning is major source of PM_{10} (305 kT/Y), $PM_{2.5}$ (293 kT/Y), CO (3,144 kT/Y) and VOC (428 kT/Y) on average (1990 – 2020). Liquid fuels are found significant emitters of CO (1,037 kT/Y) followed by NOx (269 kT/Y) and SO_2 (268 kT/Y) during 1990 – 2020 in Punjab.

An overall increasing trend was observed during 1990–2020 for all air pollutants: PM_{10} (245 – 1,156 kT/Y), $PM_{2.5}$ (161 – 525 kT/Y), NOx (225 – 617 kT/Y), SO_2 (142 – 460 kT/Y), CO (1,008 – 3,773 kT/Y), and VOCs (231 – 486 kT/Y). The bi-decadal increasing trend in emissions is in line with growing economic activities in Punjab in the form of increasing number of vehicles, factories; and installation of new power plants during the same period as depicted in Figures 5.1 to 5.3.

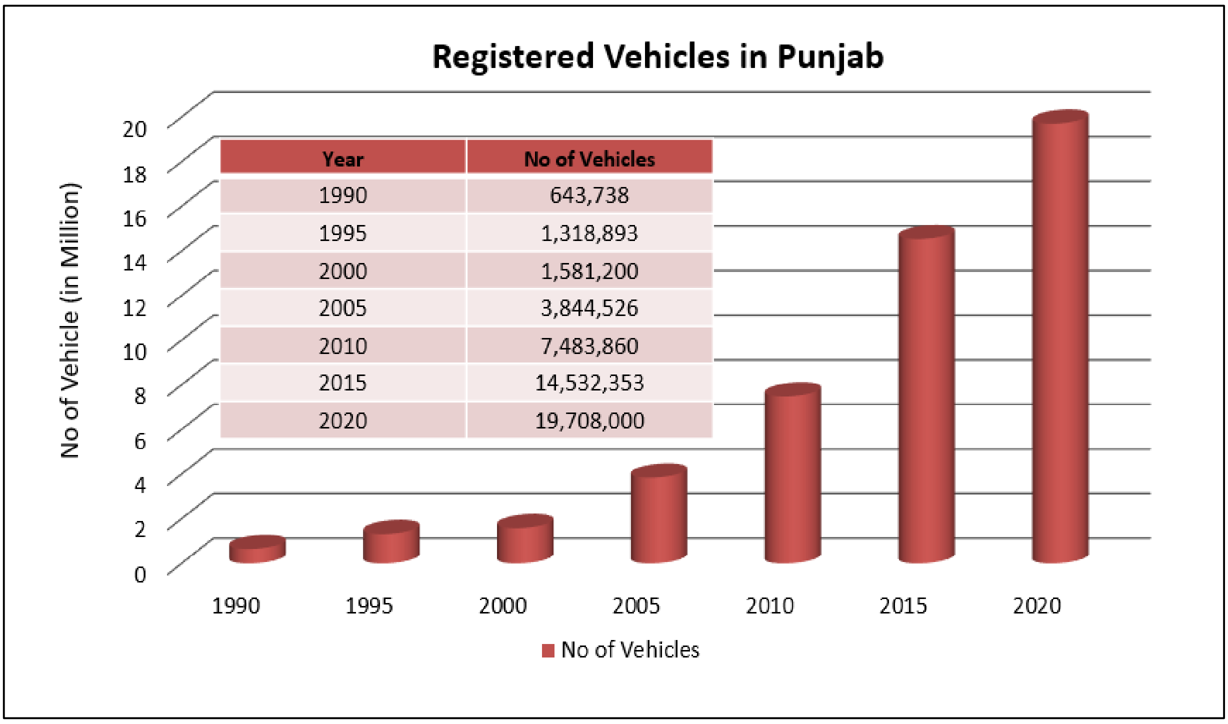


Figure 5.1: Numbers of registered vehicles in Punjab (1990 – 2020) [Source: Punjab Development Statistics Reports 1995 to 2021]

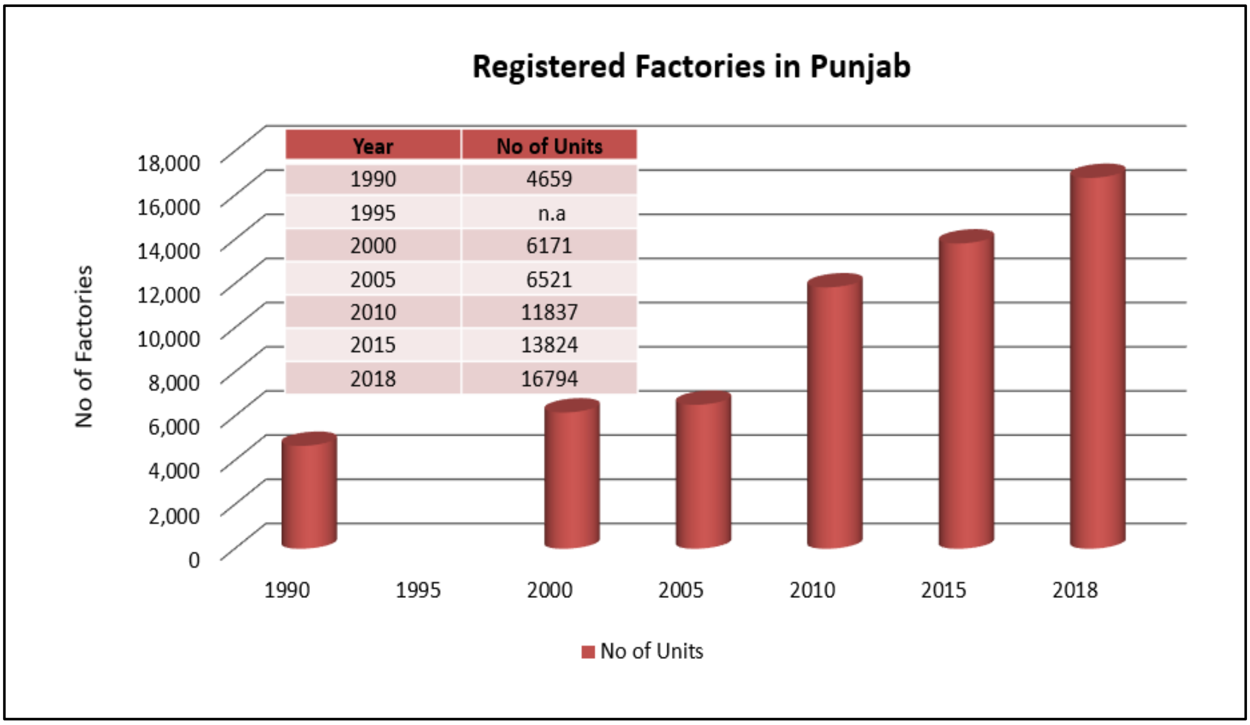


Figure 5.2: Numbers of registered factories in Punjab (1990 – 2020) [Source: Punjab Development Statistics Reports 1995 to 2021]

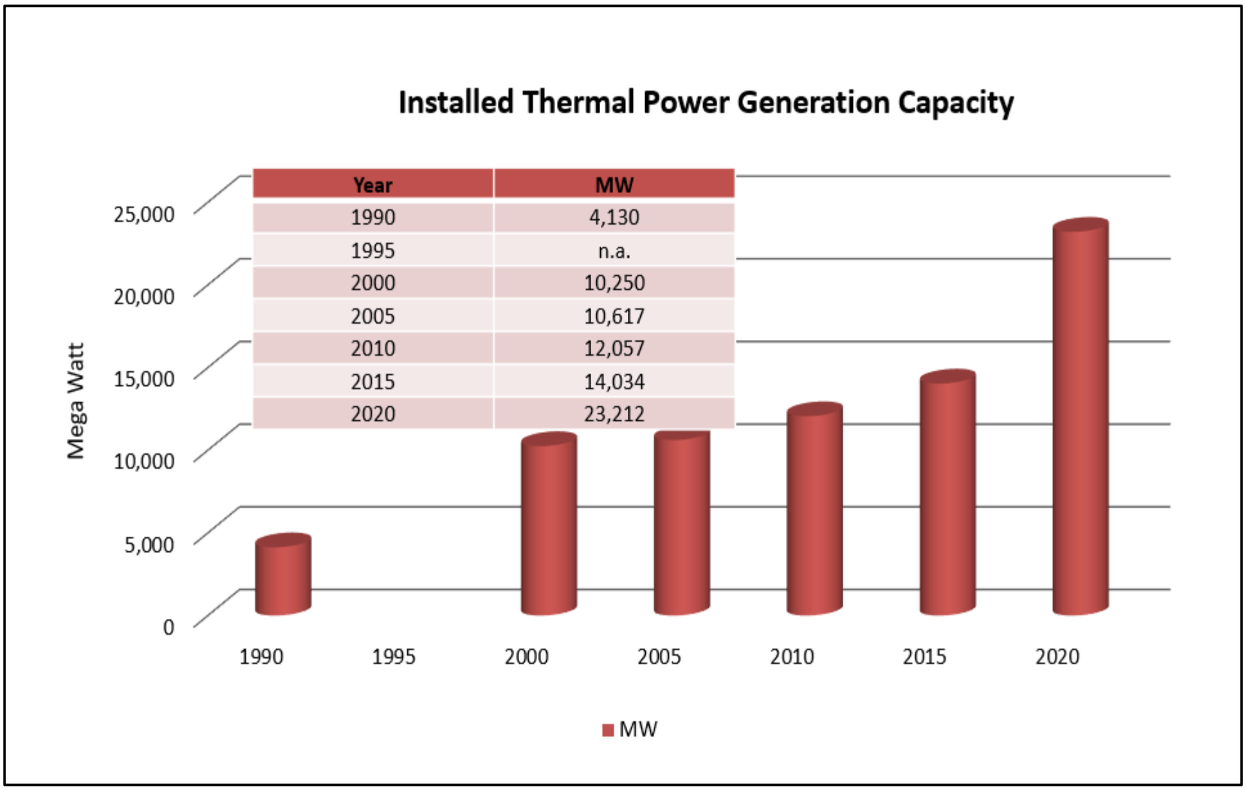


Figure 5.3: Power generation capacity in Punjab (1990 – 2020) [Source: Punjab Development Statistics Reports 1995 to 2021]

The outcomes of the report in the form of emissions information of different pollutants shall assist in identifying hotspot sectors as well as planning the technical and financial measures to set safe air emission levels and meet sustainable development goals (SDGs). The current emission inventory can also be used as the basis for estimating future emissions according to projected changes in socio-economic indices (e.g., population growth, economic growth, changes in energy use per unit activity); lowering the emissions (e.g., by introduction of better control measures); switching to renewable energy sources and so forth.

The increasing frequency of emissions of air pollutants calls for a swift and well-planned approach towards the diminution of air pollutants. The foremost steps in this direction could be as follow:

1. Geographical allocation of the estimated emissions may be carried out by simulation of air quality models and ground-based observations. This is utterly important for the identification of areas of priority interventions.
2. Formation of Tier 2 and Tier 3 air pollution emission inventories by developing country-specific and/or activity-specific emission factors rather than relying on international manuals / dataset. This will improve the accuracy of the national / provincial emission inventories by taking in to account the local practices and technologies.
3. An update to the emission inventory is recommended every three to five years to check the effectiveness of control measures and compliance of regulatory standards.
4. The process of collecting the activity data at local level is an enormous and laborious task. Most of the time, fuel consumption and production data by industries is not easily available. A policy may be formulated by national / provincial government to make every industry responsible to provide their activity data on annual basis to concern environmental protection agencies.

ANNEXURES

ANNEXURE A

Emission estimates of particulate matters (PM_{10}) from different sources (1990 to 2020)

(Unit: Kilogram tons per year, kT/Y)

Sub-sectors / Processes	1990	1995	2000	2005	2010	2015	2020
Public electricity and heat production	2.87	4.62	10.39	8.99	9.15	13.41	302.08
Petroleum refining	0.03	0.03	0.05	0.06	0.05	0.10	0.10
Manufacture of solid fuels and other energy industries	n.a	n.a	n.a	n.a	n.a	1.42	2.32
Stationary combustion in industry Iron and steel	0.00	0.00	0.00	0.00	0.00	1.85	2.85
Stationary combustion in industry: Chemicals	0.00	0.01	0.01	0.02	0.02	0.01	0.01
Stationary combustion in industry: Food processing, beverages and tobacco and Other	17.07	20.10	22.41	24.76	27.46	205.64	264.99
Stationary combustion in industry: Nonmetallic minerals	56.32	62.87	73.19	100.92	167.82	152.64	179.17
Mobile Combustion in industry	n.a	n.a	n.a	0.03	0.02	0.09	0.11
Road transport: Passenger cars	0.02	0.04	0.61	1.27	2.02	3.54	4.53
Road transport: Light duty vehicles	0.03	0.25	0.32	0.43	3.10	3.49	4.44
Road transport: Heavy duty vehicles and buses	7.30	11.45	14.88	12.34	8.69	14.10	17.95
Road transport: Mopeds and motorcycles	14.39	12.40	8.70	6.30	5.63	4.30	6.09
Road transport: Automobile tyre and brake wear	0.57	0.89	1.19	1.16	1.32	6.13	7.07
Road transport: Automobile road abrasion	0.35	0.54	0.72	0.72	0.88	3.79	4.38
Agriculture/Forestry/Fishing: Stationary	0.03	0.03	0.03	0.01	0.01	0.01	0.01
Field burning of agricultural residues	35.77	52.23	53.91	59.12	62.06	65.47	68.97
Agriculture/Forestry/Fishing: Off_road vehicles and other machinery	0.41	0.39	0.36	0.13	0.06	0.07	0.08
Fugitive emissions Oil	0.59	0.62	0.65	0.74	0.75	0.47	0.51
Quarrying and mining of minerals other than coal	0.16	0.27	0.35	0.53	n.a	n.a	n.a
Storage, handling and transport of mineral products	0.34	0.34	0.37	0.58	0.71	1.40	1.91
Chemical industry: Other	74.35	104.24	132.15	156.44	168.27	216.49	238.98
Storage, handling and transport of chemical products	0.14	0.18	0.22	0.30	0.30	0.30	0.30
Other solvent use	8.19	9.23	10.49	11.74	12.25	12.93	13.61
Pulp and paper industry	0.02	0.02	0.02	0.02	n.a	n.a	n.a
Wood processing	5.83	6.57	7.46	8.35	8.71	9.20	9.69
Commercial / institutional: stationary	0.08	0.10	0.16	0.18	0.15	0.33	0.43
Other / mobile (including military / land based and recreational boats)	n.a	n.a	n.a	n.a	0.06	n.a	n.a

Civil aviation	0.00	0.00	0.00	0.01	0.01	0.00	0.00
Coal mining and handling	0.13	0.14	0.16	0.20	0.26	0.26	0.23
Solid fuel transformation	1.50	1.42	1.16	1.14	n.a	n.a	n.a
Oil: Refining / storage	0.55	0.72	0.96	1.23	n.a	n.a	n.a
Venting and flaring	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Dairy cattle_Manure management	3.33	3.67	3.95	4.05	3.77	4.01	4.25
Laying hens_Manure management	0.76	1.04	1.28	1.50	1.93	2.37	2.80
Other poultry_Manure management	1.19	1.63	1.99	2.34	3.06	3.75	4.43
N-fertilizer	11.96	11.87	11.84	11.93	11.96	11.94	11.92
Storage, handling and transport of agricultural products	0.80	0.96	1.09	1.21	1.39	1.39	1.39
Sum	**245.09**	**308.87**	**361.07**	**418.74**	**501.87**	**740.87**	**1155.63**

ANNEXURE B

Emission estimates of particulate matters ($PM_{2.5}$) from different sources (1990 to 2020)

(Unit: Kilogram tons per year, kT/Y)

Sub-sectors / Processes	1990	1995	2000	2005	2010	2015	2020
Public electricity and heat production	2.59	4.11	6.35	5.56	6.27	11.32	82.84
Petroleum refining	0.02	0.02	0.03	0.04	0.04	0.07	0.07
Manufacture of solid fuels and other energy industries	0.00	0.00	0.00	0.00	0.00	1.07	1.37
Stationary combustion in industry Iron and steel	0.00	0.00	0.00	0.00	0.00	0.48	0.74
Stationary combustion in industry: Chemicals	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Stationary combustion in industry: Food processing, beverages and tobacco and Other	14.75	17.37	19.36	21.41	23.75	60.50	77.96
Stationary combustion in industry: Non metallic minerals	30.83	35.88	42.32	55.51	86.74	84.88	99.84
Mobile Combustion in industry	0.00	0.00	0.00	0.03	0.02	0.09	0.11
Road transport: Passenger cars	0.02	0.04	0.59	1.22	1.93	3.38	4.32
Road transport: Light duty vehicles	0.03	0.24	0.31	0.41	2.96	3.33	4.25
Road transport: Heavy duty vehicles and buses	7.16	11.24	14.60	12.12	8.54	13.85	17.62
Road transport: Mopeds and motorcycles	13.66	11.77	8.25	5.98	5.34	4.08	5.78
Road transport: Automobile tyre and brake wear	0.17	0.27	0.37	0.36	0.40	1.91	2.20
Road transport: Automobile road abrasion	0.19	0.30	0.40	0.40	0.49	2.12	2.45
Field burning of agricultural residues	31.74	46.34	47.84	52.46	55.06	58.09	61.20
Agriculture/Forestry/Fishing: Stationary	0.02	0.02	0.02	0.01	0.01	0.01	0.01
Agriculture/Forestry/Fishing: Off_road vehicles and other machinery	0.39	0.37	0.34	0.12	0.06	0.06	0.08
Fugitive emissions Oil	0.59	0.62	0.65	0.74	0.75	0.47	0.51
Quarrying and mining of minerals other than coal	0.02	0.03	0.03	0.05	n.a	n.a	n.a

Storage, handling and transport of mineral products	0.04	0.04	0.04	0.06	0.08	0.15	0.21
Chemical industry: Other	43.42	61.23	77.79	92.39	99.52	127.80	140.96
Storage, handling and transport of chemical products	0.02	0.02	0.03	0.04	0.04	0.04	0.04
Other solvent use	8.19	9.23	10.49	11.74	12.25	12.93	13.61
Pulp and paper industry	0.02	0.02	0.02	0.02	n.a	n.a	n.a
Wood processing	1.94	2.19	2.49	2.78	2.90	3.07	3.23
Commercial / institutional: stationary	0.07	0.09	0.12	0.15	0.15	0.32	0.42
Other / mobile (including military / land based and recreational boats)	n.a	n.a	n.a	n.a	0.06	n.a	n.a
Coal mining and handling	0.01	0.01	0.02	0.02	0.03	0.03	0.02
Solid fuel transformation	1.01	0.96	0.78	0.77	n.a	n.a	n.a
Civil aviation	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Oil: Refining / storage	0.44	0.58	0.77	0.98	n.a	n.a	n.a
Venting and flaring	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Dairy cattle_Manure management	0.74	0.82	0.88	0.90	0.84	0.89	0.95
Laying hens_Manure management	0.17	0.23	0.28	0.33	0.43	0.53	0.62
Other poultry_Manure management	0.26	0.36	0.44	0.52	0.68	0.83	0.98
N-fertilizer	2.66	2.64	2.63	2.65	2.66	2.65	2.65
Storage, handling and transport of agricultural products	0.13	0.15	0.17	0.19	0.22	0.22	0.22
Sum	**161.30**	**207.17**	**238.44**	**269.98**	**312.21**	**395.17**	**525.28**

ANNEXURE C

Emission estimates of sulfur dioxide (SO_2) from different sources (1990 to 2020)

(Unit: Kilogram tons per year, kT/Y)

Sub-sectors / Processes	1990	1995	2000	2005	2010	2015	2020
Public electricity and heat production	79.70	163.16	255.75	179.16	332.51	317.70	224.14
Petroleum refining	3.85	4.39	6.09	7.60	6.70	10.99	11.42
Manufacture of solid fuels and other energy industries	n.a	n.a	n.a	n.a	n.a	0.18	0.35
Stationary combustion in industry Iron and steel	0.21	0.21	0.17	0.57	0.24	0.69	1.16
Stationary combustion in industry: Chemicals	0.44	2.76	1.69	4.79	3.88	2.16	2.85
Stationary combustion in industry: Food processing, beverages and tobacco and Other	18.84	25.01	26.59	20.31	21.56	98.41	127.65
Stationary combustion in industry: Non metallic minerals	9.55	11.09	13.06	17.21	26.77	25.92	30.40
Mobile Combustion in industry	n.a	n.a	n.a	0.23	0.12	0.12	0.14
Road transport: Passenger cars	0.62	1.37	3.16	6.42	11.46	19.19	25.54
Road transport: Light duty vehicles	1.04	1.69	1.89	2.30	9.79	5.14	6.84
Road transport: Heavy duty vehicles and buses	15.63	24.52	31.86	26.44	18.63	12.24	15.56
Road transport: Mopeds and motorcycles	3.52	3.58	3.06	2.83	5.35	4.38	6.21
Field burning of agricultural residues	1.13	1.66	1.71	1.87	1.97	2.07	3.99

Agriculture/Forestry/Fishing: Stationary	0.09	0.08	0.08	n.a	n.a	n.a	n.a
Agriculture/Forestry/Fishing: Off_road vehicles and other machinery	0.64	0.60	0.57	0.25	0.09	0.08	0.09
Commercial / institutional: stationary	1.71	2.56	5.52	4.49	0.58	1.86	3.41
Other/mobile (including military/land-based and recreational boats)	n.a	n.a	n.a	n.a	0.45	n.a	n.a
Solid fuel transformation	0.28	0.27	0.22	0.22	n.a	n.a	n.a
Civil aviation	0.02	0.03	0.03	0.04	0.04	0.02	0.03
Oil: Refining / storage	4.13	5.44	7.22	9.20	n.a	n.a	n.a
Venting and flaring	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions Oil	0.02	0.02	0.02	0.03	0.03	0.02	0.02
Chemical industry: Other	0.46	0.47	0.38	0.42	n.a	n.a	n.a
Pulp and paper industry	0.05	0.05	0.05	0.05	n.a	n.a	n.a
Sum	**141.95**	**248.95**	**359.11**	**284.42**	**440.17**	**501.17**	**459.80**

ANNEXURE D

Emission estimates of nitrogen oxides (NOx) from different sources (1990 to 2020)

(Unit: Kilogram tons per year, kT/Y)

Sub-sectors / Processes	1990	1995	2000	2005	2010	2015	2020
Public electricity and heat production	46.28	69.05	75.02	71.11	77.43	153.64	105.20
Petroleum refining	0.51	0.97	1.10	1.10	1.15	1.04	1.09
Manufacture of solid fuels and other energy industries	0.00	0.00	0.00	0.00	0.00	0.94	1.13
Stationary combustion in industry Iron and steel	0.25	0.25	0.20	0.67	0.29	0.59	1.02
Stationary combustion in industry: Chemicals	0.15	2.17	1.24	2.25	1.87	1.30	1.71
Stationary combustion in industry: Food processing, beverages and tobacco and Other	14.83	17.93	20.18	25.29	25.20	20.53	27.24
Stationary combustion in industry: Non metallic minerals	7.85	8.08	8.96	14.00	27.64	22.53	26.68
Mobile Combustion in industry	0.00	0.00	0.00	0.85	0.47	0.77	0.93
Road transport: Passenger cars	2.35	5.19	11.18	29.74	57.57	73.79	90.49
Road transport: Light duty vehicles	3.90	5.34	5.73	6.83	22.54	19.08	25.28
Road transport: Heavy duty vehicles and buses	87.36	137.08	178.11	147.79	104.23	172.41	219.27
Road transport: Mopeds and motorcycles	2.56	2.47	1.99	1.73	2.87	2.69	3.81
Managed soils_Direct and indirect emissions	19.71	26.58	30.06	38.54	41.56	46.61	52.61

Field burning of agricultural residues	16.47	24.05	24.83	27.23	28.58	30.15	31.77
Agriculture/Forestry/Fishing: Stationary	0.02	0.02	0.02	0.05	0.07	0.04	0.05
Agriculture/Forestry/Fishing: Off_road vehicles and other machinery	3.20	3.00	2.82	1.18	0.46	0.51	0.62
Fugitive emissions Oil	0.33	0.34	0.36	0.41	0.41	0.26	0.29
Pulp and paper industry	0.03	0.03	0.03	0.03	n.a	n.a	n.a
Commercial / institutional: stationary	0.39	0.55	1.09	1.19	0.70	1.57	2.04
Other / mobile (including military / land based and recreational boats)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Civil aviation	0.06	0.08	0.09	0.12	0.11	0.07	0.09
Oil: Refining / storage	1.38	1.81	2.41	3.07	n.a	n.a	n.a
Venting and flaring	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Sheep_Manure management	3.38	3.83	4.21	5.37	6.29	6.66	7.02
Laying hens_Manure management	0.21	0.29	0.36	0.42	0.54	0.66	0.78
Manure management_Other poultry	13.42	14.88	16.08	16.55	15.66	16.80	17.94
Sum	**224.66**	**324.00**	**386.07**	**395.51**	**415.64**	**572.68**	**617.08**

ANNEXURE E

Emission estimates of carbon monoxide (CO) (1990 to 2020)

(Unit: Kilogram tons per year, kT/Y)

Sub-sectors / Processes	1990	1995	2000	2005	2010	2015	2020
Public electricity and heat production	13.74	20.17	22.96	24.77	24.00	423.15	372.68
Petroleum refining	0.12	0.32	0.32	0.30	0.31	0.26	0.27
Manufacture of solid fuels and other energy industries	n.a	n.a	n.a	n.a	n.a	2.08	2.28
Stationary combustion in industry Iron and steel	0.13	0.12	0.10	0.34	0.14	0.22	0.39
Stationary combustion in industry: Chemicals	0.08	1.08	0.62	1.12	0.94	0.66	0.86
Stationary combustion in industry: Food processing, beverages and tobacco and Other	25.69	30.40	34.03	39.53	42.37	7.01	9.43
Stationary combustion in industry: Non-metallic minerals	260.15	309.83	368.73	469.60	694.97	707.92	830.82
Mobile Combustion in industry	n.a	n.a	n.a	26.78	14.66	0.53	0.64
Road transport: Passenger cars	40.84	89.36	144.78	239.11	425.88	856.19	1192.23
Road transport: Light duty vehicles	54.44	69.03	72.61	85.53	235.88	158.90	217.01

Road transport: Heavy duty vehicles and buses	131.04	205.63	267.17	221.69	156.30	251.28	319.61
Road transport: Mopeds and motorcycles	214.35	213.45	178.56	161.20	292.45	231.57	327.84
Field burning of agricultural residues	226.70	331.01	341.70	374.70	393.31	414.92	437.14
Agriculture/Forestry/Fishing: Stationary	0.02	0.02	0.01	0.03	0.05	0.03	0.04
Agriculture/Forestry/Fishing: Off_road vehicles and other machinery	2.21	2.07	1.95	10.61	0.32	0.35	0.43
Fugitive emissions Oil	1.65	1.71	1.82	2.06	2.07	1.30	1.43
Chemical industry: Other	6.27	6.93	7.88	7.75	7.60	11.01	12.81
Other solvent use	27.83	31.37	35.64	39.91	41.63	43.95	46.28
Pulp and paper industry	0.14	0.14	0.14	0.14	n.a	n.a	n.a
Commercial / institutional: stationary	0.20	0.28	0.53	0.64	0.44	0.98	1.27
Other / mobile (including military / land based and recreational boats)	n.a	n.a	n.a	n.a	43.64	n.a	n.a
Solid fuel transformation	2.35	2.22	1.82	1.79	n.a	n.a	n.a
Oil: Refining / storage	0.44	0.57	0.76	0.97	n.a	n.a	n.a
Venting and flaring	0.01	0.01	0.01	0.01	0.03	0.03	0.02
Sum	**1008.37**	**1315.71**	**1482.15**	**1708.58**	**2377.00**	**3112.33**	**3773.47**

ANNEXURE F

Emission estimates of volatile organic compounds (VOCs) (1990 to 2020)

(Unit: Kilogram tons per year, kT/Y)

Sub-sectors / Processes	1990	1995	2000	2005	2010	2015	2020
Public electricity and heat production	4.79	7.18	8.30	7.80	8.42	26.29	16.25
Petroleum refining	0.01	0.02	0.02	0.03	0.03	0.03	0.03
Manufacture of solid fuels and other energy industries	n.a	n.a	n.a	n.a	n.a	0.69	0.76
Stationary combustion in industry Iron and steel	0.01	0.01	0.01	0.02	0.01	0.02	0.04
Stationary combustion in industry: Chemicals	0.01	0.07	0.04	0.09	0.08	0.05	0.06
Stationary combustion in industry: Food process, beverages, tobacco and Other	3.94	4.65	5.19	5.84	6.39	1.21	1.58
Stationary combustion in industry: Non metallic minerals	2.72	3.47	4.21	4.95	6.03	7.00	8.11
Mobile Combustion in industry	n.a	n.a	n.a	1.20	0.66	0.13	0.15
Road transport: Passenger cars	1.91	4.21	7.63	18.20	35.11	50.09	63.82
Road transport: Light duty vehicles	3.18	3.90	4.07	4.77	12.12	8.06	11.09
Road transport: Heavy duty vehicles and buses	8.06	12.65	16.44	13.64	10.64	17.01	20.81

Road transport: Mopeds and motorcycles	86.99	78.63	58.87	46.73	60.81	48.54	68.72
Road transport: Gasoline evaporation	13.77	16.42	16.96	19.77	37.94	47.78	67.64
Field burning of agricultural residues	42.62	62.23	64.24	70.44	73.94	78.01	82.18
Agriculture/Forestry/Fishing: Stationary	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture/Forestry/Fishing: Off_road vehicles and other machinery	0.52	0.49	0.46	0.51	0.07	0.08	0.10
Fugitive emissions Oil	0.02	0.02	0.02	0.02	0.02	0.01	0.01
Other solvent use	54.04	60.13	62.61	81.73	95.70	111.33	127.01
Commercial / institutional: stationary	0.01	0.02	0.04	0.04	0.03	0.07	0.09
Other / mobile (including military / land based and recreational boats)	n.a	n.a	n.a	n.a	2.39	n.a	n.a
Civil aviation	0.10	0.12	0.15	0.20	0.17	0.12	0.15
Oil: Refining / storage	4.13	5.44	7.22	9.20	n.a	n.a	n.a
Distribution of oil products	4.06	3.92	3.82	3.99	7.10	12.43	17.52
Venting and flaring	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**230.90**	**263.57**	**260.29**	**289.17**	**357.67**	**408.94**	**486.14**

Air Pollution Emission Inventory of Punjab, Pakistan (1990-2020)

The Urban Unit

Urban Sector Planning & Management Services Unit (Pvt.) Ltd.

SUPARCO

PAKISTAN SPACE & UPPER ATMOSPHERE RESEARCH COMMISSION