SPACE TECH IN SOCIO-ECONOMIC DEVELOPMENT

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

Sectoral Emission Inventory of Lahore




SECTORAL EMISSIONS INVENTORY OF LAHORE

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List of Acronyms

EPI	Environment Performance Index
IPCC	Intergovernmental Panel on Climate Change
AMIS	Agriculture Marketing Information System
EEA	European Environment Agency
EF	Emission Factor
GCISC	Global Change Impact Studies Center
GDP	Gross Domestic Product
FAO	Food and Agricultural Organization
GoKP	Government of Khyber Pakhtunkhwa
CPEC	China-Pakistan Economic Corridor
IPPU	Industrial Products and Process Use
AFOLU	Agriculture, Forestry and Land Use
PM	Particulate Matter
NMVOCs	Non-Metallic Volatile Organic Carbons
SOx	Sulfur Oxides
NOx	Nitrogen Oxides
TSP	Total Suspended Particulates
CO	Carbon Oxides
CH_4	Methane
BC	Black Carbon
OC	Organic Carbon
O_3	Ozone
UNECE	United Nations Economic Commission for Europe
TFEIP	Task Force for Emission Inventory Preparation
CAMSRA	Copernicus Atmospheric Monitoring Services Reanalysis Data
USEPA	United States Environment Protection Agency
BAM	Beta-Attenuation Monitor
LPG	Liquefied Petroleum Gas
LNG	Liquefied Natural Gas
GHG	Greenhouse Gas
PDS	Punjab Development Statistics
FIRMS	Fire Information for Resource Management
VIIRS	Visible Infrared Imager-Radiometer Suite
MODIS	Moderate Resolution Imaging Spectroradiometer
ECMWF	European Center for Medium-Range Weather Forecast

MERRA	Modern-Era Retrospective analysis for Research and Applications
NASA	National Aeronautics and Space Administration
LWMC	Lahore Waste Management Company
RDF	Refused Derived Fuel
PEQs	Punjab Environment Quality Standards
AQI	Air Quality Index
AQMS	Air Quality Monitoring System
DHIS	District Health Information System
AURI	Acute Upper Respiratory Infections
MoCC	Ministry of Climate Change

Units

ha	Hectares
GJ	Giga-Joules
Gt	Giga-Tons
Gg	Giga-Grams
AOD	Aerosol Optical Depth
$MtCO_2$-eq	Metric tons of CO_2 equivalent
AURI	Acute Upper Respiratory Infections
g	Grams
Kg/m3	Kilogram per cubic meter
µg/m3	Micro-grams per cubic meter

01

EXECUTIVE SUMMARY

1. Executive Summary

Air pollution has been on the rise in Pakistan, posing a significant threat to human well-being and the environment. Lahore, as the provincial capital and commercial center with a high population density and increased energy usage, is particularly affected. The district's air quality is further worsened by ineffective urban planning and landscape management, a high concentration of industries, and limited mass transit coverage. While several studies have been conducted to track the presence of various types of emissions in the air, a more comprehensive understanding of the sources of these pollutants in Lahore is needed. This report endeavors to investigate the origins of air pollution in Lahore, utilizing sectoral data from various government departments and peer-reviewed research articles available online.

Despite repeated warnings about hazardous levels of atmospheric pollutants from the World Air Quality Report and the World Health Organization since 2019, Lahore still lacks an adequate number of real-time air quality monitoring systems. Two standard continuous air quality monitoring systems installed at Shimla Pahari (US Consulate Office) and Township (Al-Jazari Academy of the Urban Unit) recorded an annual average concentration of PM2.5 in 2022 of 147.8µg/m3 and 129.3 µg/m3, respectively. These concentrations are 9-10 times higher than the annual average PEQs limits (15 µg/m3). Additionally, air quality data for aerosols and PM2.5 was obtained from the Copernicus Atmospheric Monitoring Services (CAMS) Portal for the years 2011-2021. The results indicate that Lahore's air quality has been classified as Unhealthy and Very Unhealthy according to AQI categories defined by the Punjab EPA throughout the entire decade. Factors such as power shortages, Covid-19, changes in the energy mix, and certain regulatory measures adopted by the government have affected air quality over the years. Moreover, the winter season is the most polluted time of the year in terms of air quality, and higher disease cases are reported, indicating the influence of regional meteorology, burning, and industrial activities.

The Sectoral Emissions Inventory of Lahore represents the first district-scale attempt in the Punjab province to measure atmospheric pollutants from human activities across six developmental sectors. The primary sources of pollution in Lahore include transportation (accounting for 83% of emissions), industry, agriculture (from crop residue burning), open waste burning, and inefficient fuel consumption in commercial and domestic sectors. The number of registered vehicles in Lahore has increased at an alarming rate, with a sharp increase in the number of two-stroke vehicles such as motorbikes, scooters, and auto-rickshaws. However, the vehicle figures may be an overestimate since anecdotal evidence suggests that most vehicles in Punjab province are registered in Lahore. Emissions from the industrial (9%), domestic (0.11%), and commercial (0.14%) sectors are primarily driven by the consumption of inefficient fuels such as coal and diesel oil. However, due to the availability of LNG as an energy source, the reliance on biomass burning is relatively low, resulting in significantly lower emissions from the domestic sector. The burning of crop residues (3.9%) and waste (3.6%) in the outskirts of Lahore is a common practice.

The study suggests that to effectively tackle air pollution in Lahore, targeted measures should be implemented to address pollution sources in each sector. Furthermore, it is recommended that emissions from other cities in Punjab should also be measured to identify the primary sources of pollution and develop regional policies accordingly. Key strategies to manage air pollution in Lahore include increasing public awareness, expanding the monitoring network under the supervision of a legal regulator, strengthening institutions, promoting coordination among stakeholders, incentivizing abatement measures, and enforcing existing legislation.

02

BACKGROUND

2. Background

Pakistan is facing the challenge of high climate vulnerability and environmental degradation. Rapid urbanization is acting as a catalyst to increase exposure within its cities. Urban areas are the centers of energy production and thus atmospheric emissions globally, but they are also the ones that are primarily affected by the climate-related disastrous impacts. Major urban centers of Pakistan are no exceptions to these impacts. Urbanization in Pakistan has its challenges, characterized by inadequate waste management, rapid urban sprawl, air pollution, poor access to water and sanitation, and congestion, all of which negatively affect the productivity, serviceability, and efficiency of these commercial centers (1). The **Environmental Performance Index (EPI) published by Yale University in 2022 ranked Pakistan at 176 out of 180 countries with a score of 5.7 in air quality points, indicating a decrease of -0.3** in comparison with the previous report (2). World Air Quality Report (2021) by IQAir ranks Pakistan as the 3rd most polluted country with respect to air quality, whereby the population is regularly exposed to hazardous levels of $PM_{2.5}$ concentrations (3), as shown in Figure 1.

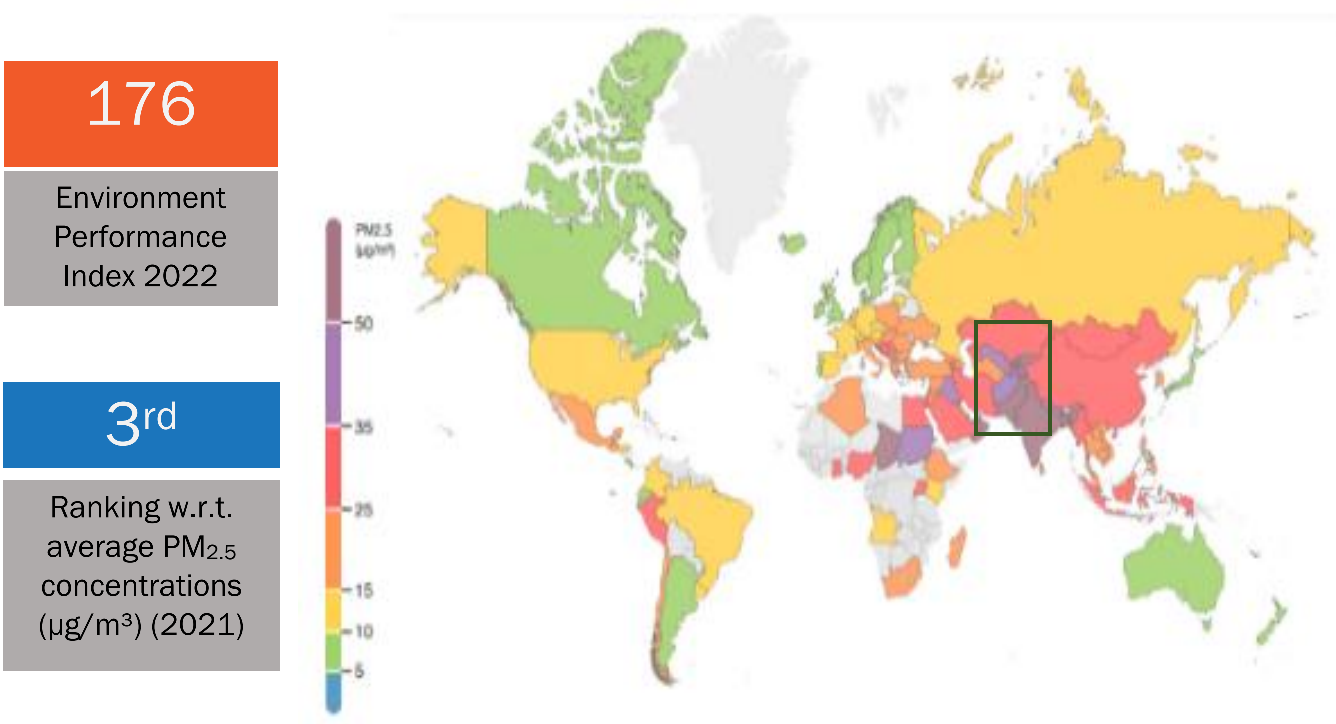

Figure 1: Global $PM_{2.5}$ Map 2021 (Source: World Air Quality Report 2021)

According to the background studies conducted by the Male Declaration, it was reported that the shortage of a network of air quality monitoring systems, which could be used to monitor the pollutants in order to develop an air quality management framework, is the primary cause of poor ambient air quality (4). Air Pollution has put the urban centers of Pakistan at the forefront of the environmental debate, associated with urban dysfunction, urban congestion, and energy shortages; representing a dystopia of urban decay while presenting a bleak view of the urban future in the country. The sectoral and district-level data constraints pose a challenge for policymakers, governing actors, and regulators to find an effective legal and planning discourse aiming to marshal cities in response to climate change. This study focuses on air quality issues in Lahore, to identify key contributors and steer attention toward them, so that sound mitigation measures may be adopted.

Lahore is the second major urban center in Pakistan, with 11.2 million residents. The air quality of Lahore is worsening with every passing day which has deteriorated the living standards of its inhabitants, due to the various multi-complex challenges. These include unplanned rapid urbanization; traffic congestions; exponential growth of vehicles (especially motorbikes), low coverage of mass transit system, lack of legal parameters and statutory frameworks pursuant to the 18th constitutional amendment, challenges of landscape management, pollution-causing industrial agglomerates in and around the district and non-effective environmental governance. Severe episodes of wintertime pollution with visibility reductions, respiratory illnesses, and disrupted life activities are representation of poor environmental quality. Lahore ranks as the top-most polluted city according to the air quality monitoring reports by IQAIR (5). **Air pollution in Lahore is responsible for wiping out nearly six years from the life expectancy of an average individual** (6). Despite visible impacts of poor air quality, it still lacks an effective air quality-monitoring framework to monitor the increasing air pollution and its impacts to develop resilience and improve the living standards of its residents.

The **Sectoral Emissions Inventory of Lahore District is one of the first efforts** to estimate the sectoral emissions at the district level in Punjab Province. The study adopts the widely accepted methodology of the Intergovernmental Panel on Climate Change (IPCC) to measure the sector-specific emissions with the support of published datasets. The study also involves space technology applications by using remote sensing datasets of various satellites to establish the air quality profile of district Lahore. Finally, it addresses the core issue of the non-availability of data, a major hurdle for informed decision-making, and provides targeted interventions for effective environmental governance.

The report has been developed under the **Space Technology Application in Socio-Economic Development Project** of the Government of Punjab.

03

LITERATURE REVIEW

3. Literature Review

Emission Inventory is a method of quantification of direct anthropogenic footprint on the environment. It represents a baseline profile of the impact of different activities in an area on the local environmental quality. Articles 4 (Para 1a) and 12 (Para 1a) of the UNFCCC Protocol require all non-Annex-1 countries to submit, within their capacity limits, a national emissions inventory with respect to sources and sinks of all GHGs (greenhouse gases), that are not a part of the Montreal Protocol, to the Conference of Parties (COP), in accordance with the guidelines attached as the Annex to Decision 17/CP-8 (7).

Emission Inventories have been previously developed for different sectors at the national level in Pakistan by Hagler Bailly (1994), Pakistan Atomic Energy Commission (2008, 2012), Global Change Impact Study Center (2015,2018), Food and Agricultural Organization (2018 – Punjab), and GoKP (2021 – Peshawar). All these studies use the approach defined by the IPCC for the estimation of emissions in 2006. Figure 2 represents the cumulative results of the sectoral emission inventories developed in 1994, 2008, 2012, 2015, and 2018 at the national scale. The results indicate increasing trends of anthropogenic emissions over the years. However, the increase is reported to be 80% between 1994-2008, and 48% between 2008-2018, indicating that some measures and policies were adopted by the government which helped curb the rate of increasing emissions. However, the emissions are still projected to increase to 1,603 $MtCO_2$-eq by 2030, considering the 2015 base-year emissions. These projections have been made using the GDP growth rate of 9%, sectoral growth rates, and CPEC Projects (8).

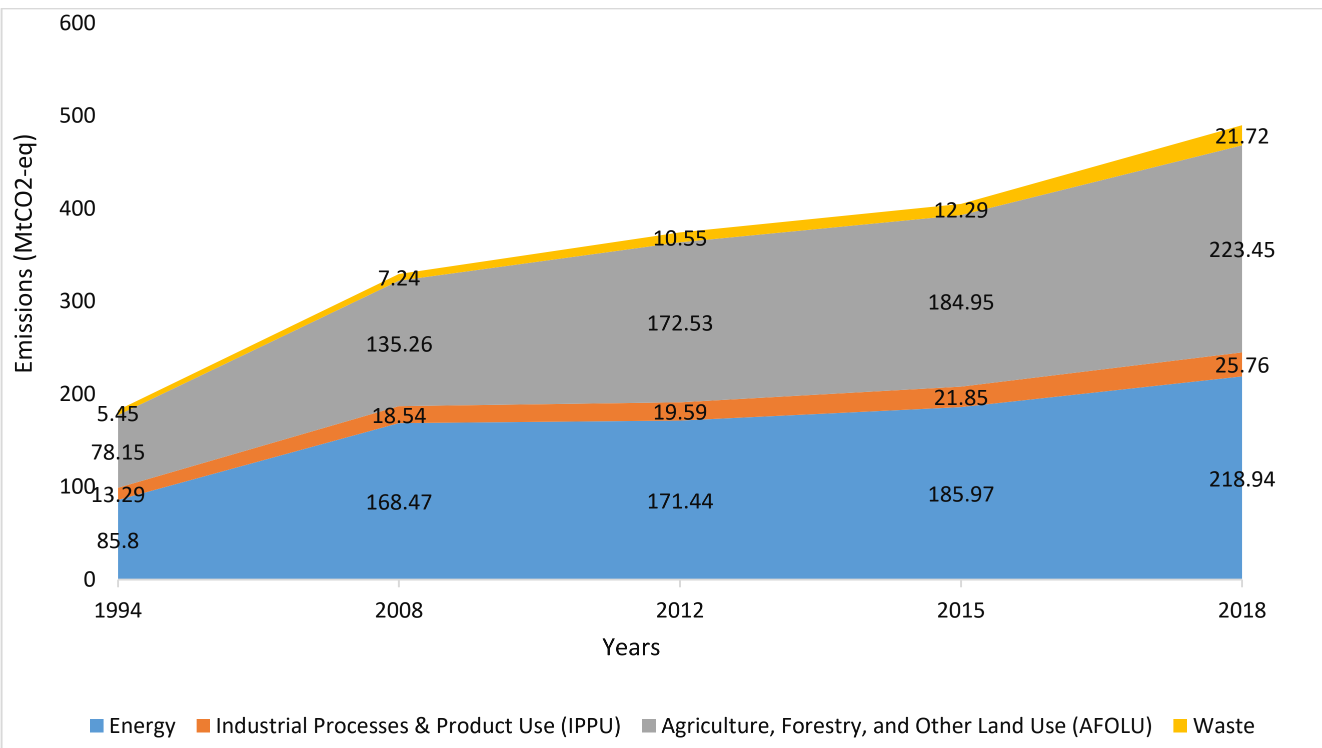

Figure 2: Historical Emissions Inventories of Pakistan (9)

The most recent emission inventory submitted at the UNFCCC by the national government is that of 2018 developed by GCISC and MoCC. It quantifies emissions from 4 broad categories using the IPCC guidelines.

According to the results given in Table 1, AFOLU has the highest emissions from all four provinces in the country. Fuel combustion in different processes accounts for the second highest emissions, i.e., 218.94 Mt-CO_2eq. In comparison, Industrial Processes & Product Use, and Waste sectors have a much lesser contribution to the total national emissions.

Table 1: 2018 Emissions Inventory of Pakistan (Unit: Mt-CO_2eq)

Key Sectors	Source-Specific Sectors	Emissions (Mt-CO_2e)	Total Emissions (Mt-CO_2e
Energy	Energy Industry	53.4	**218.94**
	Manufacturing Industries & Construction	66.2	
	Transport	51.34	
	Others	44.06	
	Fugitive Fuel	3.94	
IPPU	Mineral Industry	22.75	**25.76**
	Chemical Industry	2.71	
	Non-Energy & Solvents Use	0.1	
	Other	0.2	
AFOLU	Livestock	109.12	**223.45**
	Land	31.52	
	Managed Soil	74.98	
	Rice Cultivation	7.83	
Waste	Dumping	10.23	**21.72**
	Incineration & Burning	0.09	
	Wastewater treatment & discharge	11.4	

The first regional emission inventory for Punjab province was developed by the Food and Agriculture Organization (FAO) in 2018. The report estimates cumulative sectoral emissions for 4 key sectors in 11 districts of the Punjab province. These districts include Gujranwala, Lahore, Hafizabad, Faisalabad, Mandi Bahauddin, Gujrat, Narowal, Kasur, Sialkot, Sheikhupura, and Nankana Sahib, all of which emit a total of 618.2 Gg of emissions. Transport Sector is the key emitter with 269,000 tons of CO, SO_x, NO_x, $PM_{2.5}$, and Non-Metallic Volatile Organic Compounds (NMVOCs). The second major polluter is Industrial Sector emitting $PM_{2.5}$ in the highest concentrations, followed by SO_x, NO_x, CO, and NMVOCs. Residues burning is a wide practice in Punjab done every year, especially during October-November. It emitted about 116 Gg (116,000 tons) of carbon monoxide in 2018 and is attributed as the major cause of Winter Smog. The power sector is the least polluting sector emitting 74,000 tons of emissions in Punjab province, as reported by the FAO Report (10).

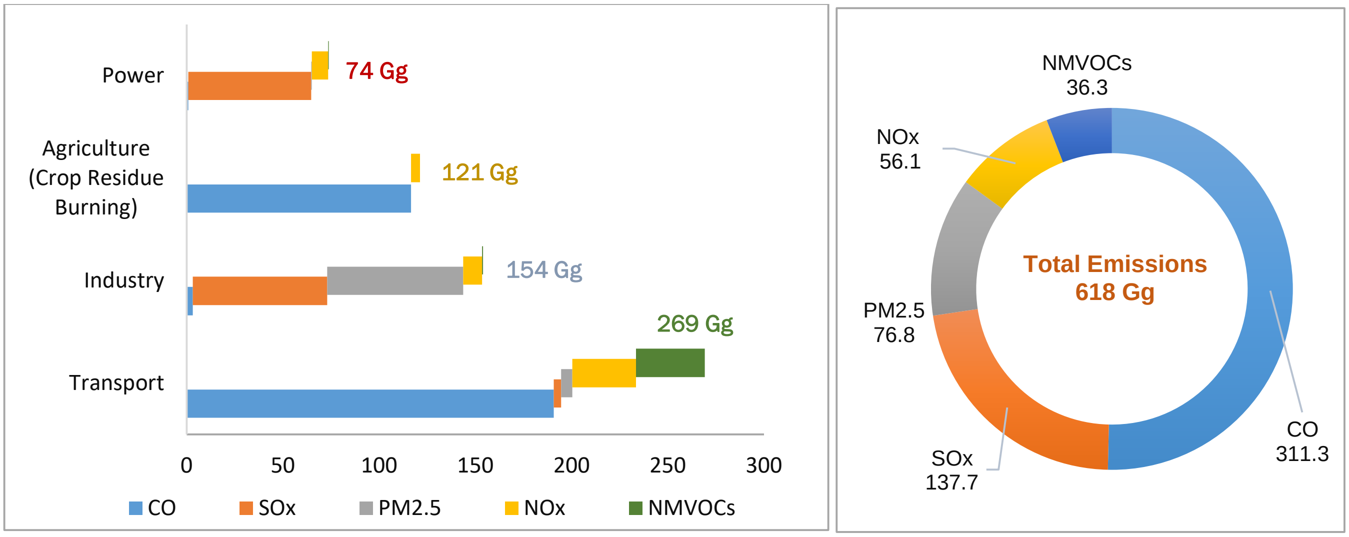

Figure 3: Emission Inventory of 11 Districts of Punjab (FAO, 2018)

A second effort on the development of emissions inventory in Pakistan was undertaken by the Government of Khyber Pakhtunkhwa on a local scale for the Peshawar District. The results are shown in Figure 4. The report is a combined effort of Adam Smith International (ASI) and Government of Khyber Pakhtunkhwa, under the UK FCDO (Foreign Commonwealth & Development Office) funded Peshawar Clean Air Alliance (PCAA) and SEED (Sustainable Energy and Economic Development) Programs. This report summarizes the emissions from five sectors, including transport, industry, waste burning, domestic, and commercial sectors. These sectors add 58.72 Gg of emissions into the atmosphere from the combustion of different types of fuel. About 85% (50.2 Gg), 7.9% (4.65 Gg), 4.3% (2.52 Gg), 1.9% (1.10 Gg), and 0.48% (0.28 Gg) of emissions are contributed by transport, industry, waste burning, domestic, and commercial sectors, respectively. The report concludes that the high content of Sulfur in fuel, lead in gasoline, wood burning, and waste burning as a source of fuel, and the non-compliance with Euro-V emissions standards are the main causes of pollution in Peshawar (11).

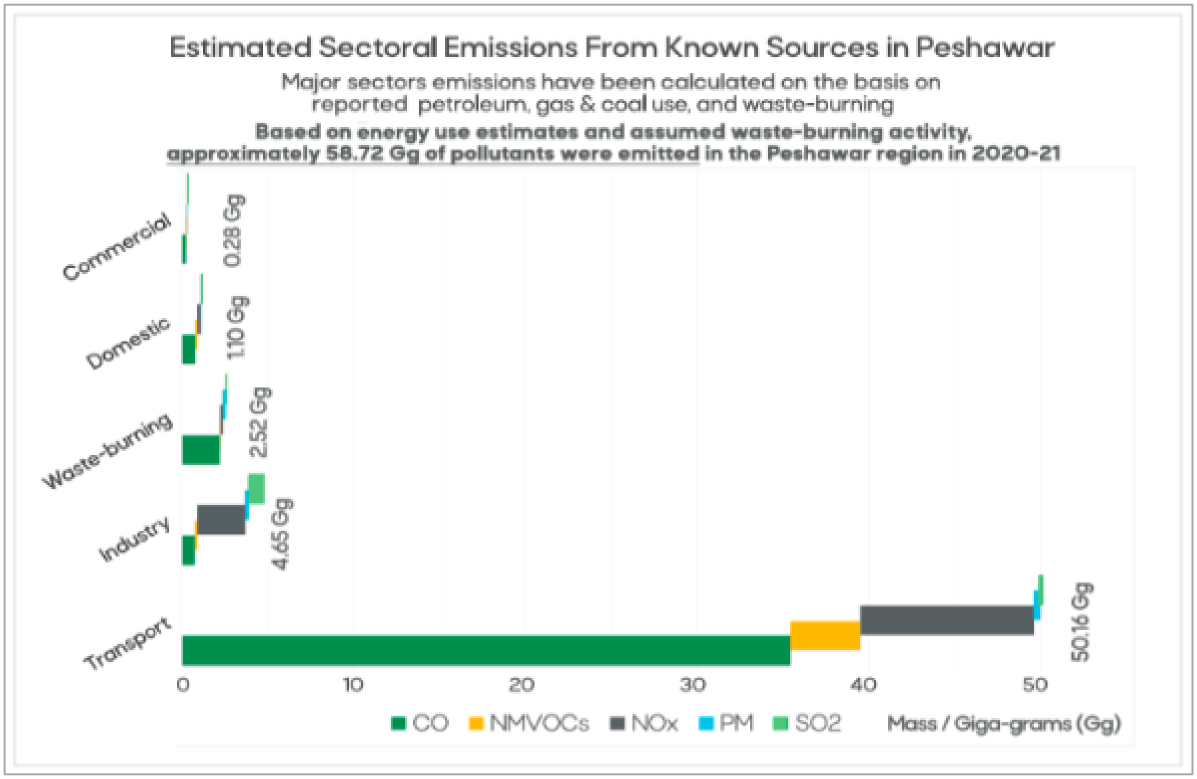

Figure 4: Sectoral Emissions Inventory of Peshawar

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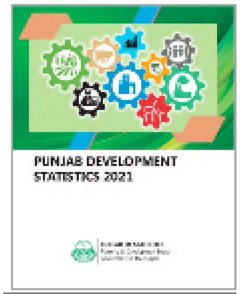
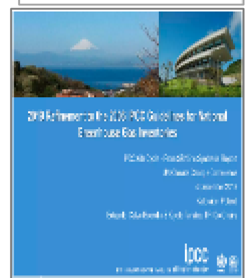
DATA ACQUISITION SOURCES

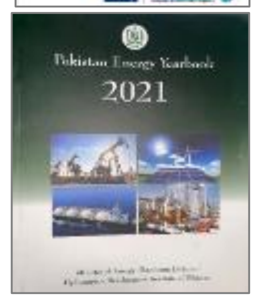
4. Data Acquisition Sources



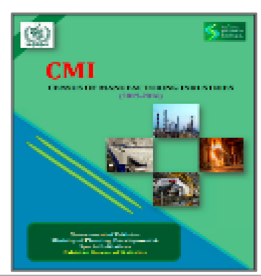
Reliance on authentic datasets as an input is the primary consideration that will set the foundation for analytical assessment. Since the report focuses on emission inventory and air quality profiling of Lahore, most of the information related to activity data of relevant sectors were taken from government departments in the form of published reports, departmental datasets, and dashboards evaluated and taken as priority sources. The report also gives a high weightage to research papers published in peer-reviewed journals.



The emission inventory provides a comprehensive baseline of emissions based on anthropogenic activities. For emission inventory, quantification of cumulative emissions based on annual fuel combustion rate in transport, industries, commercial, and domestic sectors has been done for district Lahore. In addition, crop residue and waste-burning sectors were also incorporated in quantifying emissions. Activity data for relevant sectors were obtained from **Punjab Development Statistics 2021, Agriculture Marketing Information System (AMIS), Census of Manufacturing Industries 2015-16, Pakistan Energy Yearbook 2021**, and published **Research Papers**. Due to the limitations of data availability, this report uses tier-1 methodology defined by **Intergovernmental Panel on Climate Change** (IPCC). This method of quantification of pollutants is commonly used in regions where emissions footprint has not been determined previously. The emission factors (EF) given in the databases of the EI Guidebooks by the IPCC and **European Environment Agency (EEA)** have been used.



Primary datasets in the form of ground-based equipment and remote sensing datasets from various satellites are also used which have bridged the data gap since data is scant. For identifying the sources of aerosols, data for black carbon (BC), dust, sulfate, and organic carbon (OC), which are the constituents of 2.5-sized particulates, was retrieved from the open data portal of **Copernicus Atmospheric Monitoring Services**. Ground-based air quality monitoring equipment at the United States Consulate Office Lahore (Shimla Pahari) and The Al-Jazari Academy of the Urban Unit (Township) was used as real-time air quality data sources.



Health data has also been taken from the **District Health Information System (DHIS)** dashboard, for analyzing the disease frequencies attributed to poor air quality.

Finally, this report identifies the key polluting sectors and major pollutants based on a detailed assessment. The findings of this study are corroborated using published national and international literature. It also provides recommendation measures for the abatement of pollution in Lahore. All the data and sources used in the study are adequately cited in the report.

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THE APPROACH

5. The Approach

Emission inventories are developed to comprehend the emissions outlook and carbon footprint of an area based on energy and fuel consumption (12). It is a comprehensive database that mainly enlists the concentration of pollutants, sources of emissions, area, and year. In addition to this, it may also cover health impacts and mitigation measures. However, the specifications in the emission inventory are dependent upon the availability of data. Considering the data availability, the approach adopted in this study is given in Figure 5.

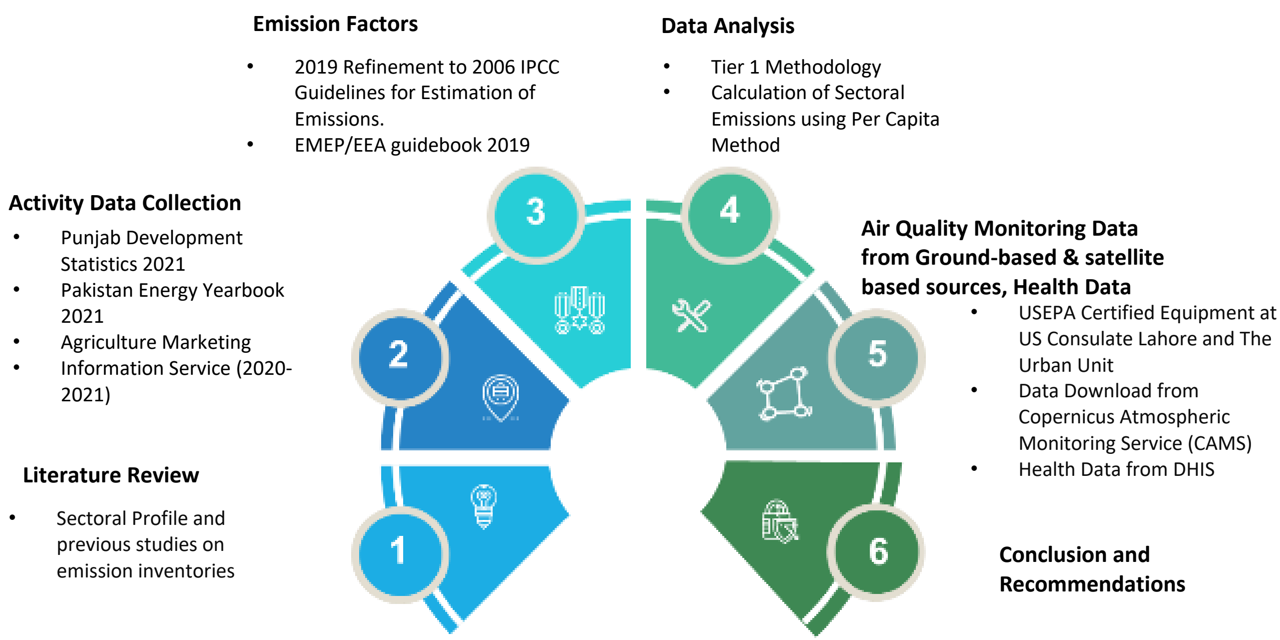


Figure 5: Approach of the study

Various models and tools have been developed globally for the estimation of source-based emissions. All these models use the basic guidelines developed by the Intergovernmental Panel on Climate Change (IPCC) and European Environmental Agency (EEA). The joint emission inventory guidebook of EEA provides methodology complementary to the guidelines of the United Nations Economic Commission for Europe (UNECE) and 2019 refinement to the 2006 IPPC Guidelines for National Inventories. The EEA Guidebook has been prepared by the Task Force on Emission Inventories and Projections (TFEIP) and provides three tiers of methodologies, depending on the complexity levels and data availability for the estimation of emissions.

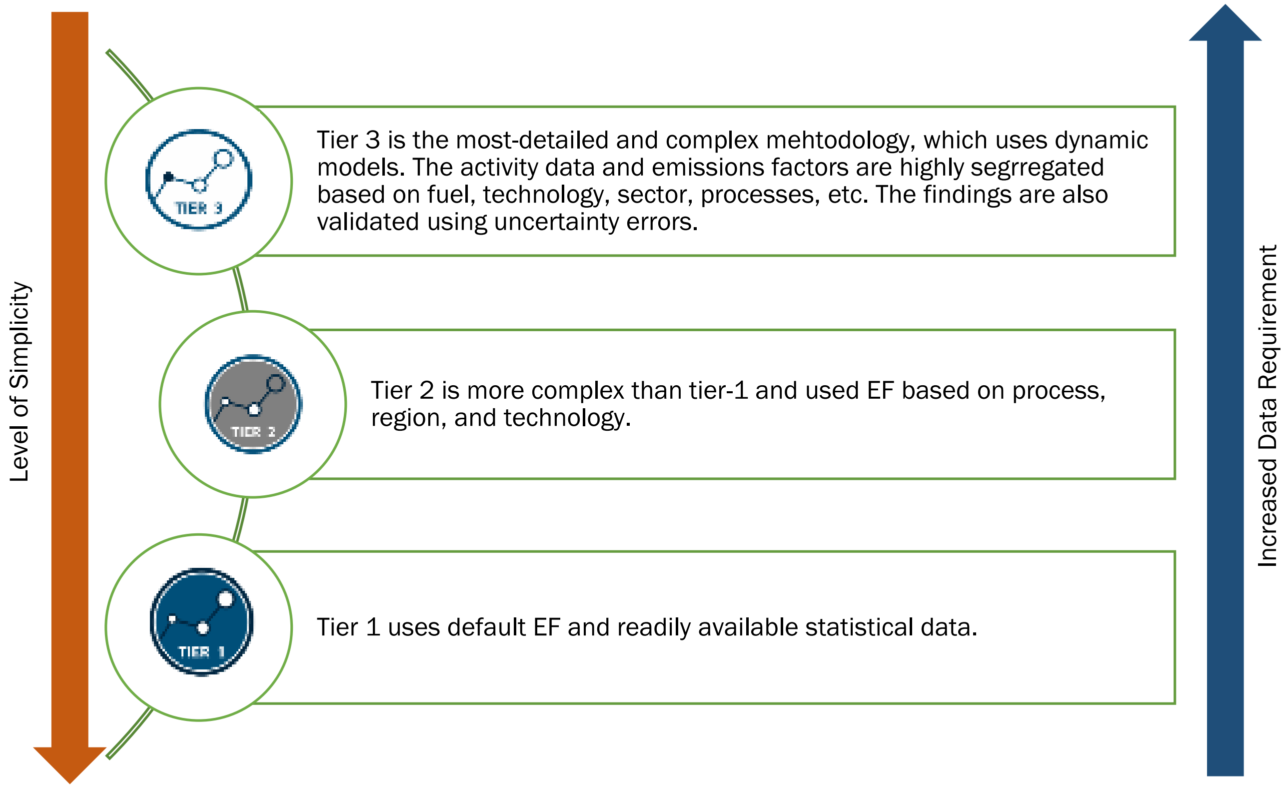


Figure 6: Methodology Tiers (IPCC Guidelines)

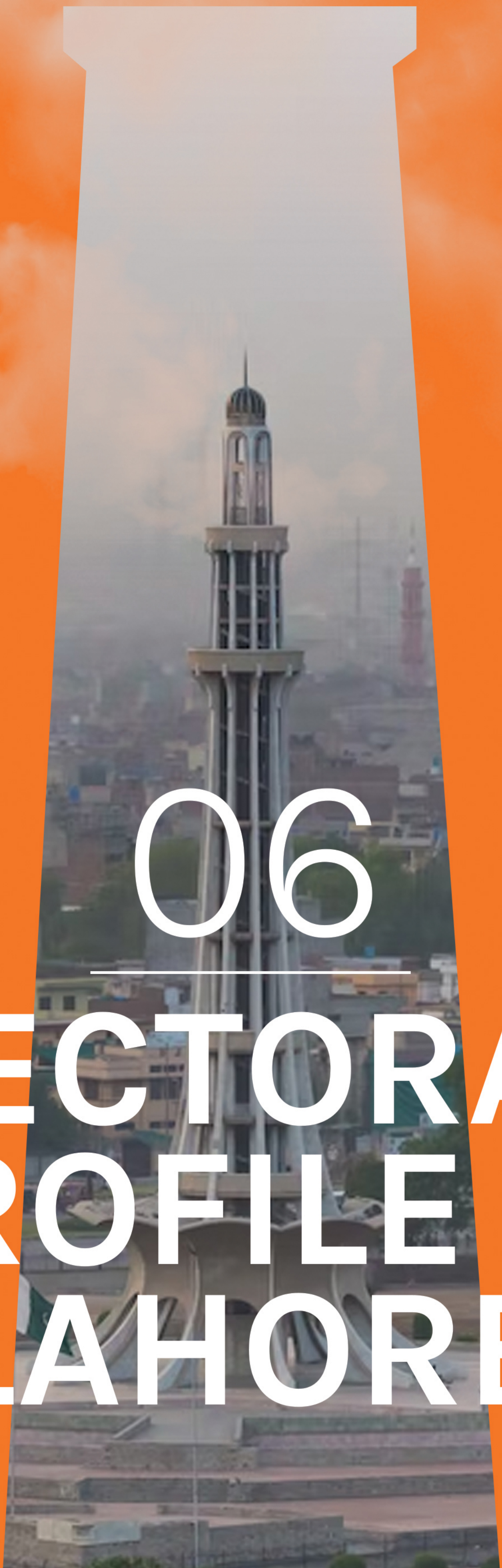
The emissions have been evaluated based on the Tier-1 methodology for six developmental sectors including transport, industry, agriculture residue burning, waste burning, commercial, and domestic. Tier-1 methodology involves emission factors and annual activity rates of fuel consumption from each sector. Data required for all these sectors is given in Figure 6. These datasets were obtained from the sources discusses in Chapter 3.

Figure 7: Data Requirements

In addition, remote sensing technology is also used to determine the historical trend of ***atmospheric concentrations of emissions*** in the Lahore District. For the purpose of this study, Atmospheric Aerosols Concentration (Dust, Sulfate, Black carbon, Organic Carbon, $PM_{2.5}$) over Lahore was downloaded from Copernicus Atmospheric Monitoring Service (CAMS) Reanalysis Web Portal. The retrieved data was processed in ArcMap 10.4 Software, using Extract Multi-Values to Point Tool, and exported in Microsoft Excel® for analysis of the data.

Real-time air quality data was obtained from the ***Ground-based Monitoring Equipment*** in Lahore. There are two US-EPA Certified Beta-Attenuation Monitors (BAM)-1020, owned by the US Consulate Office (Shimla Pahari) and The Urban Unit (Township) in Lahore. Both these equipment measure concentrations of $PM_{2.5}$ in ambient air, and provide hourly averaged concentrations.

Figure 8: BAM-1020 located at the Al-Jazari academy of The Urban Unit (Township, Lahore)



06

SECTORAL PROFILE OF LAHORE

6. Sectoral Profile of Lahore

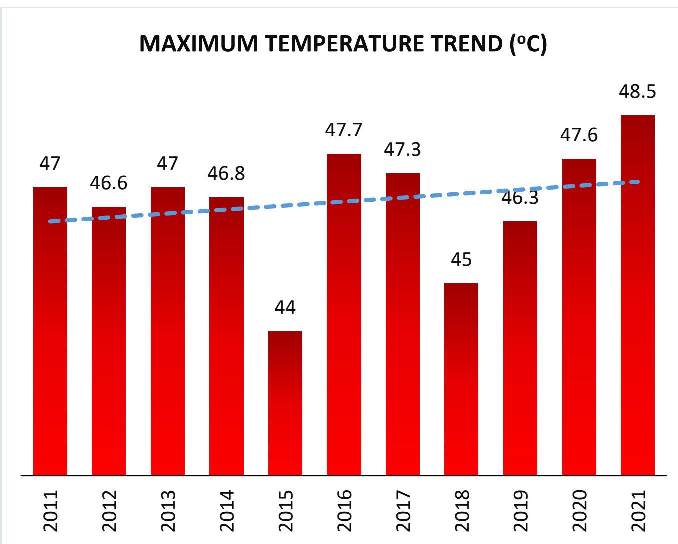
This section provides a baseline assessment of the Lahore district using secondary data analysis of multiple factors which are linked with the deteriorating urban air quality.

6.1. Climate

Lahore District is located at 31°15'0" to 31°45'0" North longitude and 74°01'00" to 74°39'0" East latitude, in the northern part of Punjab province. The geography of the region is formed by the alluvial plain of River Ravi, in the Upper part of the Indus Basin (13). The elevation ranges from 150 meters to 200 meters, above sea level (14). According to the Copenhagen Climate Classification, Lahore is present in the semi-arid region and possesses the characteristic tropical climate. The climate of Lahore is formed by the following five seasons.

- Foggy Winter with Smog (15th November – 15th February)
- Mild Spring (15th February – 15th May)
- Hot Summer with dust storms and rainfall (15th May – 30th June)
- Monsoon (1st July – 15th September)
- Dry Autumn (15th September – 15th November)

The annual average rainfall as reported by Pakistan Meteorological Department from 2011 to 2021 (15) and the annual average maximum temperature trend from 2011 to 2021 (16) are given in Figure 9.



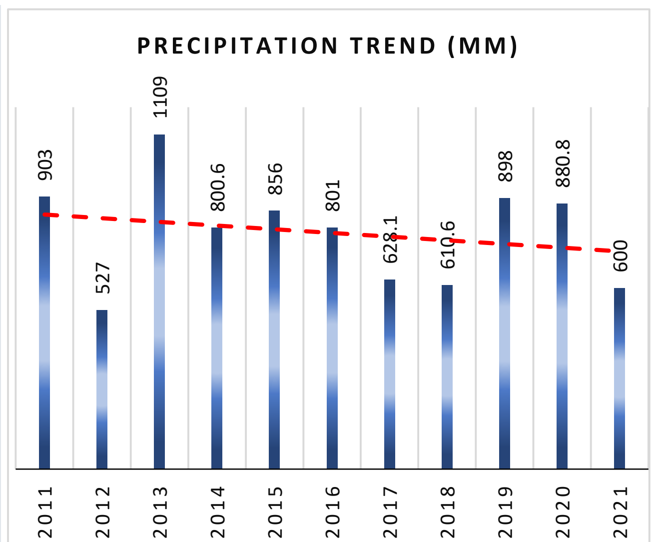


Figure 9: Annual Temperature and Precipitation Trend in Lahore (2011-2021)

The above figure indicates a decreasing trend of annual average rainfall (15%) in Lahore between 2011-2021, which is also consistent with the overall trend of (average annual) rainfall in Pakistan i.e. 10%-15% decrease since 1960. However, the frequency of heavy rainfall events has increased in frequency in the country. Temperature increased has also been observed in Lahore during the last ten years, as indicated in Figure 9.

6.2. Fuel Consumption

The ever-growing urban centers are contributing to surging gaseous emissions worldwide. Lahore makes upto 10% of the total population in Punjab. Per capita income and better literacy rate have boosted the demand for better living standards. Population growth and urban sprawl are the main factors in increasing road transport and energy consumption. Transportation, Industries, and the Electricity sector are the major consumers of petroleum products. The key pollutants which emit from petroleum combustion include carbon dioxide, nitrogen dioxide, and methane (17).

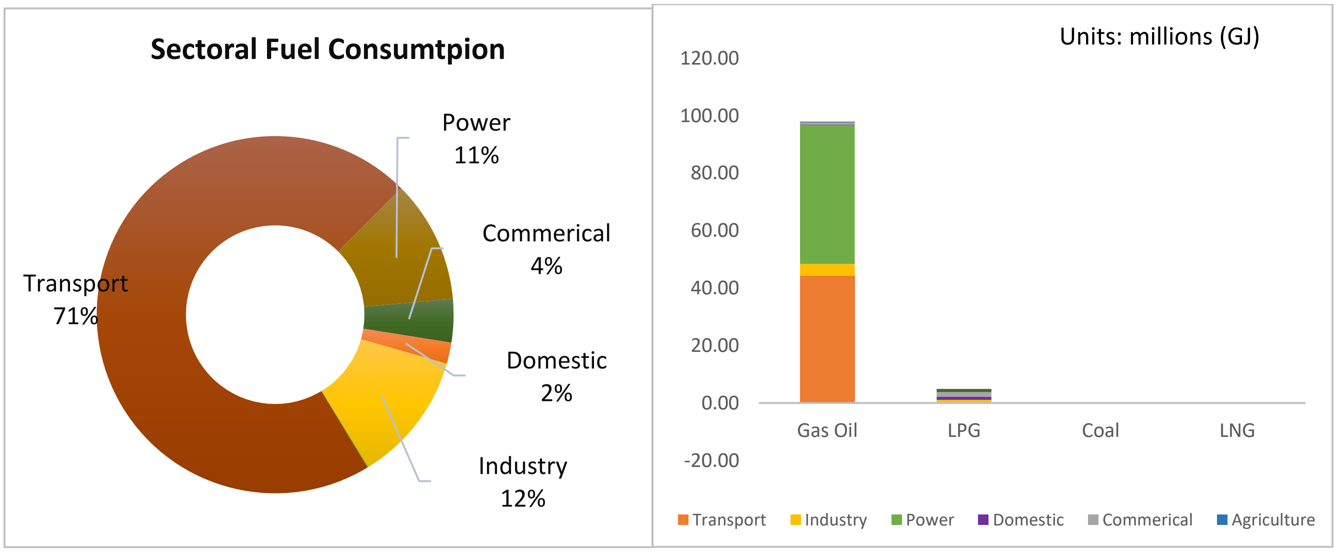


Figure 10: Sectoral Share and Fuel-wise breakdown of Consumption of Petroleum Products in Lahore (2021) (18)

Fuel consumption significantly influences the concentrations of emissions in urban areas (19). The transport, industrial, and power sectors consume 71%, 12%, and 11% of the total fuel consumption in Punjab, respectively. About 4.4×10^{7} GJ, 4.1×10^{6} GJ, and 1.2×10^{5} GJ of gas oil are consumed in these sectors, respectively. Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG) are used mainly in the domestic and commercial sectors in Lahore for fulfilling energy needs. However, the consumption of gas oil in these sectors releases harmful emissions and is a major concern for air quality. Brick Kilns are the major consumers of coal in the outskirts of Lahore. The source-apportionment studies on particulate matter report that diesel combustion sources and two-stroke vehicles contribute 36%, coal combustion sources contribute 13%, and biomass burning contributes 15% of the carbonaceous matter in the formation of <2.5-sized particulates. Non-carbonaceous pollutants such as sulfate and dust form 30% of the $PM_{2.5}$ mass (20). Another study on source characterization of atmospheric aerosols ($PM_{2.5}$ and PM_{10} sized) reported that residual fuel combustion in non-catalytic motor engines makes up more than half of the mass of particulates. Other sources include diesel combustion, biomass burning, and coal combustion (21).

6.3. Urbanization

Lahore district spreads over an area of 1,772 km^2. Its population has been increasing at a rate of 3% since 1998 (22) and reached 11.12 million people in 2017 (23). The density of the population per sq. km was 3,565.9 in 1998 and increased to 6,275.39 in 2017. The urban proportion of the population has increased from 82% to 100%, during 1998-2017 in Lahore (24).

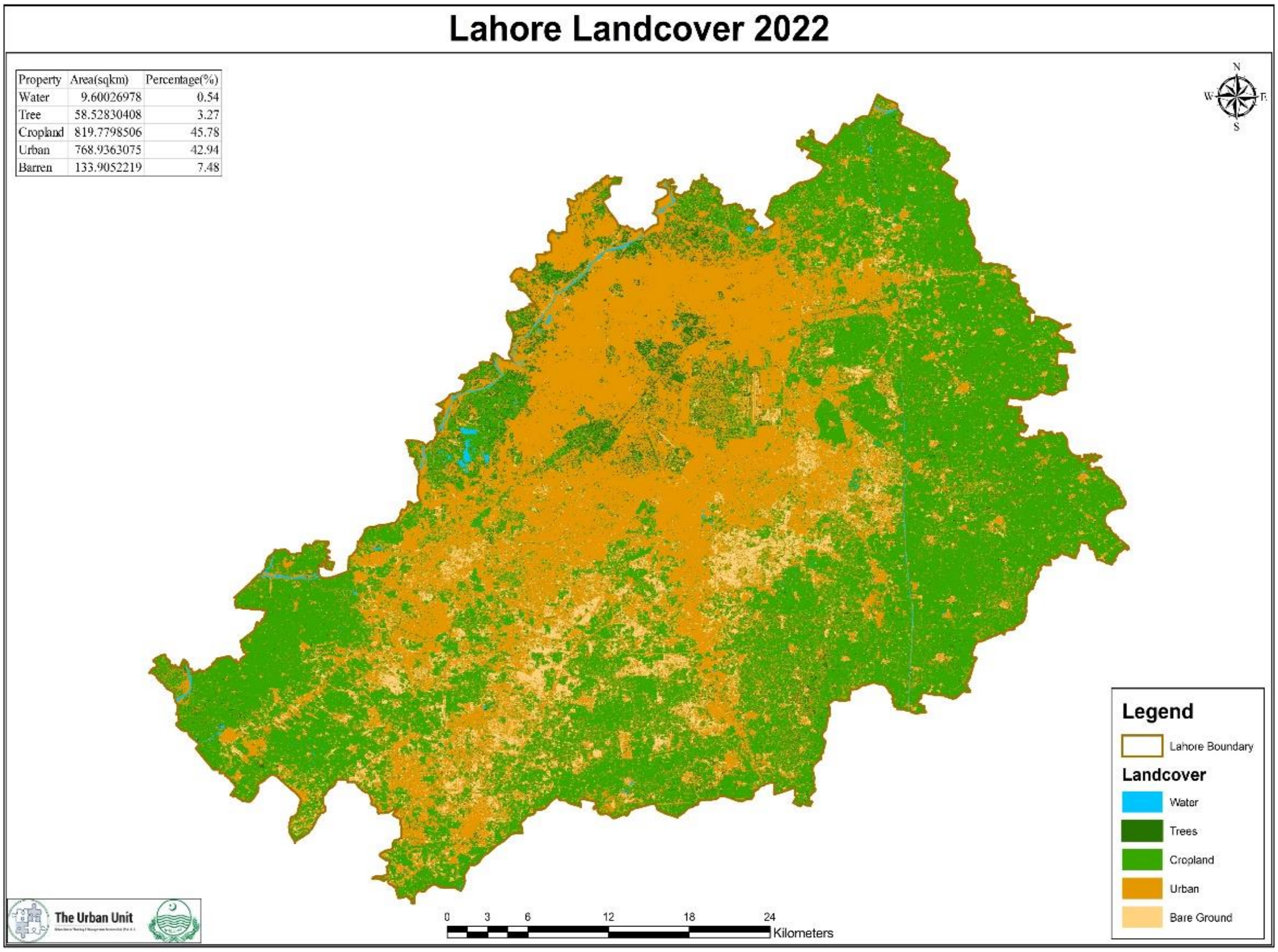


Figure 11: Urban Sprawl in Lahore District

The Land-use and Land-cover (LULC) is the second largest contributor to GHG emissions globally (25). As the built-up land area increases, the carbon sinks in any locality are reduced. An analysis of land cover changes in Lahore reported a gradual decrease in vegetation cover consequent to the increasing built-up cover (26). Over the last 30 years, green cover decreased by 392.78 km^2, increasing the built-up area by 113.85 km^2 in Lahore (27). Decrease in green cover due to increased urbanization is reported to be directly linked with increased land surface temperature and carbon emissions with CO_2, CH_4, and NO_2, as the key pollutants (28).

6.4. Transport

Commercial advancements, urbanization trends, and poor enforcement mechanism under motor vehicular laws/policies have contributed to the irresistible increase in vehicles plying on the roads of Lahore. The accumulation of local transport vehicles, i.e., qingqis, wagons, etc., during peak hours creates a mess in the central areas. Despite the development of low-cost and rapid public transport services through the overhead ways, the rush of the vehicles on roads remains a plight (29).

The total registered vehicles in Lahore increased drastically between 2011-2021. This increase is attributed to the inclination of a majority of the people towards private mode of transport rather than the mass-transit system. This behavior has benefited the transport service providers such as Uber, Careem, etc. While these applications have given freedom and comfort of commute, they reduced the willingness among people towards using the local mass-transit system (30).

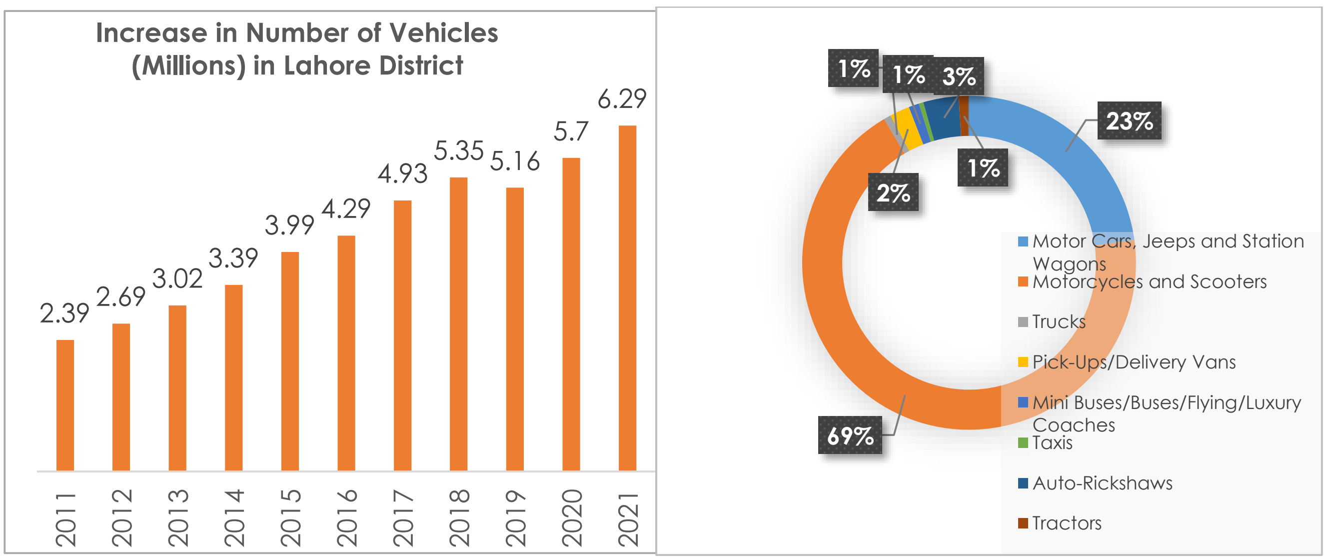


Figure 12: Increase in Registered Vehicles (2011-2021) and Proportion of Vehicle Categories in Lahore.

The per capita transport-related emissions in the country have been estimated at 0.27 tons of CO_2 (31). The flexible rental system by credit institutions also causes an upsurge in rickshaws, cars, and other two-stroke vehicles (32). Pakistan's fuel quality falls under the Euro-II standard, which is far behind the Euro-VI standards adopted by India and other developing countries. In addition to fuel quality, two-stroke vehicles including motorcycles and auto-rickshaws make up the major share of vehicles in Lahore. Inefficient and poorly maintained engines are responsible for generating higher emissions (33).

Vehicular emissions depend upon the type of fuel used by the vehicles (34). The average vehicle in Pakistan emits 3.6 times NOx, 8 times Lead, 20times HCs, and 25 times Carbon emissions per kilometer of travel, relative to an average vehicle in the USA (35). Traffic Congestion is another factor that contributes to higher emissions. It is mainly caused by weak mass-transit system and road networks, pedestrian obstructions, limited freight transport, illegal parking, encroachments, as well as lack of awareness (36).

6.5. Industries

A total of 4,800 registered industries and 230 brick kilns are present in Lahore District, according to 2015 report of the Census of Manufacturing Industries in Punjab. The spatial locations of different industries and brick kilns are shown in Figure 13. Majority of these industrial units are located within 20km distance of the residential areas.

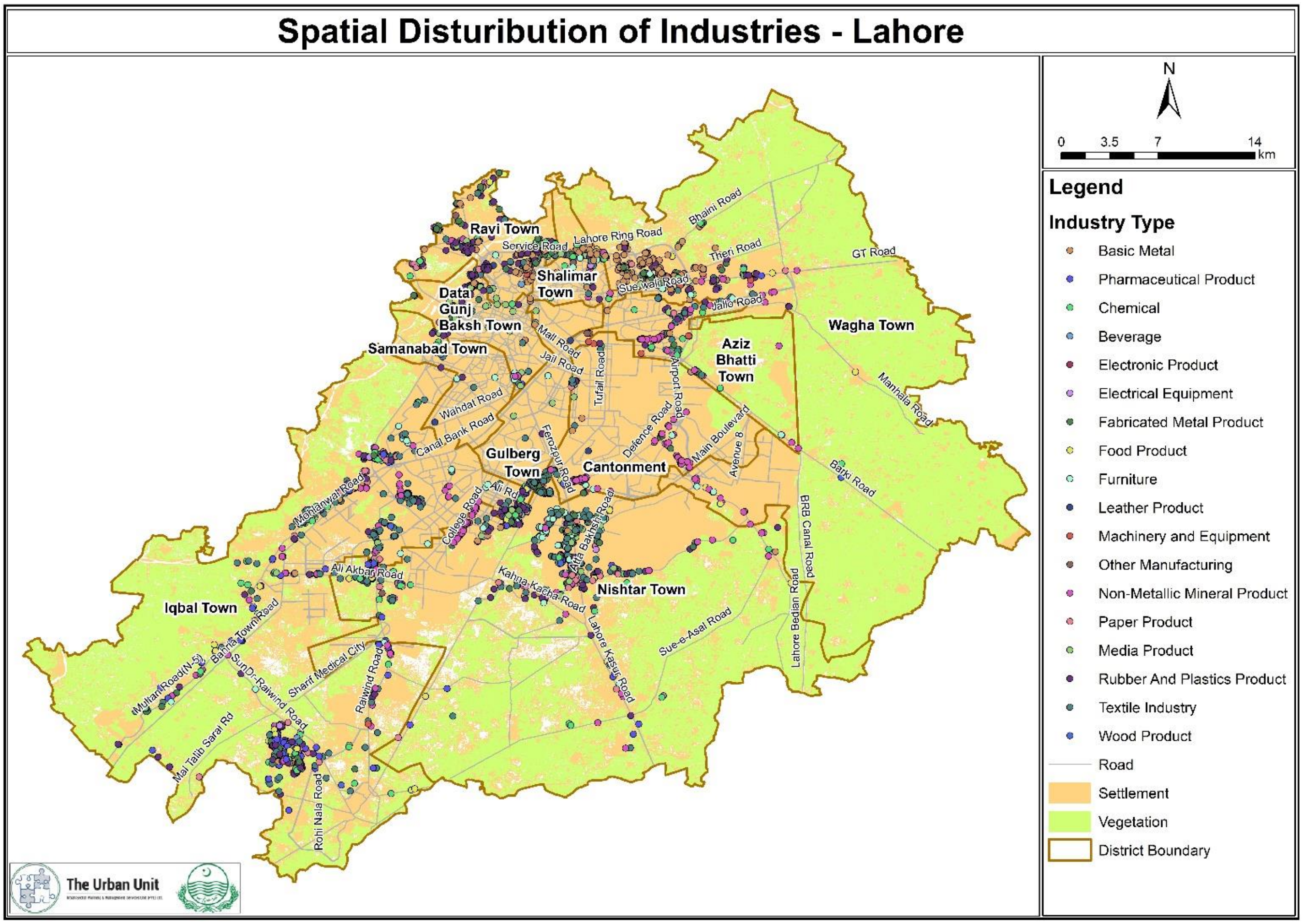


Figure 13: Spatial Location of Various Industries in Lahore

These industries emit harmful greenhouse gases during different phases (i.e., raw material extraction, processing, refining, and product manufacture) of their production cycle. An inventory of different categories of Industries in Lahore and their emissions are given in Table 2. These emissions have been determined using the European Environmental Agency (EEA) emission inventory guidebook 2019. This document provides types of emissions from different production processes with respective emission factors. As evident in the table below, majority of the industries in Lahore are responsible for emitting the six criteria air pollutants in Lahore. These emissions deteriorate air quality, raise health concerns, cause warming, and environmental degradation from the consequent formations of acid rain and smog.

Table 2: Types of Industries and their emissions

Types of Industries	VOCs	TSP	CO_x	NO_x	CH_4	PM_{10}	$PM_{2.5}$	BC	SO_x
Chemicals & Chemical Products	✓	✓				✓	✓	✓	
Pharmaceuticals	✓								
Beverages	✓								
Refined Petroleum Products	✓	✓	✓			✓	✓	✓	
Food Products	✓								
Paper & Paper Products	✓	✓	✓		✓	✓	✓	✓	
Printing	✓								
Other Non-Metallic Mineral Products		✓	✓						
Rubber and Plastic Products	✓	✓				✓	✓		
Basic Metals	✓	✓	✓	✓	✓	✓	✓	✓	✓
Computer Electronics & Optical Products	✓								
Motor Vehicles, Trailers, Semi-Trailers	✓	✓	✓	✓	✓	✓	✓	✓	✓
Other Manufacturing			✓	✓	✓	✓	✓	✓	✓
Other Transport Equipment	✓		✓	✓	✓	✓	✓	✓	✓
Textile Dyeing	✓		✓	✓	✓	✓	✓	✓	✓
Machinery & Equipment	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fabricated Metal products	✓		✓	✓	✓	✓	✓	✓	✓
Wood Products	✓	✓							
Leather & Related Products	✓		✓		✓	✓	✓		
Electrical Equipment	✓								
Brick Kilns	✓	✓	✓	✓	✓	✓	✓	✓	✓

6.6. Agriculture (Crop Residues Burning)

Burning of residues is a common practice in the agricultural lands of developing countries like Pakistan, where the alternative benefits of these residues are less known to the farmers, making burning an appealing solution for disposal of this waste (37). This sector contributed to an increase in the global burned land cover from 345 to 464 million hectares per year, between 2001-2010 (38). Punjab is the major agriculture zone and contributes to 53% of the national GDP, and 74% of the national cereal production. Rice is an important crop of the Khareef season (June to October). The majority of the crop residues at the end of the cropping season are managed through open field burning or domestic cooking purposes (39). Crop residues are burned for weed control, land clearing for upcoming cultivation, and for provision of nutrients for the next crop cycle (40). Apart from these benefits only known to farmers, residue burning alters the chemical composition of the atmosphere by releasing toxic pollutants. These contaminants include Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxides (NOx), and Sulfur Oxides (SOx). All these pollutants are responsible for the formation of tropospheric ozone and photochemical smog, and the enhanced concentrations of particulates in the air (41). Such consequent events of residue burning have caused serious respiratory diseases and deaths (42). According to the study by FAO on 11 districts in Punjab (including Lahore), agriculture residue burning accounts for about 121,000 tons of emissions (43). To quantify the emissions for Lahore district, the data for rice production has been obtained from the Agriculture Marketing Information System (AMIS) which reported almost 68,700tons production in 2021. The year-wise analysis of rice production in Lahore is given in the subsequent Figure 14.

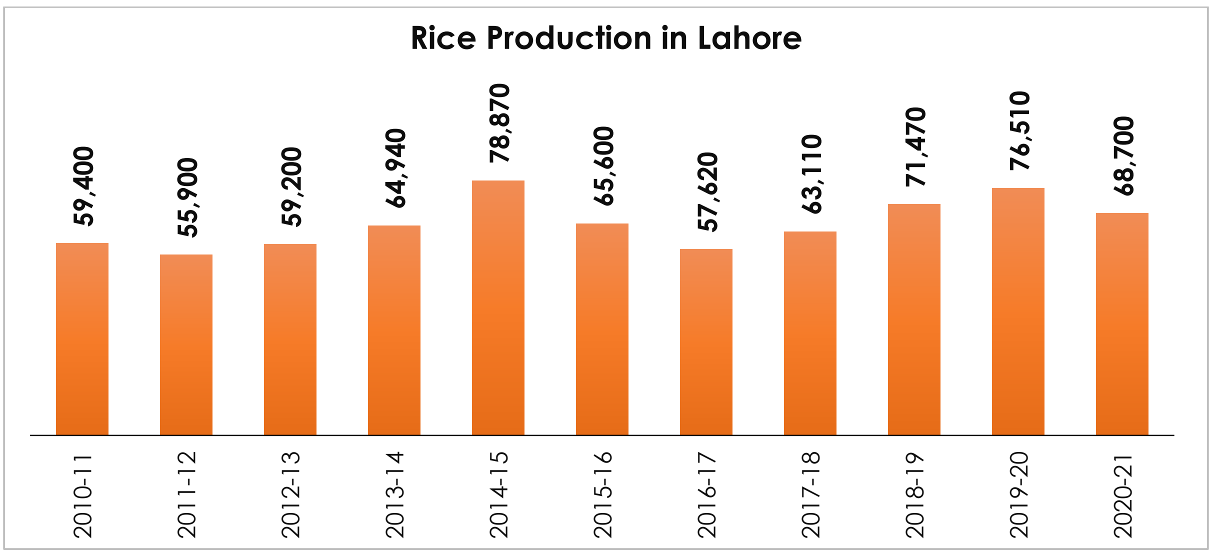


Figure 14: Rice Production in Lahore (Tons)

Fire Hotspots have also been observed, using remote sensing data sources, to validate the burning activities in Lahore from August 2021 to January 2022. Fires Information for Resources Management System (FIRMS) is an online interface tool by NASA (National Aeronautics & Space Administration). It gives satellite imagery of the near real-time fire hotspots from VIIRS and MODIS data from over 160 countries. The satellite imagery of fire hotspots obtained from FIRMS is given in Figure 15. The data shows an increasing number of fire hotspots from August to December, indicating that open burning activities were mainly carried out in the Punjab province.

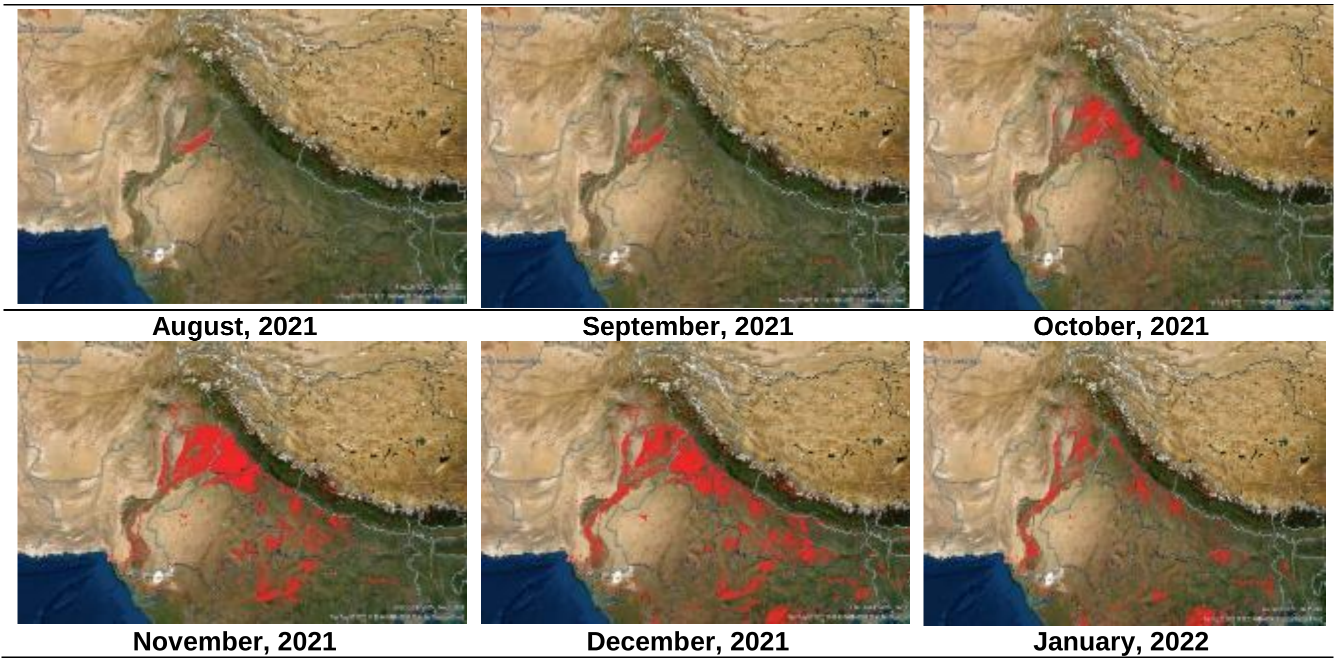


Figure 15: FIRMS Fire Hotspots Data (2021-2022)

6.7. Waste Burning

Urbanization and economic activities have increased the waste generation rate, posing a challenge to effective solid waste management in Pakistan (44). A study on solid waste management services in South-Asian cities against the indicators like collection efficiency, mode of collection, transfer station availability, existing waste treatment facilities, and recycling rate, indicated that Lahore has the maximum waste collection efficiency of 84%, followed by Delhi (80%), Dhaka (77%), Colombo (75%), and Kathmandu (60%). Waste segregation and recycling in Lahore are also practiced by the informal sector and are responsible for 21% of waste recycling in Lahore, the highest in South Asia. Concerning the availability of waste management facilities, Lahore has only one facility, i.e., Refused Derived Fuel (RDF) plant responsible for the conversion of waste to energy. Moreover, it has converted open dumping sites to engineered landfill sites with leachate and gas collection mechanisms in Lakhoder (45). A study reports that the various contemporary waste management practices including anaerobic digestion, composting, recycling, LFG flaring, uncollected waste, and open burning at landfill sites contribute to 238 kg, 192 kg, 796 kg, 474 kg, 454 kg, and 289 kg of CO_2-eq. per tons of waste (46). Currently, about 7,000 tons of waste per day is generated in Lahore and LWMC manages this waste with 90% collection efficiency, whereas 30% of the uncollected waste is openly burned (47). The proportion of burned waste as reported in this study is used for the estimation of emissions from waste burning in this study.

07

SECTORAL EMISSION INVENTORY

7. Sectoral Emission Inventory

This section quantifies the emissions in Lahore district considering domestic, commercial, municipal waste burning, agriculture residue burning, industrial, and transport sectors. Based on the statistics obtained for the afore-mentioned sectors, the sectoral emissions inventory of Lahore is developed and represented in Figure 16.

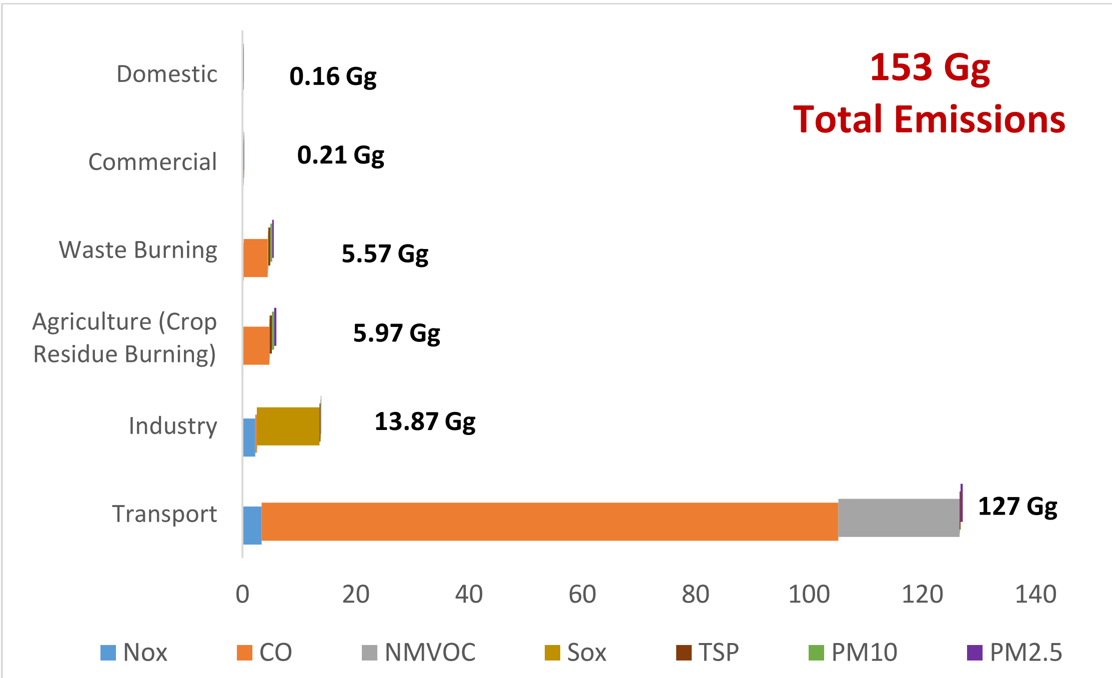


Figure 16: Emissions Inventory of Lahore

Pakistan Energy Yearbook 2021 reports that about 63.5 million GJ energy is cumulatively consumed by industrial, commercial, and domestic sectors in Lahore. Figure 16 represents that these sectors emit 13.87 Gg, 0.21 Gg, and 0.16 Gg of CO, SOx, NOx, NMVOC, TSP, PM_{10}, and $PM_{2.5}$ emissions, respectively. However, transport sector is the key polluter contributing to 127 Gg of total emissions in Lahore. Municipal Waste burning emits 5.57 Gg of total emissions while burning of crop residues emits 5.97 Gg emissions in Lahore. The sectoral emissions share in Lahore is given in Figure 17.

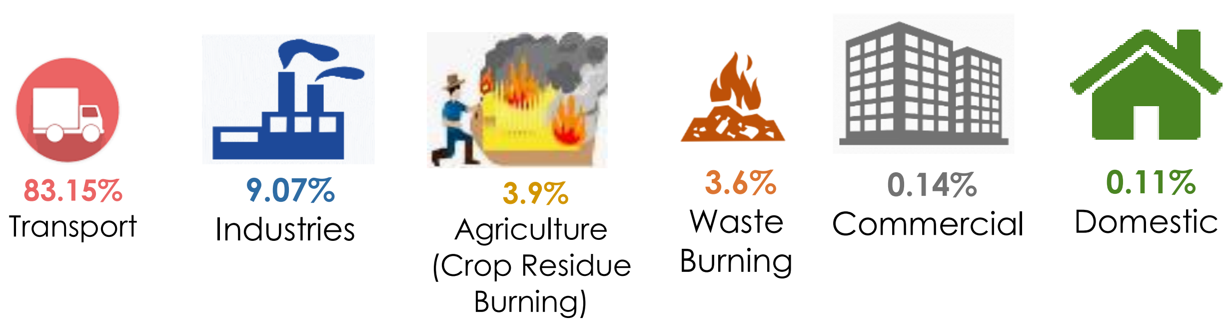


Figure 17: Sectoral Contribution of Pollutants

In all these sectors, the contribution of different types of emissions to the total emissions were also estimated. The results are represented in Figure 18. It can be seen that CO is the key pollutant, followed by NMVOCs, SOx, and NOx. Carbon Monoxide and Non-Metallic VOCs are mainly released from incomplete fuel combustion in vehicular engines, residue burning, and waste burning; NMVOCs mainly from industrial processes; Sulfur Oxides from Industrial processes; and other particulates are released mainly from wastes and residue burning.

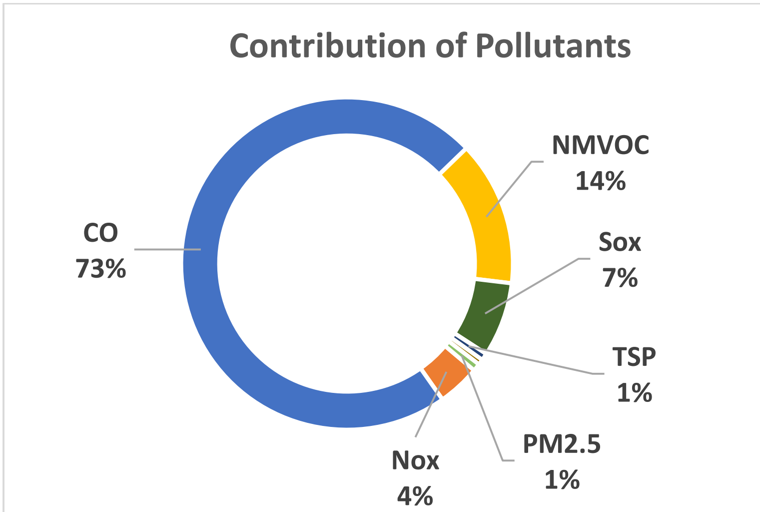


Figure 18: Emissions Share

Table 3 provides a summary of the amount of emissions (tons) released from each sector under study. It can be inferred from the results that the type of fuel determines the emissions from each sectoral activity.

Table 3:Concentration of Pollutants (Tons) from different sectors

Emissions (Tons)	Transport	Industry	Agriculture (Crop Residue Burning)	Waste Burning	Commercial	Domestic	Total Emissions
NOx	3,390	2,296	158	240	142	104	6,330
CO	101,820	258	4,582	4,220	62	44	110,987
NMVOC	21,440	20	34	90	4	3	21,591
SOx	0	11,050	34	10	0	7	11,102
TSP	170	138	398	350	1	2	1,060
PM_{10}	-	82	392	340	1	1	817
$PM_{2.5}$	397	29	371	320	1	1	1,120

The above results show that transport sector is the main cause of poor air quality in Lahore. Motorcycles and scooters (two-stroke vehicles) have the highest emissions (104.76 Gg) in this sector, followed by motorcars, jeeps, and wagons (16.34 Gg). Incomplete combustion of fuels in mobile engines and other processes emit Carbon Monoxide in the highest concentrations in Lahore. NMVOC and NO_x are the second major pollutants emitted mainly from the transport sector and industrial sectors. Small-sized particulate matter including total suspended particulates, $PM_{2.5}$, and PM_{10} are emitted in the least concentrations, as evident from the data. These particulates form condensation nuclei and cause smog in the winter season in Lahore. The emissions from each vehicular category are given in Figure 19.

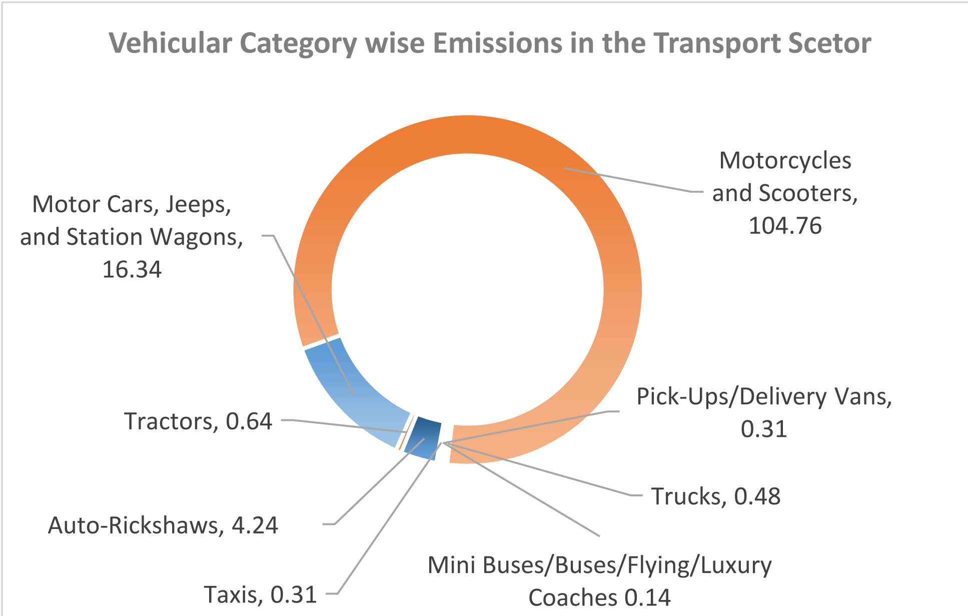


Figure 19: Emissions (Gg) w.r.t Vehicular Category

The Industrial sector is the second major contributor, emitting 13.87 Gigagrams of emissions. The emissions from the commercial and domestic sectors are relatively less because of the availability of gas and electricity for fulfilling the power and energy demands of the locals. This implies that the residents of Lahore are less dependent on biomass for their needs. Coal (61%) in the industrial sector is the major contributor of SOx emissions. Gas Oil (Diesel) used in generators and other processes in industrial, commercial, and domestic sectors contribute to 37% of the total emissions. Natural gas contributes to a negligible concentration of emissions, whereas LPG mainly emits Nitrogen oxides. Fuel-wise emissions are represented in Figure 20.

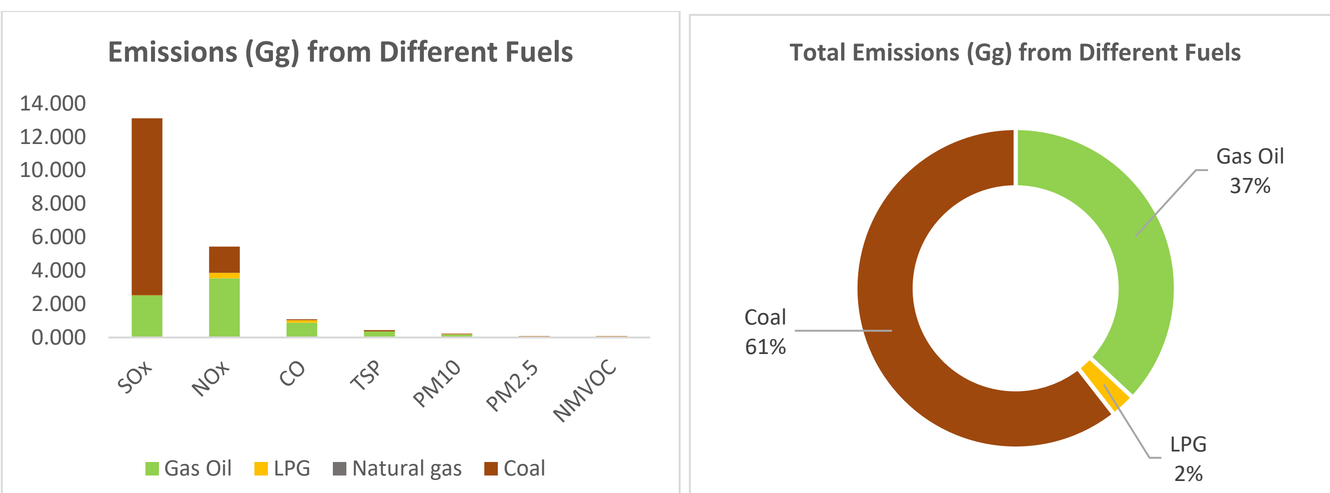


Figure 20: Fuel Wise Emissions in Industrial, Domestic, and Commercial Sectors

08

TRACKING HISTORICAL AIR QUALITY

8. Tracking Historical Air Quality

8.1. Evaluation of emissions using remote sensing

Reanalysis data of air quality estimates the concentration of particulate matter along spatial and temporal range, using chemical transport models with modern data assimilation methods, ground-based and satellite-based observations over Lahore. One of these datasets includes Copernicus Atmospheric Monitoring Service reanalysis (CAMSRA) data developed by the ECWMF (48, 49).

8.1.1. Concentration of Aerosols

The satellite reanalysis data for Black Carbon (BC), Dust, Organic Carbon (OC), and Sulfate from the CAMS data portal, was accessed over a monthly time range for the years 2011-2021 and processed using Extract Multi-Values to Points Tool in ArcGIS. The results of the analyses show the annual trend of aerosol emissions in Lahore, represented in Figure 21.

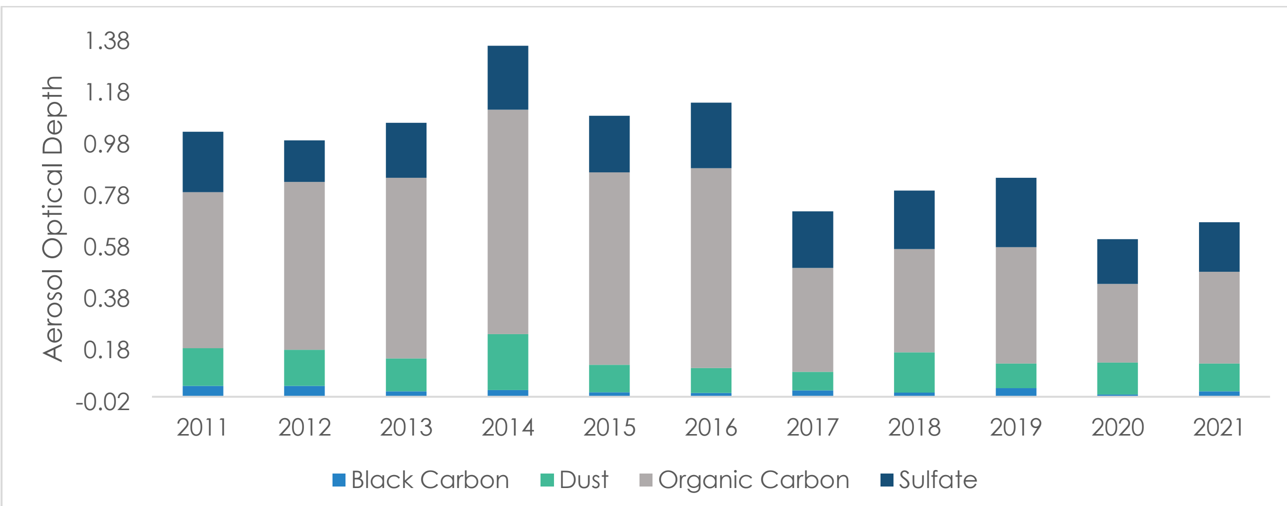


Figure 21: Concentrations of Aerosols in Lahore

Organic Carbon aerosols are the highest whereas, black carbon is the least in concentration. Black carbon has the lowest residence time (1-2 weeks) in the atmosphere; therefore, its concentration is low and appears only in winter-time. The emissions trend from 2011-2021 in Figure 21, indicates that the annual emissions increased from 2011 to 2016, and then declined in 2017. These emissions increased again till 2019, but experienced a declining trend in 2020. The impact of the lockdown during Covid-19 also slowed down the economy and resulted in better air quality in 2020, as reported in various regional studies (50). There is a slight increase in emissions in 2021 as compared to 2020. However, as evident from the Figure 21, the emissions in 2021 are 65% of the emissions in 2014. This trend of emissions can be correlated with the annual fuel consumption trend in the country. Pakistan faced a severe power shortage at the onset of the second decade of the 21st century. Electricity shortage in the country exceeded 7,000 MW, whereas the gas shortfall was 2 billion f^{3}/day in 2011 (51). A survey conducted in Pakistan reported that about 9% of households and 51% of commercial centers were dependent on generators for continuous power supply (52). Diesel-powered generators were a source of high emissions levels. The consumption of hydroelectricity and nuclear electricity in the total energy mix was only 11% and 1% respectively in Pakistan in 2008 (53). In 2020, these sources make up 29% and 4% of the total energy mix. The remaining proportion is contributed by coal, oil, natural gas, and LPG (54). Till 2016, Liquefied Natural gas (LNG) was not present in the energy mix of the country. These fuels emit lesser emissions as compared to conventional fuel sources.

Carbonaceous emissions including black carbon, organic carbon, dust, etc. have a shorter residence time in the atmosphere. These aerosols are crucial components of $PM_{2.5}$ and PM_{10} particles. Source apportionment studies on the constituency of particulate matters in Lahore reported that $PM_{2.5}$ is predominantly composed of carbonaceous aerosols including Organic Carbon (OC) and Black Carbon (BC), whereas PM_{10} is mainly composed of dust particles. Carbonaceous pollutants are emitted from vehicular combustion processes, whereas dust particles are emitted as fugitive emissions from unpaved roads and construction processes. Sulfate is an inorganic secondary pollutant that forms in the atmosphere from gas-phase precursors (55). These aerosols form particulates of $PM_{2.5}$ and PM_{10}, which combined with water molecules to form haze during the winter season (56). Atmospheric pollution is influenced by fuel use, energy efficiency, urbanization, and meteorological factors. Nevertheless, it has been reported that urbanization is the leading cause of increased carbon emissions. The generation of energy depends directly on its demand in developmental sectors, thus influencing the emissions pattern as well (57). The percentage contributions of each sector to the emissions of aerosols show that the energy and industrial sectors each contribute 10-20% of Sulfate; the residential sector contributes 60% and 70% of BC and OC, whereas the transport sector contributes 5-20% of BC and OC emissions, as reported in a study in Lahore (58).

8.1.2. Concentration of $PM_{2.5}$

CAMS Reanalysis data was used to retrieve the monthly averaged $PM_{2.5}$ concentrations over Lahore. The results are represented as an annual trend (Figure 22) and a monthly trend (Figure 23) during the years 2011-2021.

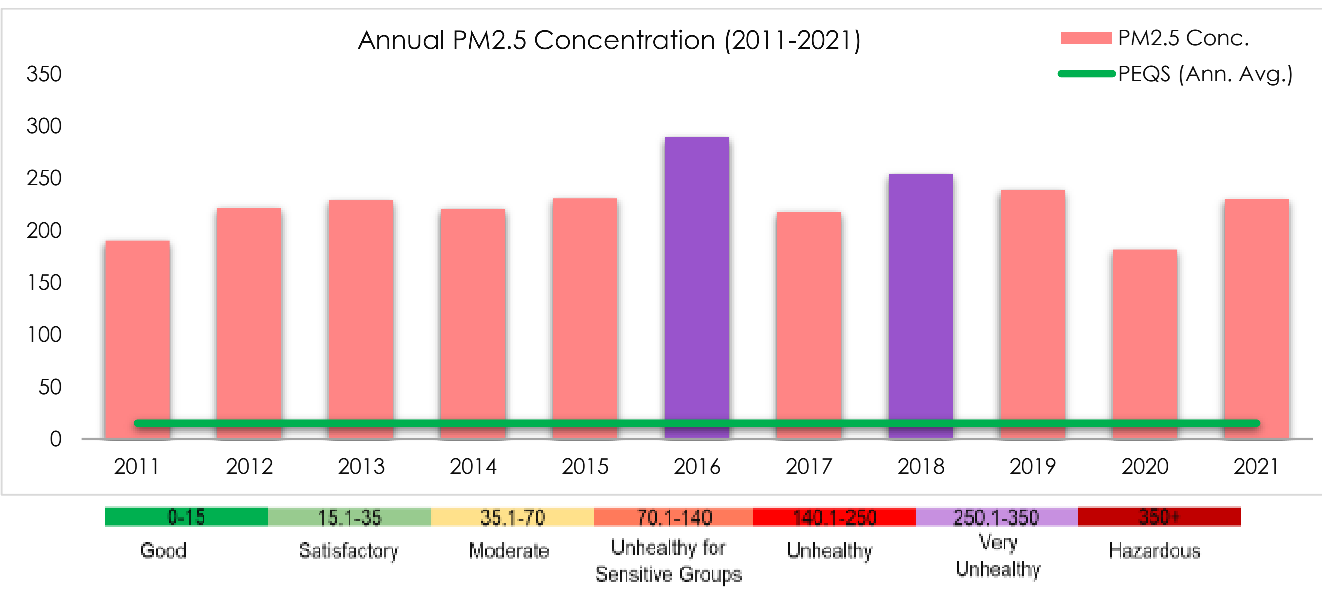


Figure 22: Concentration of $PM_{2.5}$ in Lahore

The $PM_{2.5}$ concentrations were highest during the year 2016 and lowest in the 2020 over Lahore. However, the average annual levels in all these years exceed the PEQs, significantly The Covid-19 lockdown was a significant contributing factor to decreased emissions in 2020, as most of the industrial and vehicular activities were halted. The surge in concentrations of $PM_{2.5}$ can again be seen in 2021 after the lockdown was lifted and economic activity was restored. Air Quality in the urban centers of Asia is also largely under the influence of the transboundary travel of pollutants (59).

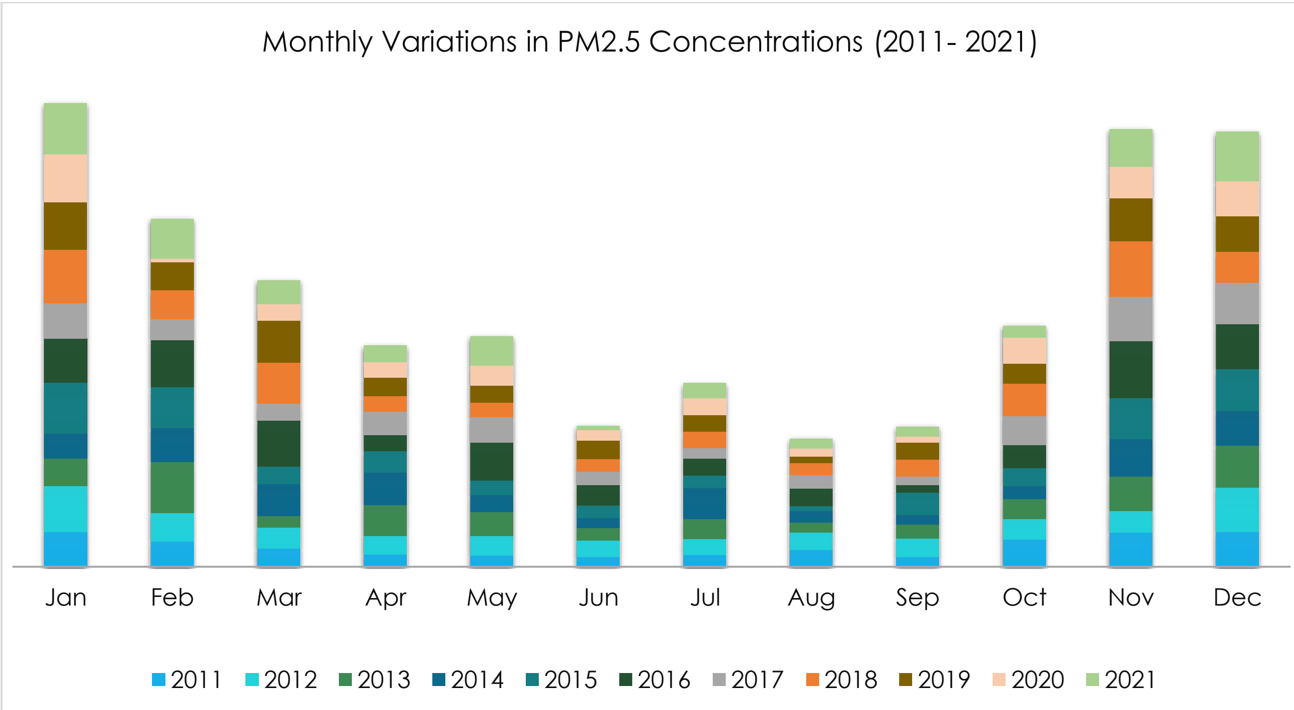


Figure 23: Monthly Variations of $PM_{2.5}$ Concentrations

The above data represents the high concentration of $PM_{2.5}$ in the winter season (November, December, and January), indicating hazardous quality of air. The concentrations of $PM_{2.5}$ vary in Lahore each season because of the varying meteorological factors. During unstable atmospheric conditions, $PM_{2.5}$ particulates remain suspended in the troposphere for about 2-3 days only and can be transported to thousands of kilometers in distance and hundreds of meters in altitude (60). The temperature inversion phenomenon significantly influences the elevated levels of $PM_{2.5}$ concentrations during the winters (61). The stable atmospheric conditions comprising of high relative humidity (average; 59±18%), low wind speed (average; 2±1 m/s), and average temperature (20±4℃) are responsible for preventing atmospheric dispersion of pollutants. These pollutants combine with water molecules to form a haze, thus forming smog (62). The concentrations of $PM_{2.5}$ are lower during the monsoon season that lasts from July to September in Lahore. Rain has a washing-out effect on the pollutants, resulting in better air quality (63).

8.2. Evaluation of Emissions using Ground-based Monitoring

The data from USEPA Certified Beta-Attenuation Monitor (BAM) 1020 has been used for monitoring of real-time ambient air quality. The data has been monitored and plotted against the AQI Breakpoints defined by Punjab Environment Protection Agency and given in Figure 24.

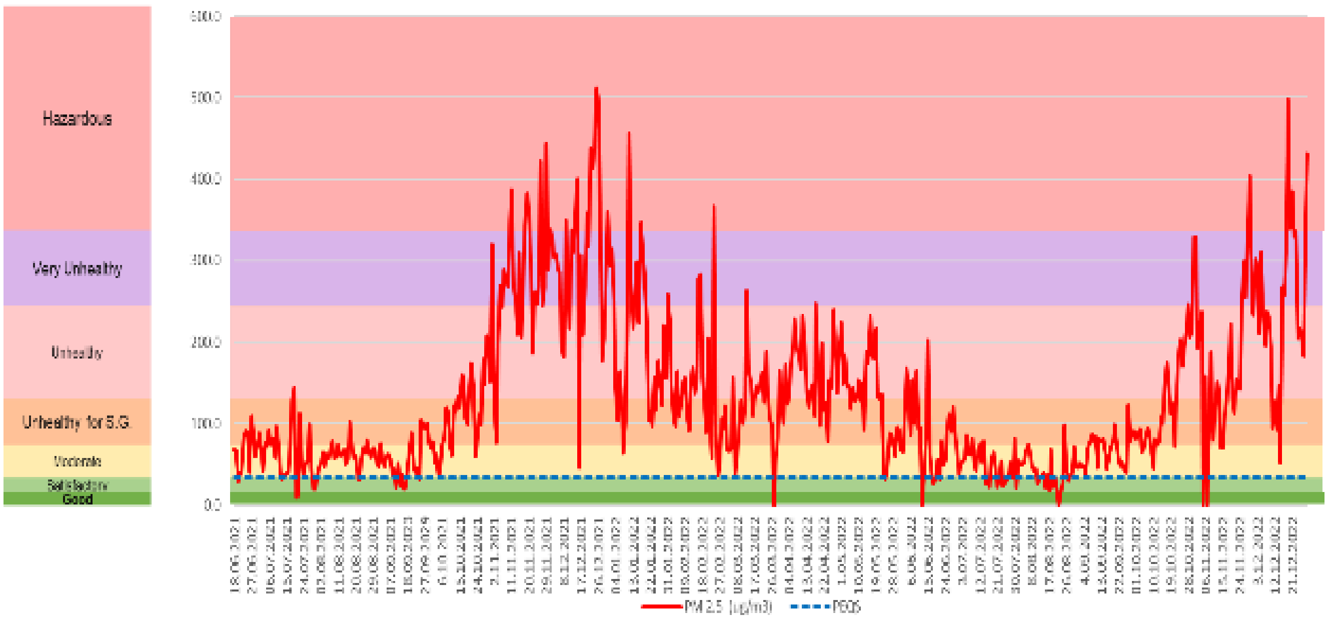


Figure 24: Average Daily $PM_{2.5}$ Concentration (Source: BAM-1020, Township)

$PM_{2.5}$ concentrations increase during winter while decrease during the summer seasons. Meteorological variations regulate the concentrations change during the entire year. As the inverse stratification develops under low temperature and high humidity conditions, air movement stabilizes, and the diffusion of pollutants stops. On the contrary, active vertical atmospheric movements with cyclones prevent the temperature inversion phenomenon. Therefore, the concentration of pollutants remains low. The rainfall is low in winter, the air mass is dry, rainfall duration is short, wind speed and intensity are less, and pollutants are less conducive to diffusion and therefore accumulate, increasing the concentrations of $PM_{2.5}$ (64). BAM-1020 has been operated by The Urban Unit at its Al-Jazari Water and Sanitation Academy located in Township Lahore, from May 11, 2021, to December 31, 2022. An analysis of the number of days of different air quality categories (Figure 25), as per the AQI breakpoints shows that the air quality was unhealthy for sensitive groups for the maximum number of days, i.e., 32% (185 days). The number of days below the specified limits of 35ug/m3 was 43 (7%) out of the total 577 days analyzed in the study.

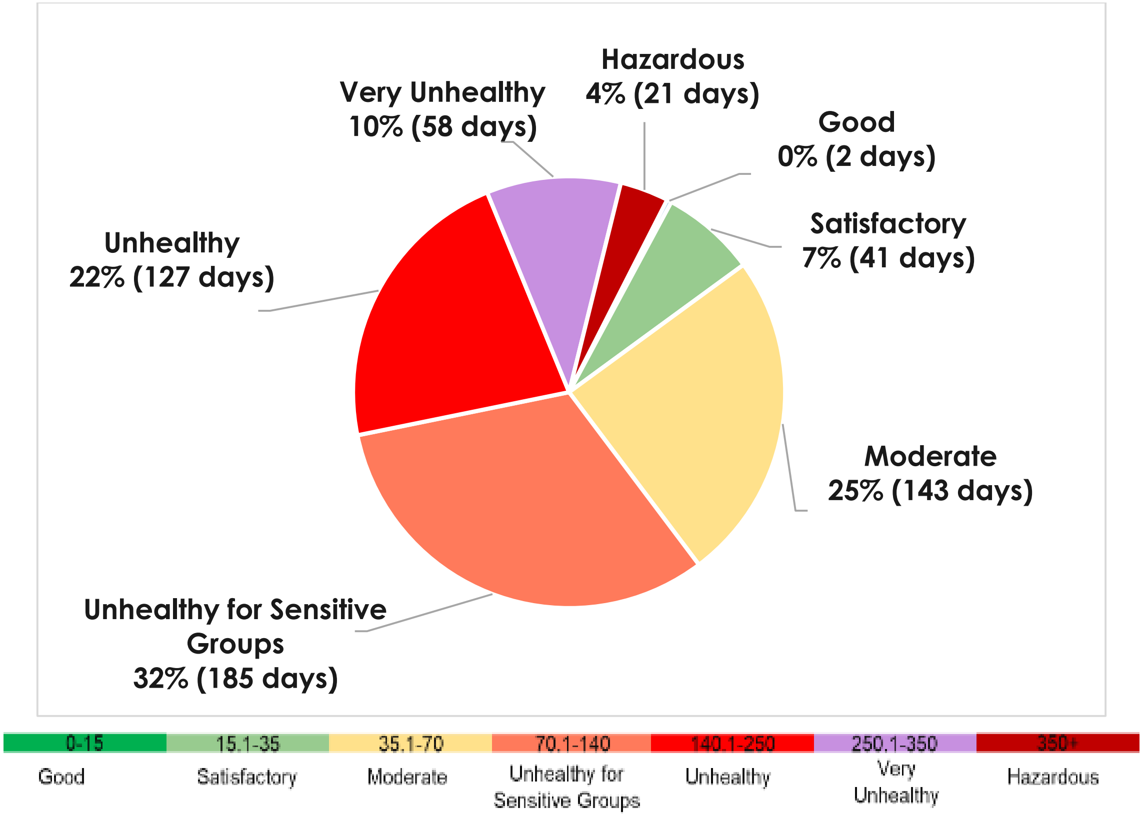
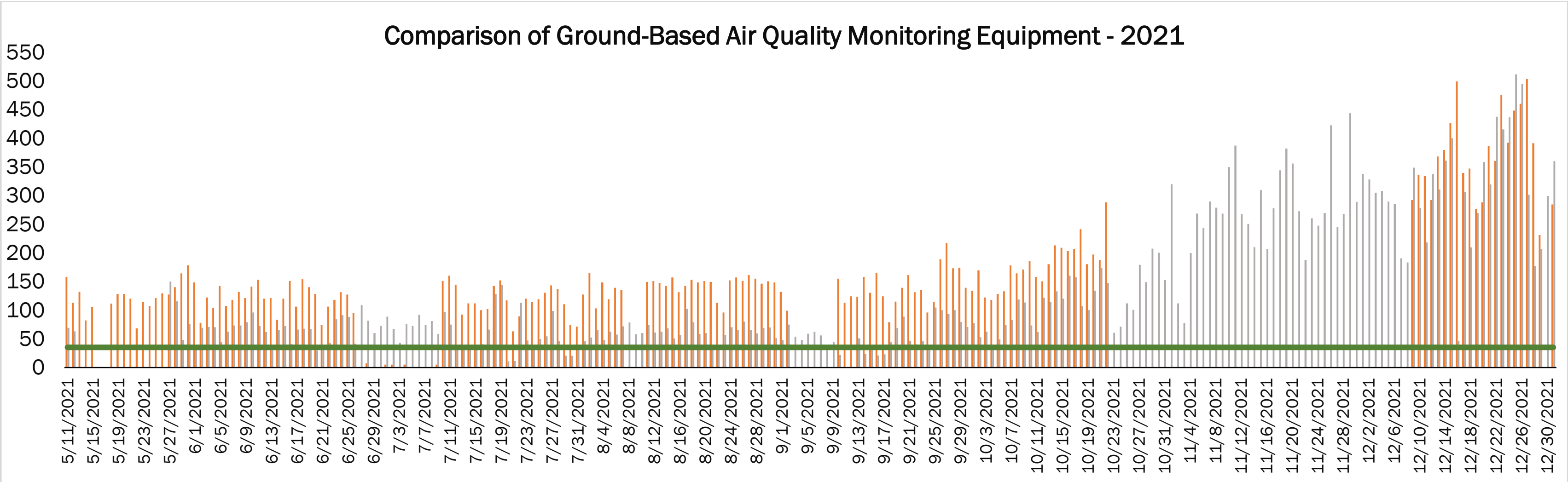


Figure 25: Number of days with respect to different categories of Air Quality Index (BAM-1020 data)

The $PM_{2.5}$ data was also derived from the US Consulate Air Quality Monitoring System installed at Shimla Pahari in Lahore. The increase and decrease in $PM_{2.5}$ concentrations from both monitoring systems are similar, because of the similar factors such as meteorological, socio-economic, and environmental influencing the concentrations in both locations. The results are given in Figure 26. The concentrations of $PM_{2.5}$ monitored by the US Consulate AQMS are slightly higher, because of its location in the vicinity of Ring road (along which many industrial units are present), poor road infrastructure (causing traffic congestion), dense population and unplanned settlements.



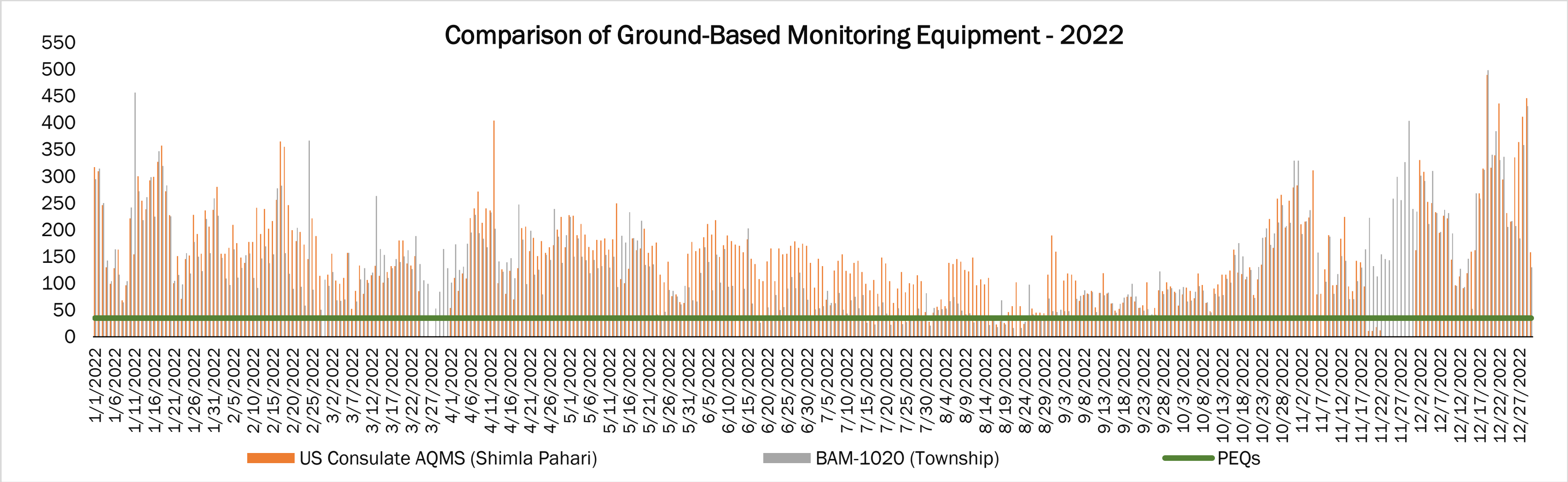


Figure 26: Comparison of Ground-Based Monitoring Equipment in Lahore

09

HEALTH IMPACTS OF EMISSIONS

9. Health Impacts of Emissions

The study of sectoral emissions, ground-based monitoring data, and CAMS data shows that the concentration of pollutants in ambient air of Lahore is significantly higher than the defined limits of PEQs. It is being considered as the worst form of pollution inflicting the residents of Lahore. According to the Air Quality Life Index Fact Sheet for Pakistan, residents in Lahore would gain 6.8 years in average life expectancy if WHO Guidelines of 5µg/m_3 (annual average $PM_{2.5}$ concentration) is met. Whereas the gain in life expectancy would be 5.8 and 2.2 years if annual average $PM_{2.5}$ concentrations are reduced to 15 µg/m_3 (PEQs), and by 30% (NDC Target), respectively (65). The sources, health impacts, and environmental impacts of key atmospheric pollutants identified through this study, are given in Table 4.

Table 4: Health Impacts of Different Gaseous Emissions

Pollutant	Type	Source	Health Impact	Environmental Impact
Particulate Matter (<2.5 and <10 microns) and Total Suspended Particulate (TSP)	Primary	Fuel (Bio-derived or Fossil-derived) Combustion in domestic, commercial, agricultural, and industrial sectors, fugitive dust emissions, and mismanagement of industrial waste.	Nervous system damage, Respiratory diseases and infections, eye irritation, cardiovascular diseases.	Greenhouse effect and global warming, damage to infrastructure, stunted vegetation yield and growth. Pollute the air.
Carbon Monoxide (CO)	Primary	Fuel (Bio-derived or Fossil-derived) Combustion in domestic, commercial, agricultural, and industrial sectors.	Binds with Hb in blood and reduces oxygen supply to body organs. Cardiovascular diseases and breathing difficulty.	Acts as GHG to cause global warming and form particulates that pollute the air.
Sulfur Oxides (SOx)	Primary	Industrial processes, natural volcanic eruptions, electric utilities, and fuel combustion.	Respiratory diseases	Causes acidification of water bodies and soil surfaces. Acts as GHG gas to cause global warming and form particulates that pollute the air.
Nitrogen Oxides (NOx)	Primary	Industrial processes, fuel combustion (majorly transport), and electric utilities.	Respiratory diseases	Contributes to the formation of tropospheric ozone, causes global warming effect, and acid rain, and forms particulates that pollute the air.
Volatile Organic Compounds (VOCs)	Primary	Fuel combustion, and chemicals evaporation from different activities.	Cancerous particles	Form particulates and tropospheric ozone.
Aerosols	Secondary	Formed from the combination of water vapors in the atmosphere with particulates of PM2.5, PM_{10}, NOx, SOx, CO, BC, Dust, Organic Matter, Sulfate, etc.	Respiratory, Cardiovascular, Kidney, and Nervous system diseases.	Cause smog and the greenhouse effect.
Tropospheric Ozone (O3)	Secondary	Formed by the chemical reaction of NOx and VOCs in sunlight	Respiratory and cardiovascular diseases.	Damage to crop yield, vegetation growth, etc.

The pollution in Lahore has remained at such high levels throughout the year that it no more remains a seasonal phenomenon. The frequency of cases of respiratory illness increases during the smog season, as compared to that reported in the entire year. Health data was obtained from the District Health Information System (DHIS) dashboard. The incidences of seasonal influenza, pneumonia (>5 years old), pneumonia (<5 years old), Acute Upper Respiratory Infections (AURI), and cataract reported during smog season was 40%, 37%, 35%, 33%, and 32% of the whole year (October 2021 – October 2022). The incidence of all other diseases reported in smog season ranges falls between 19-26%. Acute Upper Respiratory Infection is the most frequently reported health concern in Lahore, as evidenced by the DHIS (District Health Information System) data. Considering the data received, this staggering increase in pollution is not an administrative issue alone, it has become a social and constitutional issue that involves guaranteed rights of inhabitants being breached at all levels owing to non-compliance of environmental protection standards.

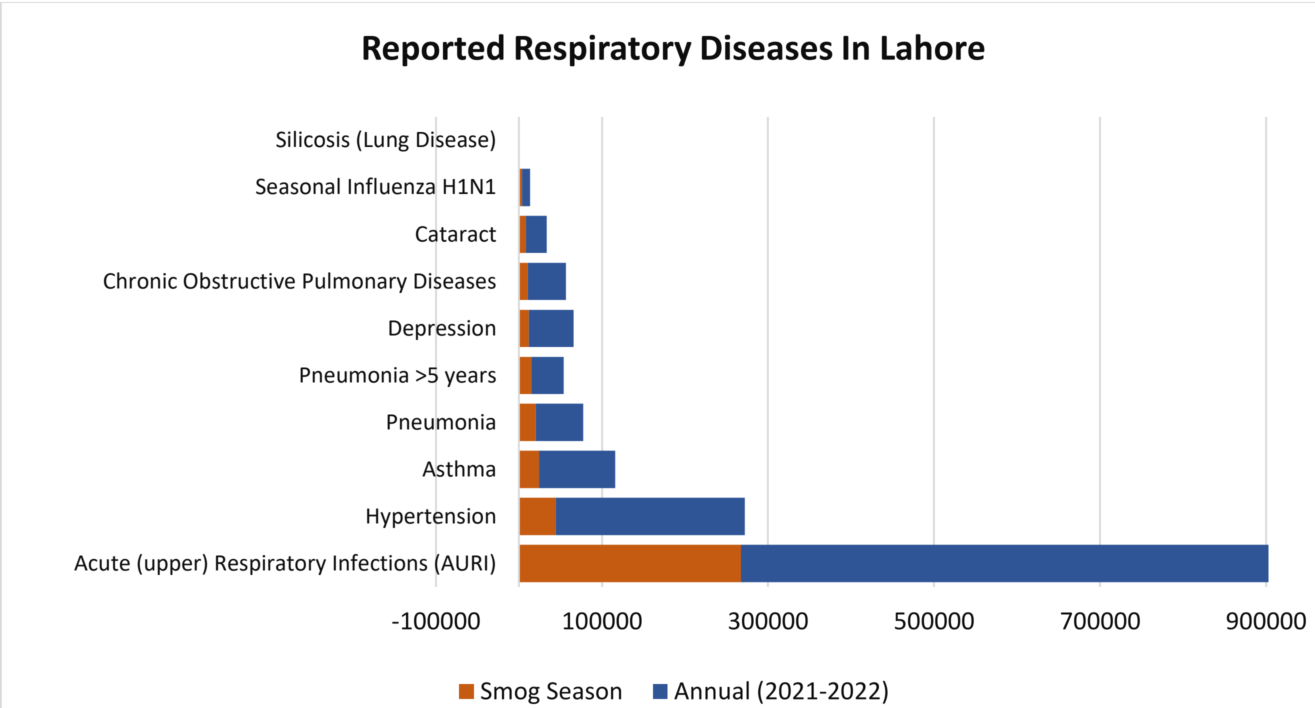
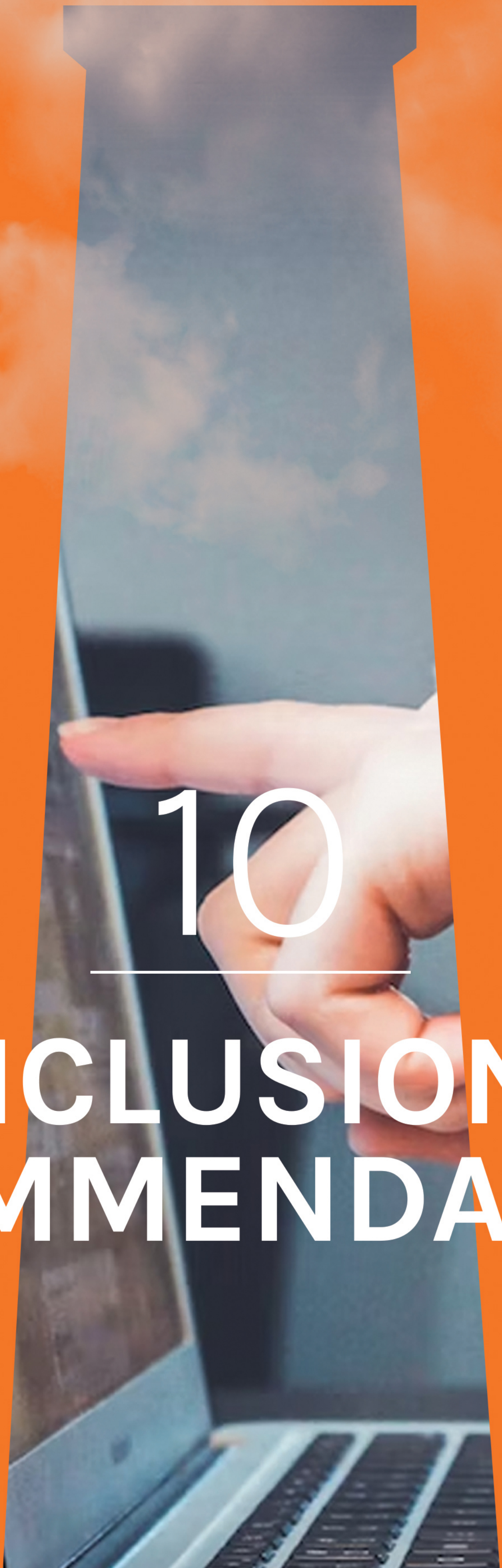


Figure 27: Air Pollution attributed Diseases reported in Lahore (DHIS)



10

CONCLUSION & RECOMMENDATIONS

10. Conclusion & Recommendations

The air quality of Lahore has been assessed using remote sensing data, ground-based monitoring, and chemo-metrical estimation of sectoral emissions based on IPCC Tier 1 methodology. Using the energy yearbook data of fuel consumption and developmental statistics of 2021, the total emissions in Lahore are 153 Giga grams from transport, industry, waste burning, commercial, domestic, and agriculture sectors. Transportation is the major polluting sector, contributing to 83% of the total emissions. The detailed study of the sectoral profile in the report shows significantly high emissions from all sectors, which are also evident from the data collected from ground-based air quality monitoring equipment and remote sensing data sources. This implies that the discussion on urban climate adaptation and urban resilience has been ongoing and has resulted in the development of Smog Action Plan 2023, developed by the Urban Unit in collaboration with the Provincial Disaster Management Authority. The plan provides a framework for collaboration of all government departments that can play their roles to prevent and mitigate air pollution in Lahore.

Lahore must adopt emissions reduction targets with a structured and systematic approach for improved environmental governance and public policymaking. There is a need to experiment with modern concepts and technologies such as the monitoring of the baseline air quality through low-cost sensors, and engaging youth in the monitoring of pollution-related violations through IT-based systems for evolving air quality governance. The abatement measures must be focused primarily on the transport sector. Public awareness of behavioral modification is very crucial in this aspect. It is recommended to estimate the sectoral emissions from each developmental sector, using tier-2 and tier-3 methodologies, for a more detailed outlook of the impact of anthropogenic activities. To overcome data limitations, installation of an increased number of monitoring equipment and data sharing through an integrated dashboard of all government and private organizations may be considered.

Legislation and legal parameters relevant to air quality in Punjab including the Pakistan Environment Protection Act (Amended 2012), Provincial Environmental Quality Standards (2010), Clean Air Action Plan (2017), Smog Action Plan (2023), Policy on Controlling Smog (2017), Electric Vehicles Policy (2020-2025), Power Policy (2015), and other rules and regulations relevant to urban air quality management should be effectively implemented along with the capacity building of the institutions for improvements in regulatory and mitigatory actions. Sectoral policies with targeted rules and regulations are required to be developed to mitigate air pollution. The ambient air pollution with its associated health impacts must be regularly monitored to offset the high environmental costs which will be inevitable in the future, under a business-as-usual scenario. Some of the immediate interventions for improving the air quality in Lahore are presented in Figure 28.

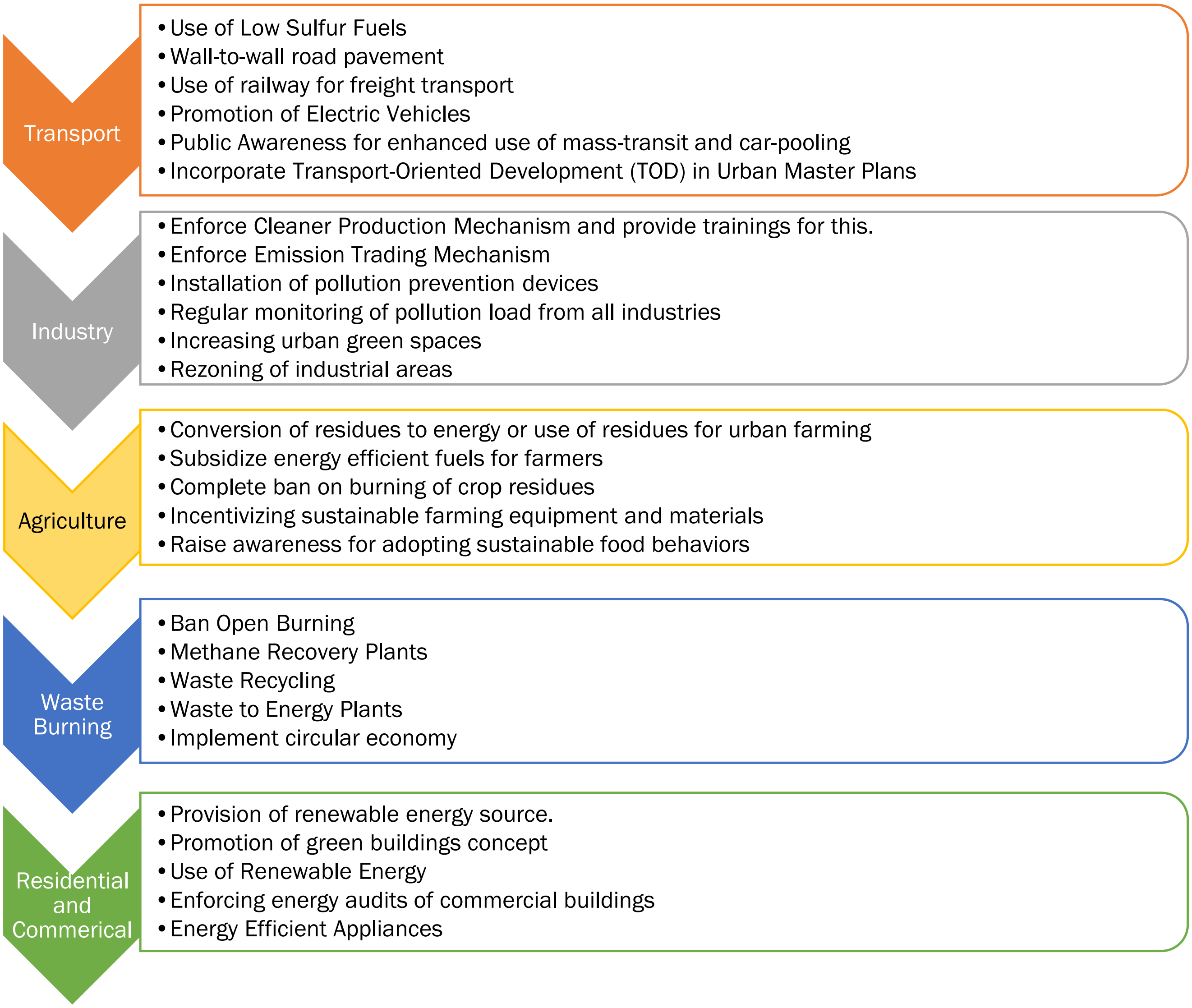


Figure 28: Proposed Interventions for Managing Air Pollution

Institutional and administrative frameworks of an area fundamentally determine the implementation of climate change abatement strategies. Lowering the concentrations of greenhouse gases is considered as the basic right for human growth and important for economic stability. However, climate change and cities are important political and human rights agendas currently. Unplanned and uncontrolled urban sprawl, lack of sufficient research-based data, dearth in policy implementation, and shortage of awareness and capacity building lie at the heart of increasingly poor air quality conditions in Lahore which must be tackled immediately for reducing emissions from all sectors.

11

LIMITATIONS OF THE STUDY

11. Limitations of the Study

This study has been completed between July 2022 and January 2023. It faces certain limitations mainly because of the lack of updated and sufficient data. The report completely relies on published literature and governmental reports. The latest version of these reports is till the year 2021. The uncertainties and errors in data published in these reports will also affect the results reported in this study. The estimations have been done based on default emissions factors defined by the IPCC methodology, as Pakistan has yet to develop its national emission factors. However, the report clearly explains the justifications and sources for all datasets used, and the margins of variations are believed to be small enough to not influence the overall objectives of this study. In addition, the process of development of emission inventory is based on a simplified methodology. To reduce such uncertainties, source apportionment and chemical composition-based studies can be conducted for in-depth estimation of sectoral emissions.

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