

SOOT AT SITE

A Scoping Study of Black Carbon Emissions from Industrial Processes in Indo-Gangetic Plains

REPORT SUMMARY

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A Scoping Study of Black Carbon Emissions from Industrial Processes in Indo-Gangetic Plains

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Maps in this report are indicative and not to scale.

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Black carbon: the 'superpollutant'

Soot, scientifically known as black carbon (BC), is one of the most concerning but least discussed 'superpollutants'. The term superpollutant refers to a substance that has a disproportionately large impact on climate and public health over a relatively short period. Black carbon is produced when fuels such as coal, diesel, biomass, and waste do not burn completely. It is present across urban, industrial and rural environments, and its impacts extend far beyond reduced visibility and poor air quality. Black carbon contributes to climate change, accelerates Himalayan glacier melt, threatens water security and harms health.

Under ideal combustion conditions, carbon in fuel is converted primarily into carbon dioxide (CO_2). When combustion is inefficient because of inadequate oxygen, poor fuel–air mixing, low temperatures, or unstable operating conditions, some carbon is emitted as tiny solid particles. These particles are known as black carbon and form the light-absorbing component of soot. Black carbon particles are extremely small, about 2,000 times thinner than a human hair. Because of their size, they can remain suspended in the atmosphere for several days and travel long distances. Unlike carbon dioxide, which can remain in the atmosphere for centuries, black carbon generally persists for only four to 12 days. Despite this short lifetime, it is a highly potent short-lived climate pollutant because it absorbs sunlight and converts it directly into heat.

Why is black carbon harmful?

While most superpollutants are heat-trapping gases, black carbon is different. It warms the climate by absorbing sunlight and heating the surrounding air. Also, black carbon mingles with other pollutants—for example, sulphur oxides (SOx), which are emitted from coal-burning power plants, brick kilns and industries—triggering cascading effects that amplify its harm. When black carbon meets SOx in the air, sulphates latch onto the carbon particles, extending their atmospheric lifetime and range. The result: pollution spreads across regions, alters cloud formation and increases the concentration of fine particles that penetrate deep into human lungs, raising the risk of respiratory and cardiovascular disease.

Health impacts due to exposure to black carbon

Black carbon's microscopic size allows it to bypass nasal cilia and the upper respiratory tract, penetrate deep into the lungs and lodge within the alveoli; the human body lacks an effective mechanism to remove these deeply embedded particles. Chronic exposure initiates persistent lung damage characterized by chronic inflammation, resulting in tissue fibrosis and scarring. For every 0.5 µg/

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m^3 increase in black carbon, lung capacity declines by an additional 0.5–0.9 per cent each year.

Black carbon as driver for water instability

Himalayan glaciers are the main freshwater source for northern India, feeding major rivers like the Ganga and Yamuna. As black carbon speeds up glacier melting, the reliability of these river systems is threatened. The region is currently experiencing a misleading 'peak water' paradox: faster glacier melting temporarily increases river flows, creating a false sense of water security. As total ice mass shrinks, projections show a 20–40 per cent decline in dry-season river flows by 2050, threatening long-term water supply.

Cryospheric damage and the albedo effect

Black carbon particles cause their worst climate damage when they land on snow and ice. Clean snow reflects 80–90 per cent of incoming sunlight, acting as a natural defense for glaciers and ice sheets. When black carbon settles on snow, it darkens the surface, reduces reflectivity (albedo), and turns reflective surfaces into heat absorbers (see *Table 1: Impact of black carbon on snow albedo and melt rates*). Black carbon deposition peaks during dry winter months, when rain and snow are minimal. During this period, black carbon makes up 30–70 per cent of total particles deposited in many Himalayan regions. As a result, snowpacks become heavily contaminated before spring melt begins, setting glaciers up for faster mass loss.

Table 1: Impact of black carbon on snow albedo and melt rates

Metric	Clean snow (%)	BC-contaminated snow (%)
Surface reflectivity	80–90	50–70
Snow albedo reduction	0 (baseline)	2–6
Increase in melt rates	0 (baseline)	20–50

Source: Pu, W., Shi, T., Cui, J., Chen, Y., Zhou, Y., and Wang, X., The Cryosphere, 15, 2255–72, 2021.

BLACK CARBON IN EMERGING INDIAN JURISPRUDENCE

Although black carbon is not yet recognized as a distinct pollutant under India's environmental laws, courts and regulatory authorities have increasingly referred to its role in air pollution, climate change and glacier melt. In its order on coal-fired brick kilns in NCR under GRAP (17/02/2021), the National Green Tribunal held that in 'severe' air quality conditions, coal-based brick kilns cannot operate, regardless of the technology used, unless they switch to cleaner fuels such as PNG,

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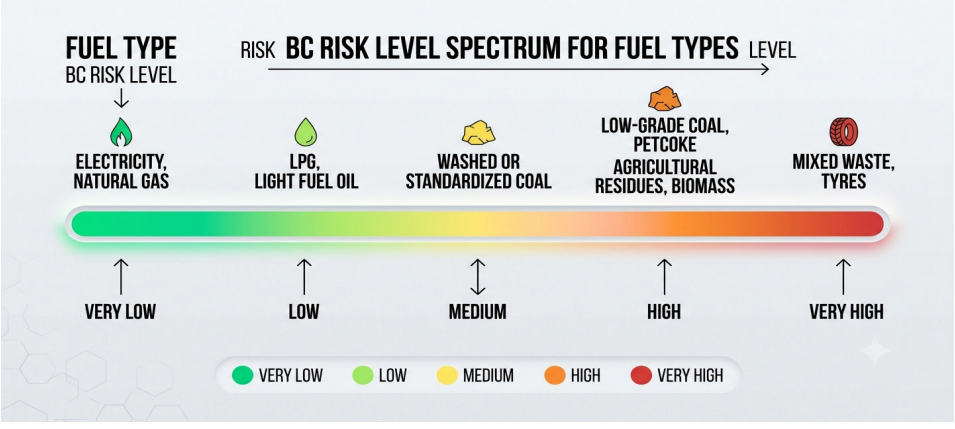
emphasizing the precautionary principle, the right to clean air and public health concerns.

Sources of black carbon

In India, black carbon comes from multiple sources embedded in daily life and the economy. Factories and industrial facilities that burn coal, petroleum products, and biomass at scale for energy generation and manufacturing are the main sources of black carbon. This includes coal-fired power plants, brick kilns, factory boilers, metal smelting furnaces and cement kilns. Other sources include diesel vehicles, trucks, buses and construction equipment; traditional cookstoves burning wood, crop residues, dried dung and coal; post-harvest burning of crop residues, intense during October–November in northern India; and open burning of garbage, including plastics and mixed waste.

In industrial areas, inefficient combustion contributes most to black carbon emissions. In India, particularly in the Indo-Gangetic Plains, industrial combustion is one of the most concentrated, persistent and understudied sources of black carbon. And here, fuel quality plays a central role. Indian coals typically contain 18–50 per cent ash (consumption-weighted average of 39 per cent), significantly higher than global averages. Solid fuels with high ash content, high volatile matter or mixed composition, such as low-grade coal, petcoke, agricultural residues and mixed waste, produce incomplete combustion more readily than refined fuels. Also, industrial black carbon is crucial because, unlike diffuse sources such as household cooking or traffic, industrial processes are characterized by high fuel consumption, prolonged operating hours, fixed emission points, strong dependence on fuel quality, combustion design and operational practices (see *Figure 1: Black carbon risk classification by fuel type*).

Figure 1: Black carbon risk classification by fuel type



Source: Bond, T. C., et al. (2013), Bounding the role of black carbon in the climate system: A scientific assessment, J. Geophys. Res. Atmos., 118, 5380–52, doi:10.1002/jgrd.50171.

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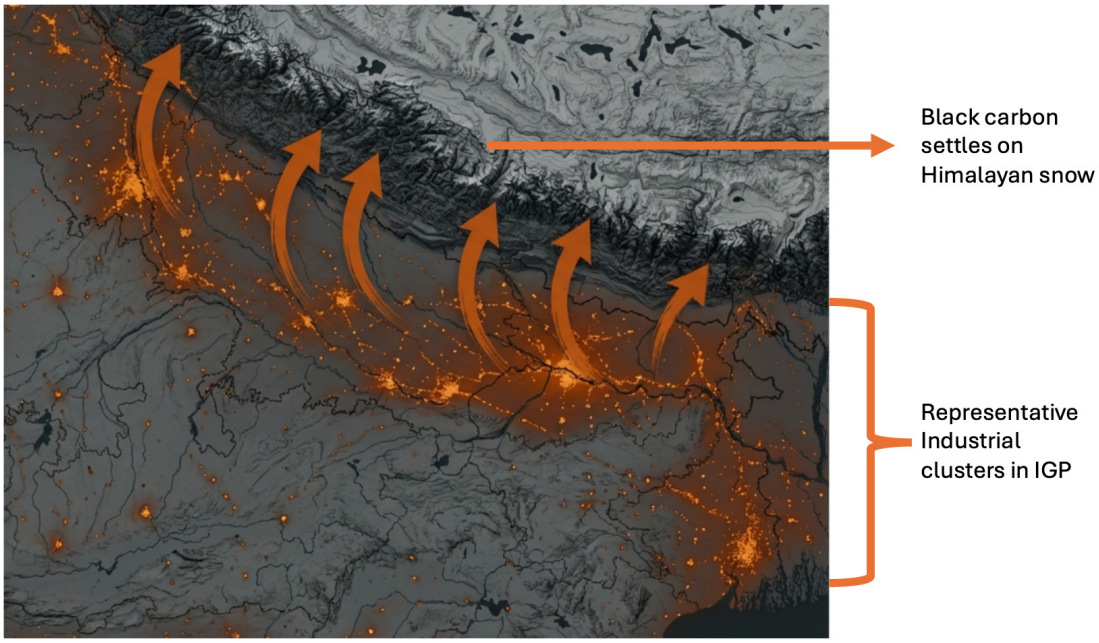
Why focus on black carbon emissions in the Indo-Gangetic Plains

The Indo-Gangetic Plains stand out as a priority zone for black carbon action precisely because of the scale of exposure. Home to more than 600 million people, the region hosts dense industrial corridors, coal-fired power plants, brick kilns, foundries and countless micro, small and medium enterprises operating on a range of fuels and combustion technologies, often with limited regulatory oversight. Beyond the direct health burden this places on one of the world's most densely populated regions, the plain's proximity to the Himalayan foothills adds a second layer of consequence: black carbon carried upward and deposited on Himalayan snow and glaciers accelerates melting by reducing surface reflectivity, linking local emissions to regional climate and water-security impacts. This dual footprint, affecting human health in the plains and glacial impact in the mountains, makes the Indo-Gangetic Plains a strategically important region for targeted black carbon mitigation (see *Figure 2: Deposition of black carbon—industrial clusters as hotspots*). Further, winter meteorological conditions in the IGP intensify the problem. Low wind speeds, temperature inversions and shallow boundary layers restrict pollutant dispersion precisely when industrial operations peak and solid fuel use increases.

Figure 2: Deposition of black carbon—industrial clusters as hotspots



Source: CSE

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What Indian researchers have uncovered

Six research studies examined black carbon pollution across the Indo-Gangetic Plain and eastern India using different methods, from satellite monitoring of entire river basins to workplace air quality measurements. Despite studying different locations and scales, all studies reached the same conclusion: black carbon in this region comes primarily from burning coal in power plants and industries, diesel fuel in vehicles, and biomass (wood, crop waste) for cooking and heating. Areas with thermal power plants had the highest concentrations of fine pollution particles, proving coal combustion is the main driver of basin-wide pollution. All studies found that winter is the most polluted season because cold air traps emissions near the ground, winds are weak, and the atmosphere doesn't mix well. The Kanpur climate study demonstrated that black carbon absorbs sunlight and heats the lower atmosphere by 1.8°C per day while reducing solar radiation at the ground surface by 62 watts per square metre. Research in Chandigarh's industrial area showed that indoor air in bottling plants contained dangerous levels of black carbon and particulate matter, with workers facing significantly increased lifetime cancer risks and respiratory problems. However, the research also reveals gaps. Most studies measured pollution concentrations and identified broad source categories (coal, diesel and biomass), but did not examine specific industrial processes that generate emissions. This makes it difficult to link particular factory operations with black carbon output (see *Map 1: Black carbon research studies across India*).

CSE's stakeholder survey

Scientists at the Aryabhatta Research Institute of Observational Sciences (ARIES) have been tracking black carbon at Mukteshwar, a high-altitude site in the Himalayan foothills; even in this remote location, far from cities, pollution levels are significant. Estimating black carbon emissions from different sources requires good data on fuel use, combustion conditions, and sectoral practices. In India, much of this information is missing, especially for small and informal industries. Experts at TERI raised another problem: there is no standard method in India for measuring BC from industrial chimneys. The technology to fix this exists, but no institution has made it a requirement. The barrier is not technical; it is institutional. The Bihar State Pollution Control Board said it has installed aethalometers at five locations across the state to measure black carbon in the air.

How India compares

Across urban European cities, black carbon levels generally range from around 0.9 to 2.0 $\mu g/m^3$. In Chinese megacities such as Beijing and Shanghai, annual mean black carbon concentrations have been measured between approximately 2 and 6 $\mu g/m^3$, though Beijing's values declined significantly from around 6.25 $\mu g/m^3$ in

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Map 1: Black carbon research studies across India

Indo-Gangetic Plain corridor Himalayan receptor zone Other research sites Dashed ring: regional or multi-site study, position indicat

9 Garhwal Himalayas, Uttarakhand
Modeled the "Elevated Heat Pump" effect of BC on monsoon dynamics and Himalayan glacial retreat
IITM Pune and HNB Garhwal University

5 Chandigarh
Assessed occupational BC exposure and long-term health/cancer risks for workers inside industrial bottling plants
IIT Kharagpur and collaborators

7 Mukteshwar, Uttarakhand
Tracked high-altitude Himalayan BC concentrations and daily upslope air transport from the Gangetic plains
ARIES (Aryabhatta Research Institute of Observational Sciences)

11 Delhi
Measured ambient BC episodes to evaluate regional transport vs. local vehicular and weather drivers
CSIR-NPL, Delhi

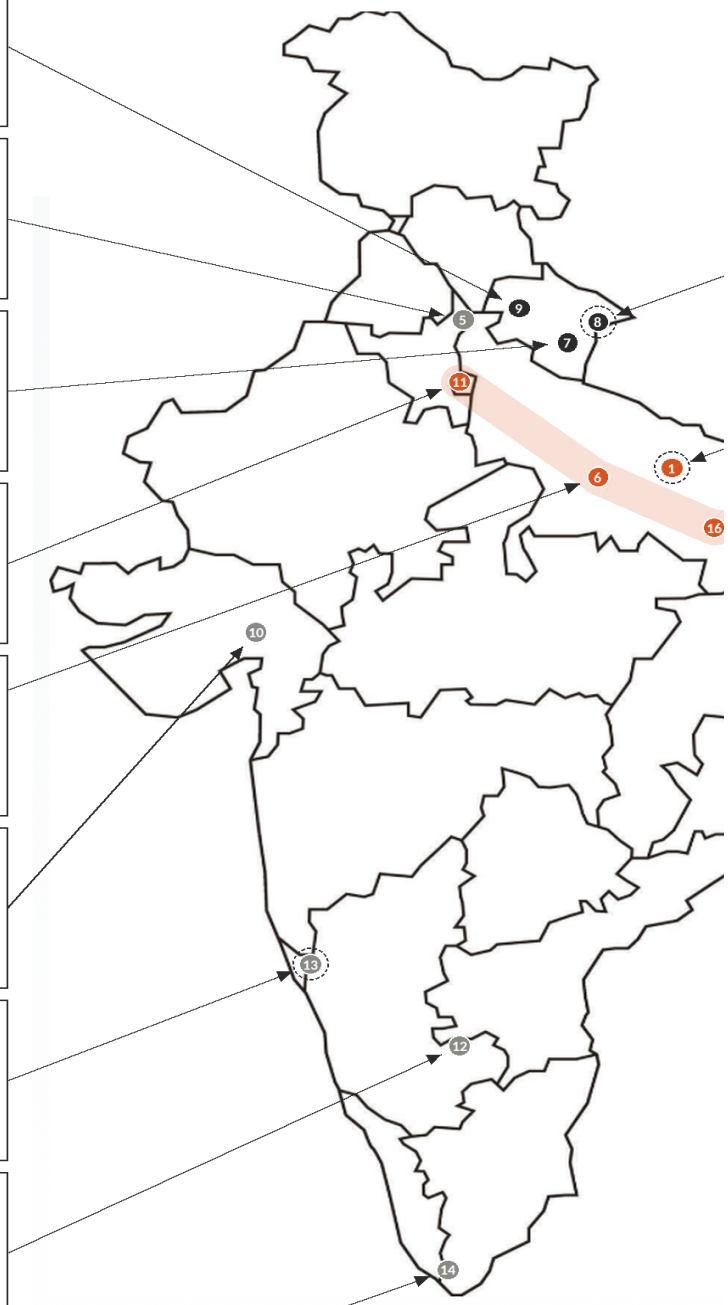
6 Kanpur, Uttar Pradesh
Quantified atmospheric heating (1.8°C/day) and surface solar dimming caused by BC radiative forcing
IIT Delhi, IIT Kanpur

10 Ahmedabad, Gujarat
Conducted radiocarbon (14C) isotopic source apportionment to differentiate fossil fuel vs. biomass carbon
Physical Research Laboratory (PRL)

13 Goa, Antarctic Station Maitri (regional)
Tracked long-term BC deposition patterns and polar aerosol transport from Indian Antarctic infrastructure
NCPOR (National Centre for Polar and Ocean Research)

12 Bengaluru, Karnataka
Developed climate models to study BC interaction with clouds, forcing factors, and Himalayan glacier melt
IISc (Indian Institute of Science), Bengaluru

14 Thiruvananthapuram, Kerala
Investigated persistent elevated BC aerosol layers in the upper troposphere linked to aviation emissions
IISER TVM and IISc



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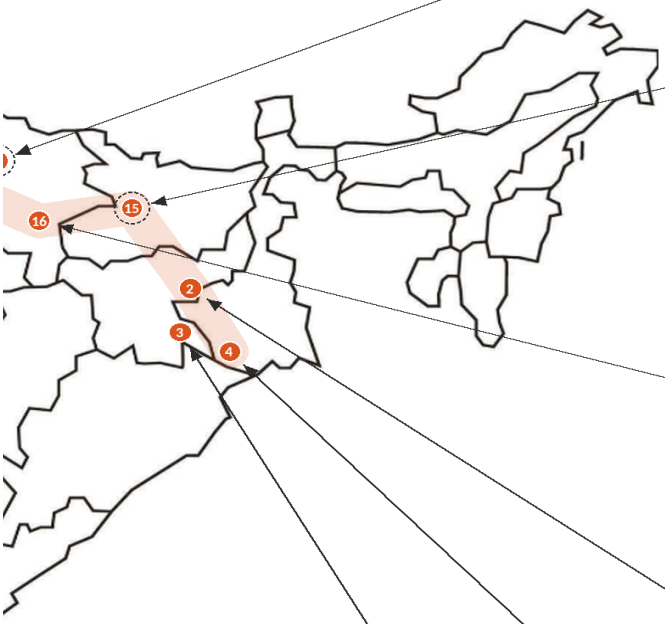

8 Central Himalayas (regional)

Measured BC deposition on glaciers to evaluate its direct role in snowpack reduction and glacier melt acceleration

IIT Roorkee and Ambedkar University

1 Gangetic Basin (regional)

Evaluated regional aerosol transport and identified coal thermal power plants as the primary driver of winter BC pollution using satellite data

ISRO (Space Applications Centre)

15 Bihar (statewide, 5 sites) (regional)

Installed multi-wavelength aethalometers across five stations to systematically track seasonal BC source profiles

Bihar State Pollution Control Board

16 Varanasi, Uttar Pradesh

Documented a long-term (13-year) mean BC concentration benchmark in the central Indo-Gangetic Plain

Academic and government research network

2 Dhanbad, Jharkhand

Quantified local vs. regional BC sources in a coalfield region, attributing 67% of BC to fossil fuels

CSIR-CIMFR, Dhanbad

4 Kharagpur, West Bengal

Investigated urban BC pollution patterns, finding residential biomass/wood burning as the primary contributor (43.8%)

IIT Kharagpur

3 Jamshedpur, Jharkhand

Analyzed PM2.5 and BC composition in a heavy industrial hub dominated by fossil fuel emissions (51.5%)

Birla Institute of Technology

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2012 to 1.80 μg/m3 by 2020 following clean air policy interventions. Closer to the present study area, long-term measurements at Varanasi recorded a 13-year mean black carbon concentration of approximately 9.18 μg/m^3, and annual mean BC at an urban IGP site in Delhi was consistently in the range of around 5.3–5.6 μg/m^3 during 2020–22. This underscores the urgency of targeted intervention in the IGP corridor, where a combination of biomass burning, low boundary layer heights, and calm winter winds creates persistent BC accumulation conditions that are among the most severe globally (see *Table 2: Comparison of international black carbon concentrations)*. For more details see detailed report.

Table 2: Comparison of international black carbon concentrations

Region/context	BC concentration range (μg/m^3)
Remote/clean atmosphere (Pacific)	0.1–0.5
European urban background	0.9–2.0
Chinese megacities (Beijing, Shanghai)	2.0–6.0
Indo-Gangetic Plain (annual mean)	5–12

International frameworks to mitigate and control black carbon

Canada's black carbon framework

Canada identified black carbon as both a potent atmospheric pollutant and a public health hazard, making it a strategic priority particularly in the context of Arctic warming. Canada's Air Quality Management System (AQMS), established in 2012, is a cooperative framework designed and implemented by federal, provincial and territorial governments. Its core elements are the Canadian Ambient Air Quality Standards (CAAQS), Base-Level Industrial Emissions Requirements (BLIERs), the Air Zone Management Framework, Mobile Emission Source Controls and Transparent Reporting. CAAQS does not regulate black carbon through a standalone standard. It is captured through the PM2.5 framework: reducing fine particulate matter reduces BC as a component. The 2030 CAAQS PM2.5 objectives are 23 μg/m^3 (24-hour) and 8.0 μg/m^3 (annual), tightened from 27 μg/m^3 and 8.8 μg/m^3 under the 2020 standards. Canada's total anthropogenic BC emissions decreased by 40 per cent between 2013 and 2023, from approximately 36,000 to 22,000 tonnes. Transportation and mobile equipment remains the dominant source at 56 per cent of national emissions. However, this national progress masks rising industrial emissions. Oil sands subsectors increased BC by 38 per cent since 2013, the iron and steel industry increased BC by 50 per cent, flaring and incineration increased by 11 per cent from 2019 to 2023, and mining and rock quarrying increased by 7.5 per cent. The lesson for policy design

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is that national progress driven by one sector (transportation) can be offset by rising emissions in under-regulated industrial sub-sectors. Canada's black carbon actions are anchored in the Arctic Council Framework for Action on BC and Methane Emissions (2015), which sets a 25–33 per cent reduction target from 2013 levels by 2025 and was already surpassed at 31 per cent by 2022, and the 2012 Gothenburg Protocol amendments.

At COP30 in Belém, nine countries, including Canada, Chile, Colombia, Costa Rica, Dominican Republic, Madagascar, Nigeria, Sri Lanka and Uganda, announced a first-of-its-kind coordinated effort to address major sources of black carbon emissions through national policies and sectoral actions. The announcement marked a shift in global climate policy by recognizing black carbon as a near-term climate and health priority (for more details refer to the detailed report).

Black carbon in the United States

The United States regulates black carbon indirectly under the Clean Air Act by controlling PM2.5. In 2024, the EPA tightened the annual PM2.5 standard from 12 $\mu g/m^3$ to 9 $\mu g/m^3$. Since diesel engines account for approximately 70 percent of US BC emissions, transportation sector controls have been the primary lever, including progressively stricter emission standards for new diesel vehicles and non-road engines, diesel particulate filters on all new vehicles, a nationwide transition to ultra-low sulphur diesel and retrofit programmes for older trucks and buses. From 1990 to 2020, US primary PM2.5 emissions declined by 38 per cent. However, national reductions have plateaued since approximately 2015, indicating the limits of indirect PM2.5 controls in driving further reductions in black carbon.

Key lessons for India

Canada and the United States reduced black carbon substantially without always regulating it as a standalone pollutant. What made the difference was not a single law but a set of interconnected systems. Three lessons stand out as directly relevant for India. Establish measurement before management: transparent, publicly accessible emission inventories updated annually and disaggregated by sector are the foundation of effective governance. Unmeasured emissions cannot be managed. Layer regulations by source, not by blanket standard: ambient air quality targets must be complemented by source-specific rules. Brick kilns, power plants, diesel transport and household biomass combustion each require distinct regulatory instruments. Prioritize data infrastructure over premature targets: unlike Canada and the US, India's dominant emitters are dispersed, informal and largely outside formal monitoring systems from the outset. Building measurement capacity is not a preparatory step, it is the first policy intervention (see *Map 2: Black carbon international frameworks*).

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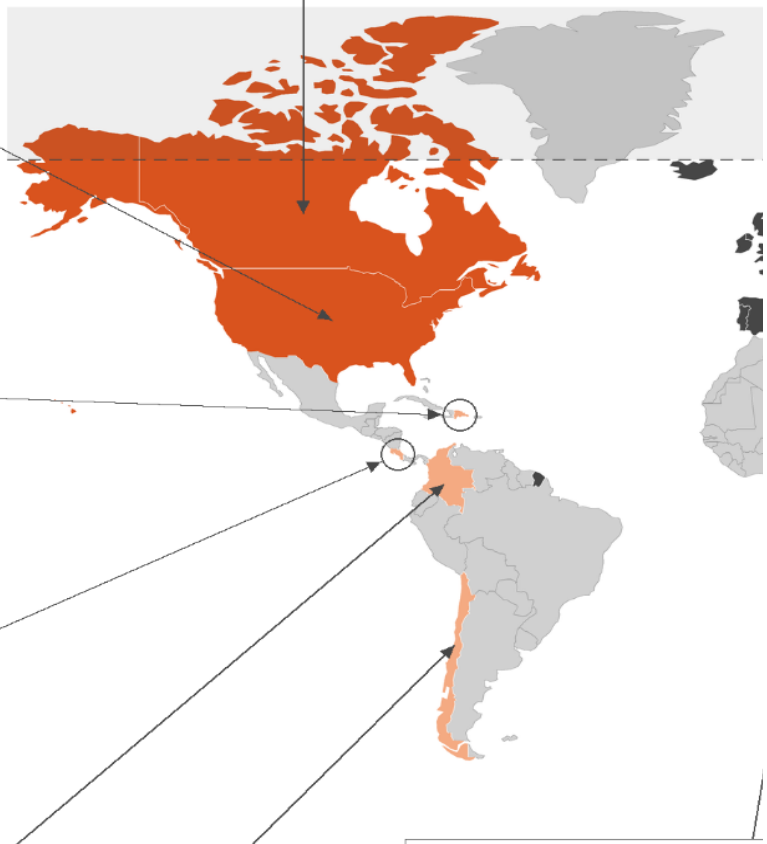
Map 2: Black carbon international frameworks

- National regulation / strategy
- COP30 Belém initiative country
- Regional framework (Arctic Council; UNECE Gothenburg Protocol)

Shaded band with dashed line: Arctic (north of 66.5°N). Ring: small country. Europe shading is indicative.



Canada

Identifies black carbon as an atmospheric pollutant and health hazard to slow Arctic warming; achieved a 40% emission reduction (2013–2023) primarily through transport controls while seeing increases in industrial sub-sectors. Joined COP30 pledge.

Body: Environment and Climate Change Canada (AQMS cooperative framework with provincial and territorial governments)
Sector: Transportation and mobile equipment (56% of emissions); oil sands, iron and steel, flaring/incineration, mining/rock quarrying
Target: CAAQS PM2.5 2030 objectives: 23 µg/m³ (24-hour) and 8.0 µg/m³ (annual); Arctic Council target: 25–33% reduction from 2013 levels by 2025 (31% achieved by 2022)

Europe / Transa

Regional treaty requiri
explicit priority on sou
Body: UNECE (Gothenbu
Sector: Black carbon co-
Target: PM2.5 reduction

United States

Regulates black carbon indirectly under the Clean Air Act through fine particulate controls; reduced primary PM2.5 by 38% (1990–2020) before national reductions plateaued around 2015.

Body: US Environmental Protection Agency (EPA)
Sector: Heavy-duty diesel vehicles and non-road engines (diesel accounts for ~70% of US BC emissions)
Target: Tightened annual PM2.5 standard to 9 µg/m³ in 2024 (down from 12 µg/m³)

Dominican Republic

Joined the COP30 Belém initiative to address major black carbon sources through national policies, measurement systems, and national climate planning.

Body: COP30 Initiative Participating Government
Sector: Transport, energy, industry, and construction
Target: Integrate black carbon reduction into national climate planning

Costa Rica

Joined the COP30 Belém initiative to address major black carbon sources through national policies, measurement systems, and national climate planning.

Body: COP30 Initiative Participating Government
Sector: Transport, energy, industry, and construction
Target: Integrate black carbon reduction into national climate planning

Colombia

Joined the COP30 Belém initiative to address major black carbon sources through national policies, measurement systems, and national climate planning.

Body: COP30 Initiative Participating Government
Sector: Transport, energy, industry, and construction
Target: Integrate black carbon reduction into national climate planning

Chile

Joined the COP30 Belém initiative to address major black carbon sources through national policies, measurement systems, and national climate planning.

Body: COP30 Initiative Participating Government
Sector: Transport, energy, industry, and construction
Target: Integrate black carbon reduction into national climate planning

Nigeria

Joined the COP30 Belém initiative to address major black carbon sources through national policies, measurement systems, and national climate planning.

Body: COP30 Initiative Participating Government
Sector: Transport, energy, industry, and construction
Target: Integrate black carbon reduction into national climate planning

Source: CSE

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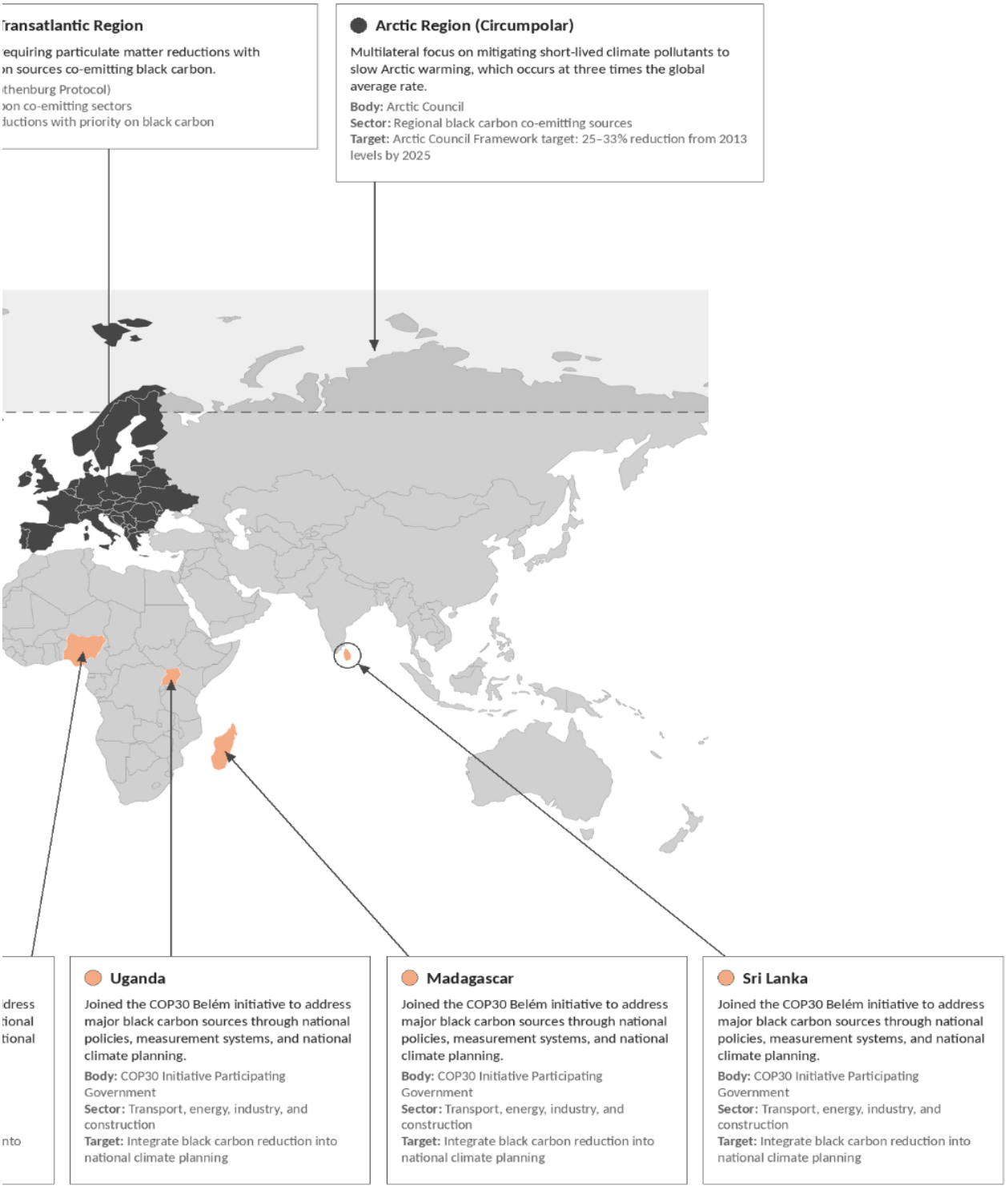

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Measuring black carbon in India: the state of assessment

Understanding the scale and sources of black carbon emissions is essential for developing effective mitigation strategies. In India, black carbon is assessed through a combination of direct measurements and estimation techniques. Direct measurements provide information on black carbon concentrations in the atmosphere, while estimation methods use activity data and emission factors to calculate emissions from different sources. In India, the balance tilts heavily toward estimation. Direct measurement networks for black carbon are limited, and most of what is known comes from academic research rather than routine government monitoring.

Direct measurement

The conventional method for stack monitoring is gravimetric sampling, which captures all particles together and cannot distinguish black carbon from other particle types. To isolate black carbon, thermal-optical analysis should be done: the filter is heated in controlled stages; organic carbon combusts at lower temperatures while elemental carbon, which corresponds closely to black carbon, combusts at higher temperatures. The method is accurate, but it is slow, labour-intensive, and cannot provide real-time results. Photoacoustic spectroscopy and laser-induced incandescence provide continuous, real-time readings, but both are significantly more expensive than conventional approaches and remain largely confined to research applications. Currently, such detailed measurement is mostly limited to research and pilot applications, highlighting a key gap in routine industrial emission monitoring. Ambient air monitoring measures black carbon already present in the air, and the aethalometer is the most widely used instrument for this purpose (for more details refer to detailed report).

Indirect estimation: building emission inventories

When measuring black carbon directly is not possible at scale, indirect methods take over. At the heart of indirect estimation is a simple relationship: Black carbon emissions = Activity data × Emission factor. Activity data tells us the scale of a source, while the emission factor translates that quantity into pollution. Tier 1 uses standardized global emission factors alongside broad activity data such as total fuel consumption by category. Tier 2 applies region-specific or technology-specific emission factors. Tier 3 relies on direct facility-level measurements and source testing, providing the highest accuracy but requiring extensive, consistent monitoring infrastructure. Most black carbon inventories for India operate at Tier 1 or Tier 2. Because there is no comprehensive direct monitoring network for black carbon across the country, inventories act as a practical substitute for measurement. Most inventories are built using a bottom-up approach: starting

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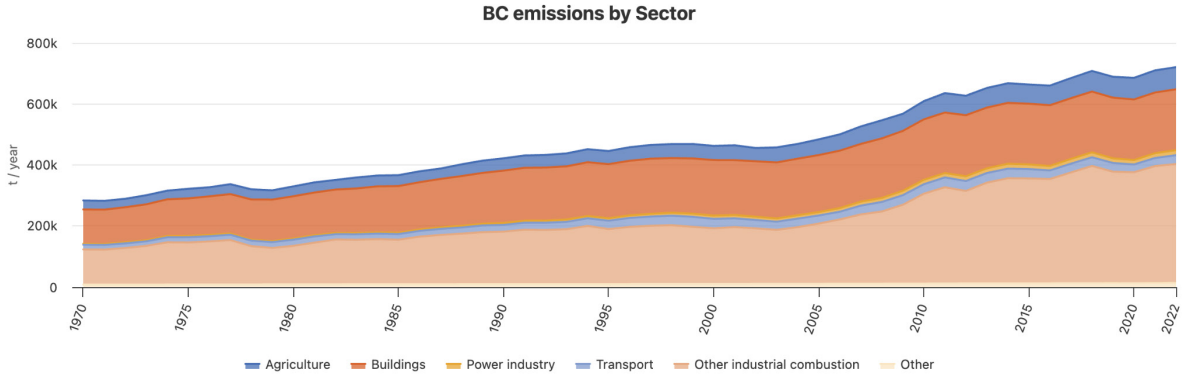
at the level of individual sources, estimating emissions for each using activity data and emission factors, then aggregating those estimates into sector totals and regional profiles (for more details see detailed report).

EDGAR: Global coverage through consistent methodology

EDGAR, the Emissions Database for Global Atmospheric Research, is designed to compare emissions across countries. For most sectors, EDGAR operates at Tier 1, the trade-off being that local variation is averaged out. When applied to India, EDGAR's estimates reveal a clear sectoral picture. The largest source of black carbon is other industrial combustion, a category that encompasses small and medium industries and brick kilns, with emissions growing from around 115 gigagram (Gg) in 1970 to approximately 390 Gg in 2022. The residential sector contributes around 199 Gg, followed by agricultural burning at 72 Gg, transport at 29 Gg, and power generation at 17 Gg. What these figures make clear is that black carbon in India does not come from a handful of large, regulated facilities. It comes from dispersed, informal, and small-scale sources that are inherently difficult to monitor (see *Graph 1: Black carbon emissions trends in India [1970–2022]*).

Graph 1: Black carbon emissions trends in India (1970–2022)



Source : Edgar 2025 report

Community Emissions Data System (CEDS)

CEDS is an open-source framework and inventory that produces annual estimates of global anthropogenic atmospheric emissions by country, sector and fuel, spanning from 1750 to the present. It provides gridded emissions with monthly seasonality and detailed, country-level emissions for 55 working sectors. CEDS data does not include open burning or agricultural wastes.

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Sector-specific data from existing global inventories

To identify the high black carbon-emitting processes across Indo-Gangetic Plain (IGP) industries, the EDGAR and CEDS inventories were considered and the GIS-based emissions data file extracted for both India and the IGP states. Data files for EDGAR were extracted for 10 different sectors, including combustion for manufacturing industry, chemical processes, non-ferrous metals production, non-metallic minerals production, iron and steel production, food and paper, power, fuel exploitation, oil refineries and transformation industries as well as agricultural waste. Agricultural waste was intentionally considered because it is a major source of air pollution in the IGP states. For CEDS, energy production and industry were relevant; transportation, Residential Commercial Others (RCO) and waste were not considered as these are outside the industrial ecosystem. However, agriculture data was not available in the CEDS (see *Graph 2: Year-wise emissions value for different sectors in IGP and rest of India* and *Graph 3: for more details see detailed report*).

Graph 2: Year-wise emissions value for different sectors in IGP and rest of India



Source: CSE

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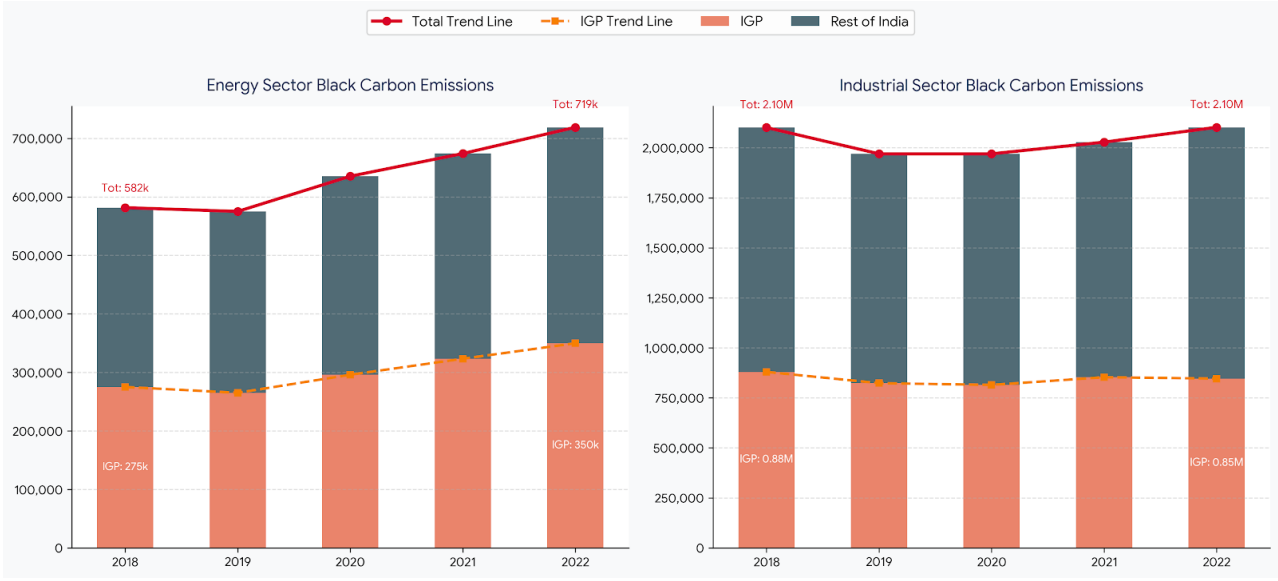
Graph 3: Sector-wise black carbon emissions (2018–22)



Source: CSE

Comparison between EDGAR and CEDS inventories

A comparative analysis of the EDGAR and CEDS inventories reveals notable differences in the quantum of black carbon emissions reported for the IGP region, largely attributable to differences in sectoral classification methodologies adopted by each inventory. The CEDS inventory reports significantly higher absolute BC emissions in both the energy and industrial sectors than EDGAR. For instance, in 2022, CEDS reports industrial black carbon emissions of approximately 846,175 tonnes/year for the IGP, while EDGAR's combined industrial sectors collectively amount to approximately 131,854 tonnes/year for the same region. This means CEDS estimates are nearly six times higher than EDGAR estimates for the IGP in 2022. Under CEDS, IGP's share of industrial black carbon emissions remained relatively stable at 40–42 per cent, while the energy sector share rose gradually from 47 per cent in 2018 to 49 per cent in 2022 *(see Graph 4: Comparative analysis of EDGAR and CEDS inventory (2018–22).*

Neither inventory can be relied upon to represent the true ground-level emission picture for the region. This divergence poses significant challenges for evidence-based policymaking, as decisions based on either inventory in isolation risk over- or underestimating emissions. A more reliable approach would be to build estimates from the bottom up, starting with sector or unit-scale fuel consumption data mapped to specific industrial clusters across the IGP. While primary data collection through direct stack monitoring and facility-level emission measurements across

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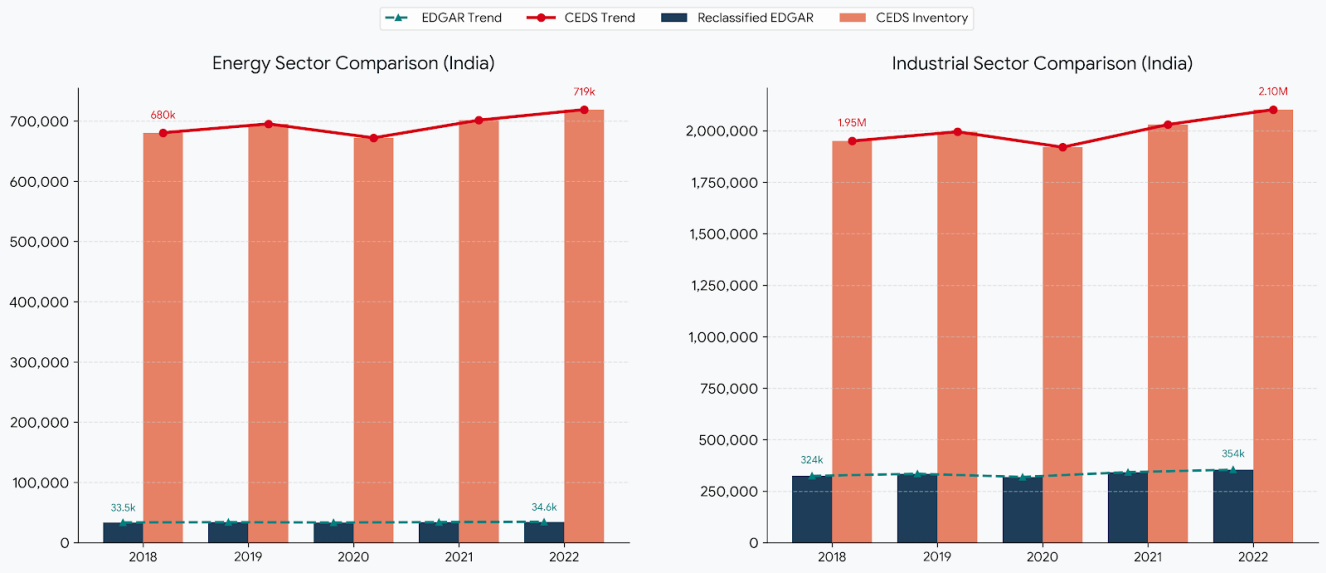
Graph 4: Comparative analysis of EDGAR and CEDS inventory (2018–22)



Source: CSE

key industrial sectors remains the most credible pathway to accurate black carbon quantification, it is resource-intensive and operationally challenging across a region as vast and industrially diverse as the IGP. In this context, the bottom-up approach used in this study, drawing on fuel consumption patterns at the sector and unit scale, offers the most feasible and scalable way to establish a credible baseline that can be validated and refined through targeted primary measurements where feasible.

High black-carbon-emitting processes across the Indo-Gangetic Plains

Identifying the industrial processes

The primary objective of this study is to identify industrial processes that are significant emitters of black carbon across the Indo-Gangetic Plain. However, the absence of an IGP-specific industrial database posed a key challenge at the outset. To address this, CSE undertook detailed research to compile a comprehensive list of major industrial sectors operating across the IGP states, including Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. As a first step, CSE extracted industry-level data from the consent to operate records maintained by the respective State Pollution Control Boards. The data covers 2022–25. Through this process, a database of approximately 200,000 industries across the identified IGP states was compiled. This was subsequently filtered to exclude green and white category industries, narrowing the list to approximately 85,000 red and orange

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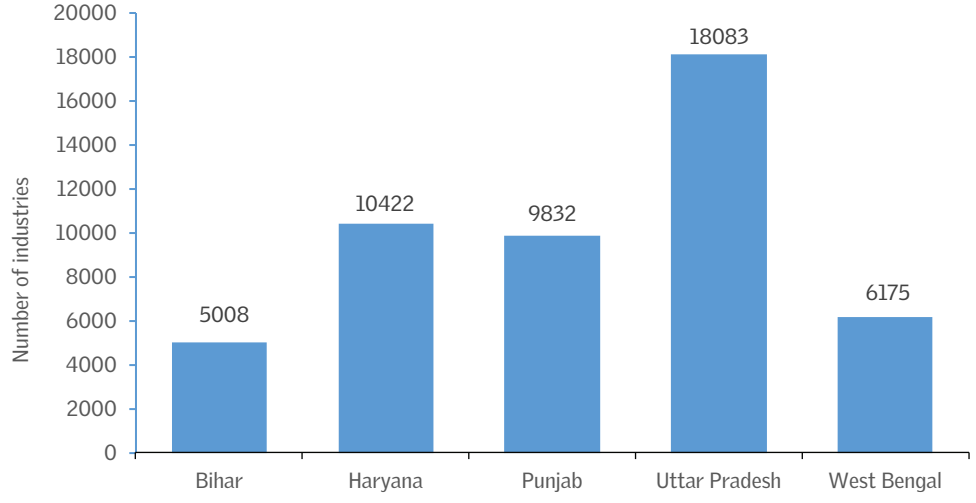
category industries, which represent higher pollution potential. The dataset was further refined to retain only those industrial sectors with a significant likelihood of black carbon emissions, reducing the industry database to about 50,000. The industries were reclassified to their closest fit with the IPCC classification, aligning them with the industry group and industrial process (for details refer to detailed report).

Black carbon emissions analysis: Industrial sector

The IGP inventory covers 49,594 industrial facilities classified into 52 industry types. These 52 industry types contribute to black carbon emissions across the IGP region. Brick kilns are the largest category in terms of numbers, with 21,178 facilities, followed by rice mills (7,011), textile units (2,936), and food processing units (2,324). Iron and steel units (1,426) and chemical industries (1,307) are also present in large numbers (see *Graph 5a: State-wise and sector-wise number of consented industries in the IGP region* and *Graph 5b: State-wise and sector-wise number of industrial units across IGP*).

Graph 5a: State-wise and sector-wise number of consented industries in the IGP region



Source: CSE analysis

Fuel consumption and emission estimation

For the fuel consumption data the information from the consent form of the industries could not be extracted due to continuous unavailability of the portal. Therefore the activity data (fuel consumption data) is consolidated using the data from the Annual Survey of Industries, Ministry of Statistics and Programme

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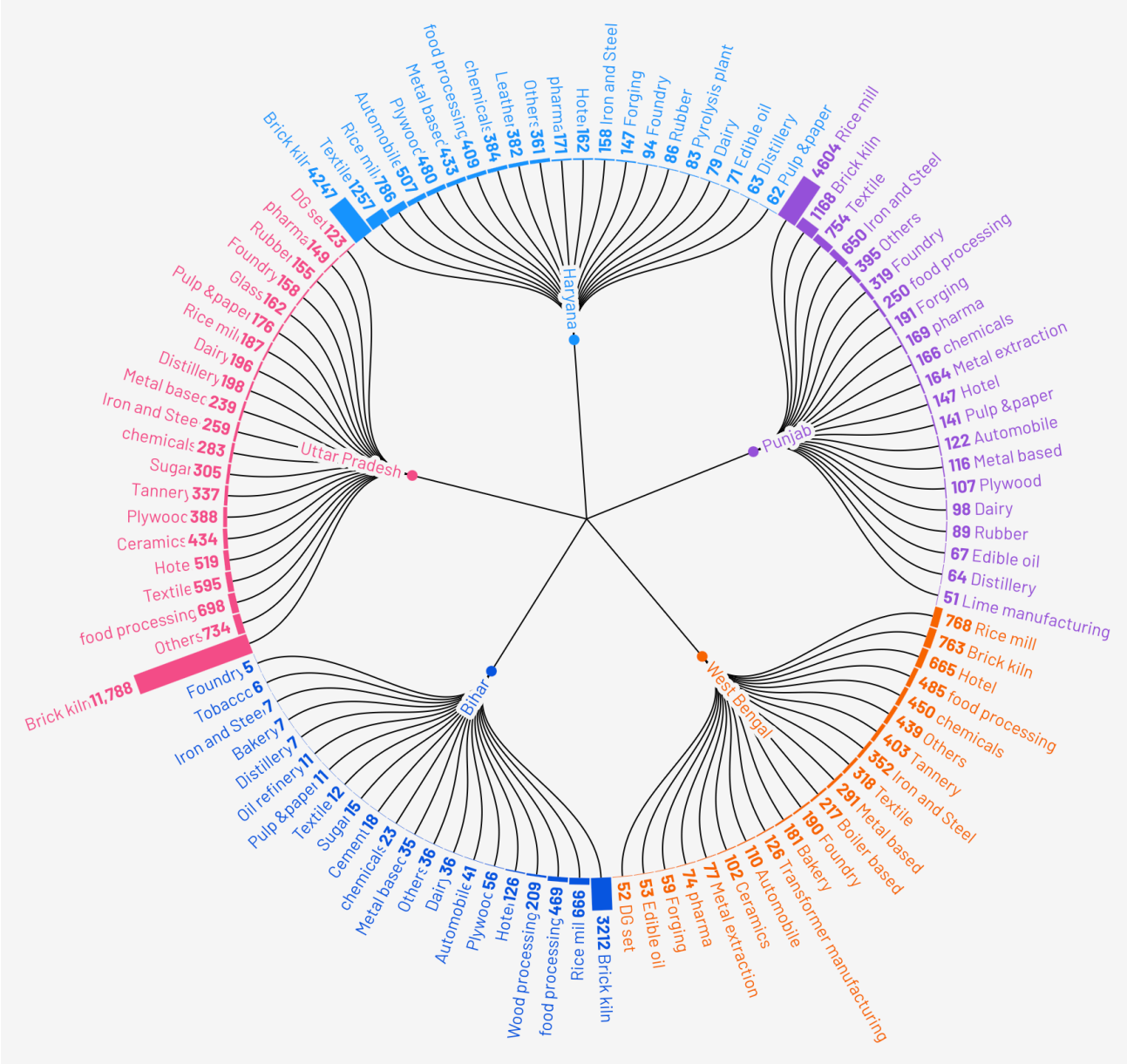
Graph 5b: State-wise and sector-wise number of industrial units across IGP



Source: CSE analysis

Implementation (MoSPI). Total fuel consumption in the IGP is estimated at 231,483,420 tonnes of coal, 3,732,168 kilolitres of petroleum products and 61,046,000 tonnes of other fuels (see *Graph 6: Sector-wise fuel usage in IGP region*).

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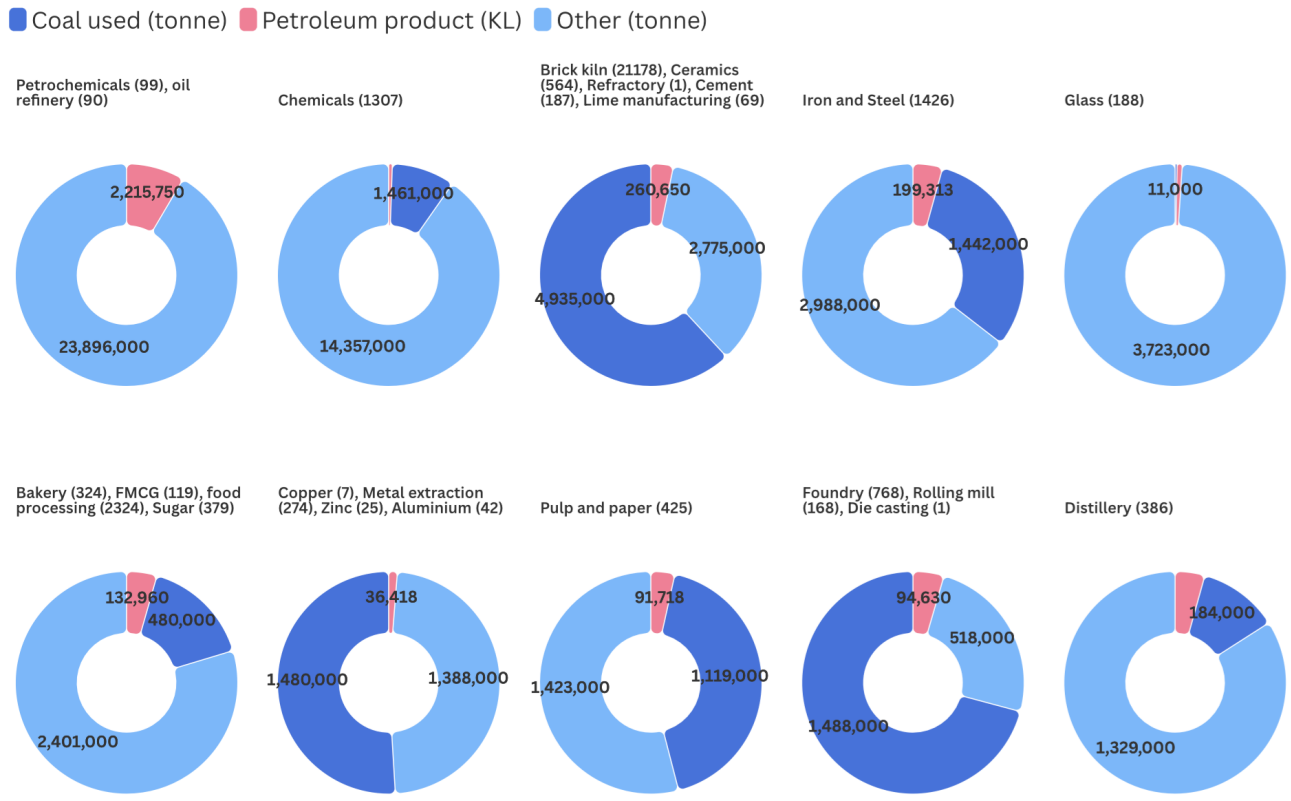
Graph 6: Sector-wise fuel usage in IGP region



Source: Annual survey of industries 2023-2024, Volume-I Annual survey of industries

Since IPCC covers only greenhouse gases and does not include particulate matter components in its emission factors, the study relied on the USEPA AP-42 document, which provides emission factors in both controlled and uncontrolled forms. The analysis of fuel-use-based emissions yielded PM2.5 values. The percentage of BC relative to PM2.5 varies by region and season. The only long-term, multi-year, global-scale research available reports a value of 15 per cent, and this value has therefore been adopted for the assessment. Although thermal power plants consume the vast majority of coal and technically account for the largest overall share of black carbon emissions, including them directly alongside other industrial sources skews the broader assessment. Because power generation emissions are so disproportionately high, they act as a statistical outlier that hides the critical contributions of smaller, non-power industrial sectors. To present a clearer and more actionable breakdown of industrial black carbon emissions, the analysis separates thermal power generation from non-power industrial activities.

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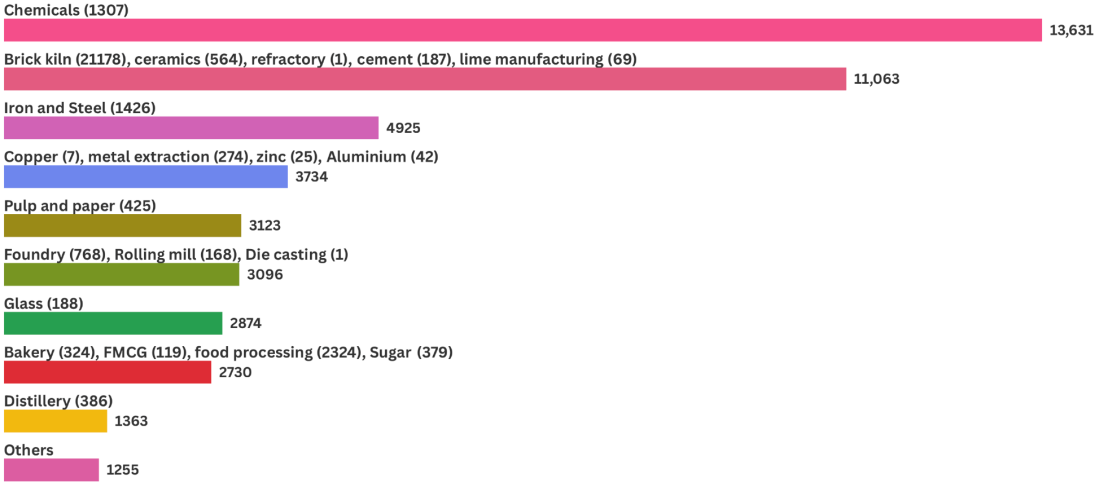
Hotspots

Based on aforementioned method, total Black Carbon emission in the IGP are estimated at 445,945 million tonne per year. The chemical sector, which includes the manufacture of basic chemicals, fertilizer and nitrogen compounds, plastics and synthetic rubber, and non-metallic mineral products, which includes brick kilns, cement plants, ceramic units and lime manufacturing facilities, emerge as the largest industrial sources of black carbon emissions. These sectors contribute approximately 13,631 tonnes per year—26 per cent of total non-power black carbon emissions—and 11,063 tonnes per year—21 per cent of non-power emissions—respectively under uncontrolled conditions and remain the most significant hotspots. The iron and steel sector represents the third-largest hotspot, with approximately 4,925 tonnes per year—9 per cent—followed by non-ferrous metal industries, including copper, zinc and aluminium production (3,734 tonnes per year—7 per cent). Other notable contributors include the paper and pulp sector (3,123 tonnes per year) and foundries and metal casting industries (3,096 tonnes per year). Together, these sectors account for a substantial share of industrial black carbon emissions outside the power sector and therefore represent important opportunities for targeted mitigation measures (see *Graph 7: Top black-carbon-emitting sectors in IGP*).

Graph 7: Top black-carbon-emitting sectors in IGP



Source: CSE analysis

Profiles of IGP states: Fuel consumption and black carbon emissions

State-wise inventories were prepared from the consent data and the fuel consumption data. The following pages profile the five IGP states: Bihar, West Bengal, Haryana, Uttar Pradesh and Punjab.

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Bihar



5,008
Industrial facilities

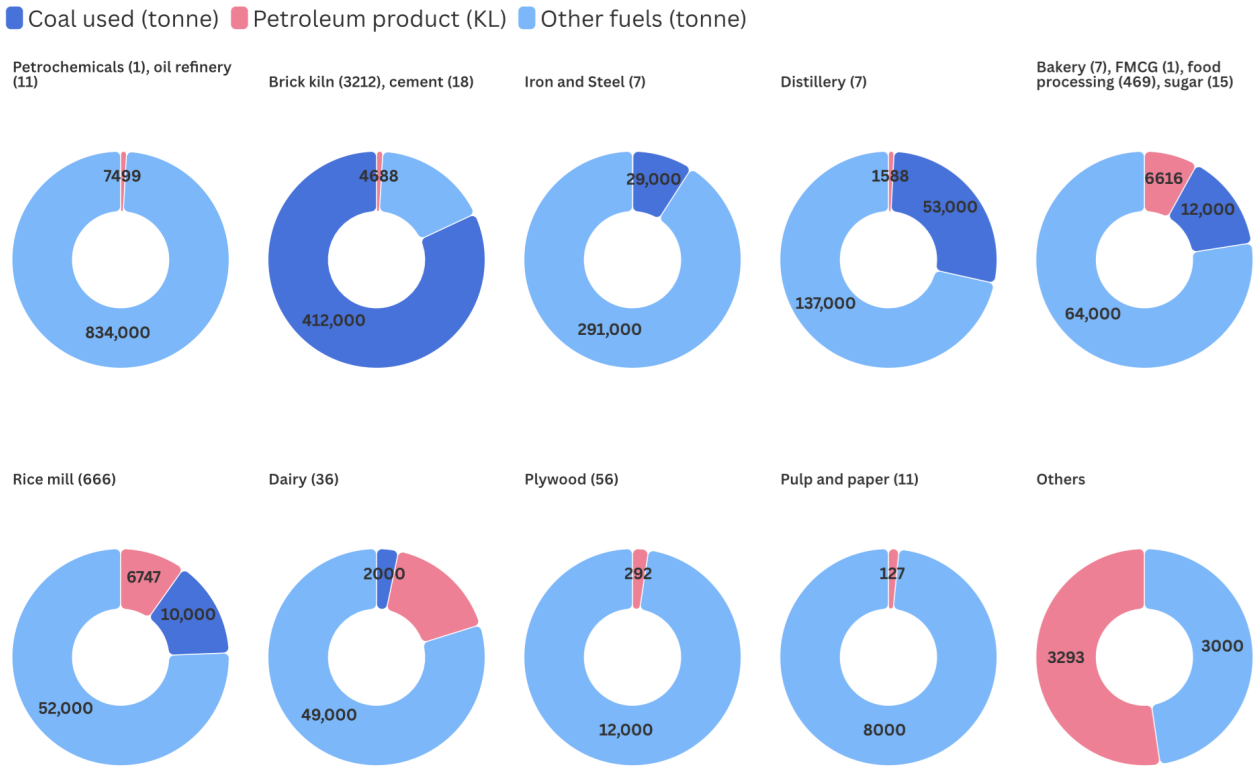
35
Industry types

80,264 tonnes BC a year

Largest categories: brick kilns **3,212** facilities; rice mills **666**; food-processing units **469**; textile units **12**

Total fuel consumption: 44,509,570 tonnes of coal, **43,240** kilolitres of petroleum products and **1,540,000** tonnes of other fuels

Graph 8: Sector-wise fuel usage in Bihar



Source: CSE analysis

Key insights

CSE analysis identifies sectors that account for the majority of industrial black carbon emissions in Bihar. The non-metallic mineral products sector, comprising primarily brick kilns and cement plants, is the largest source at approximately 404 tonnes per year—37 per cent of total non-power emissions—driven by the large

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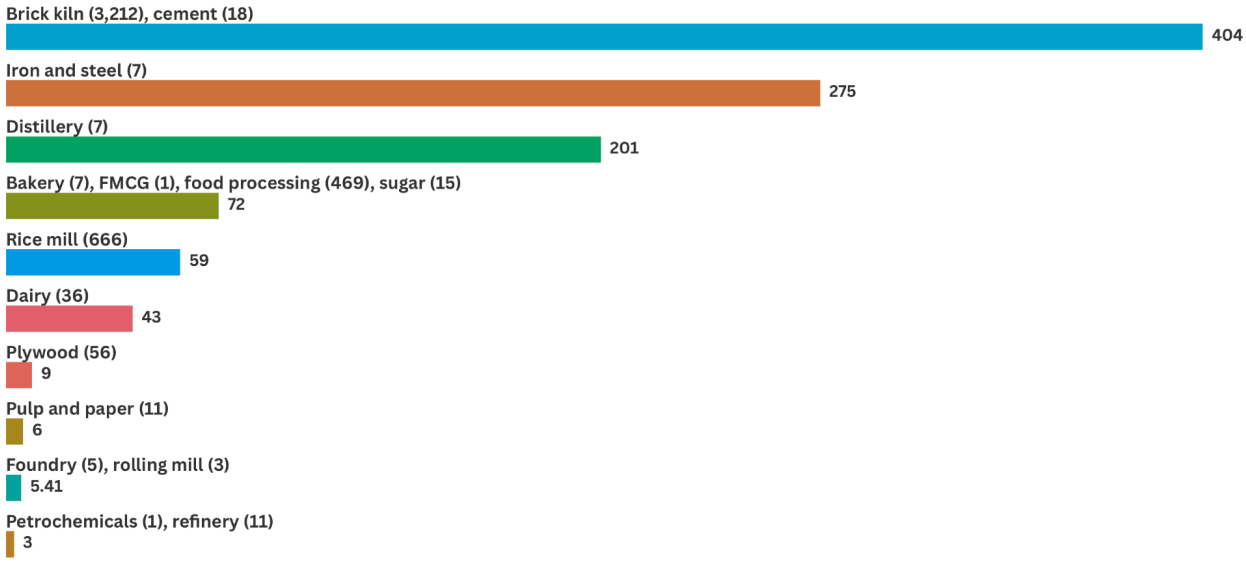
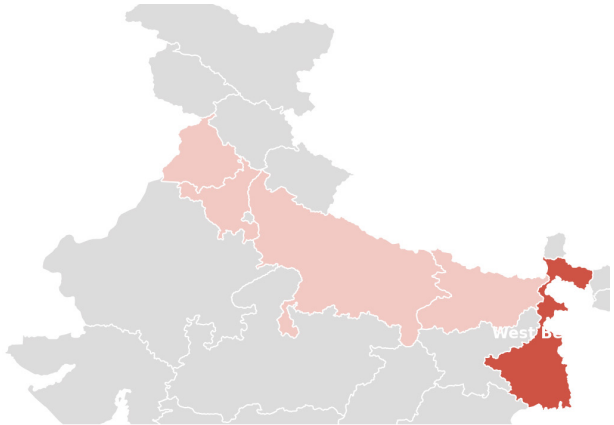
Graph 9: Top black-carbon-emitting sectors in Bihar



Source: CSE analysis

number of brick kilns and their continued reliance on combustion technologies that generate significant black carbon emissions. The iron and steel sector ranks second (approximately 275 tonnes—25 per cent—per year), and the distillery sector contributes approximately 201 tonnes—19 per cent—per year through coal and biomass-based fuel use for steam generation and process heating. Coal-related emissions are concentrated in brick kilns, iron and steel plants, distilleries, and rice mills, while emissions from other fuels are particularly important in petrochemical operations and several agro-processing industries.

West Bengal



6,175
Industrial facilities

38
Industry types

95,683 tonnes BC a year

Major categories: rice mills **768**; brick kilns **763**; food processing units **485**; chemicals **450**; tanneries **403**; textile units **318**

Total fuel consumption: 51,566,450 tonnes of coal, **251,416** kilolitres of petroleum products and **4,816,000** tonnes of other fuels

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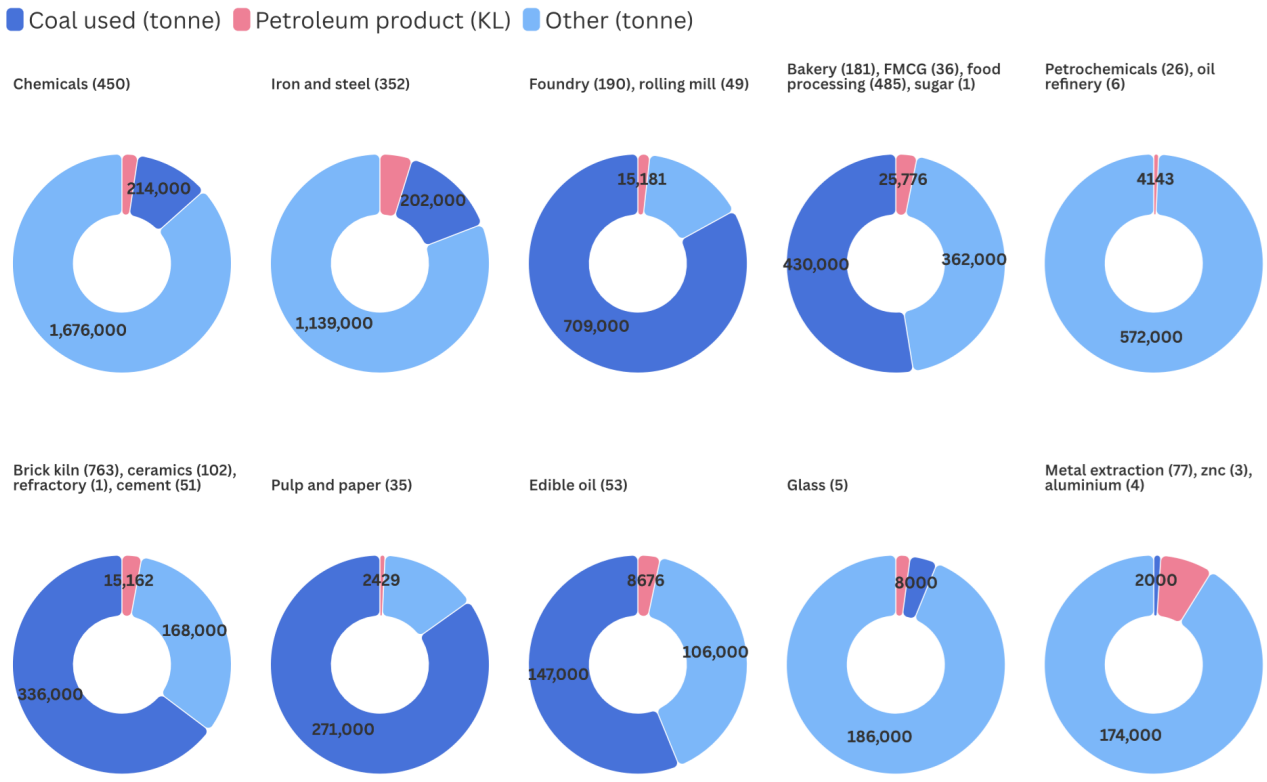
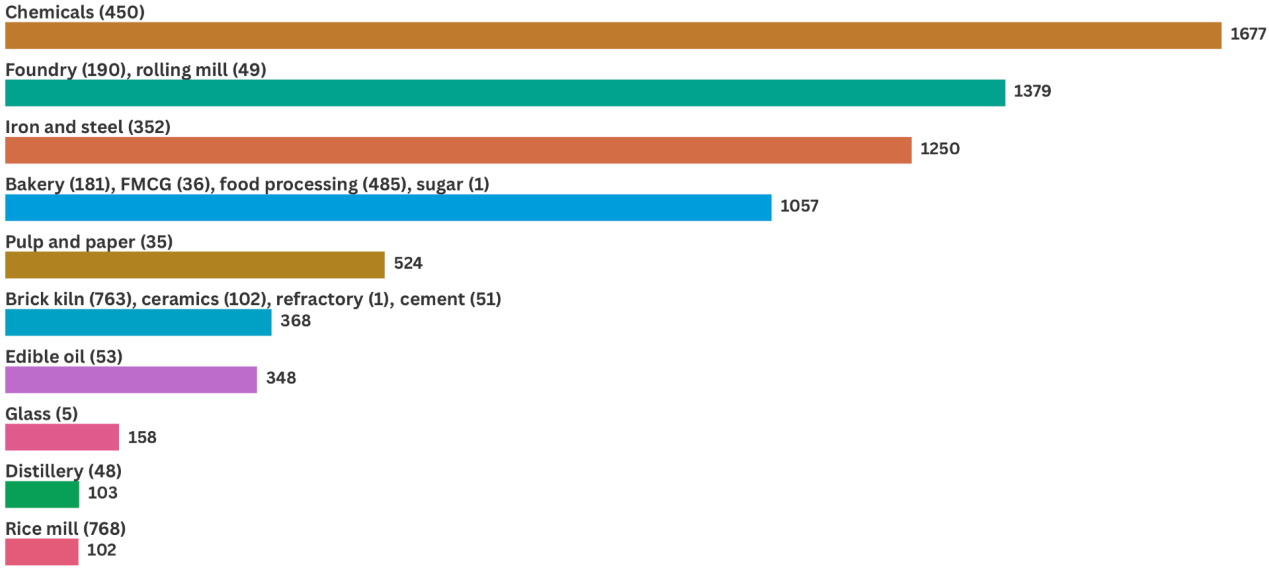
Graph 10: Sector-wise fuel usage in West Bengal



Source: CSE analysis

Graph 11: Major black-carbon-emitting sectors in West Bengal



Source: CSE analysis

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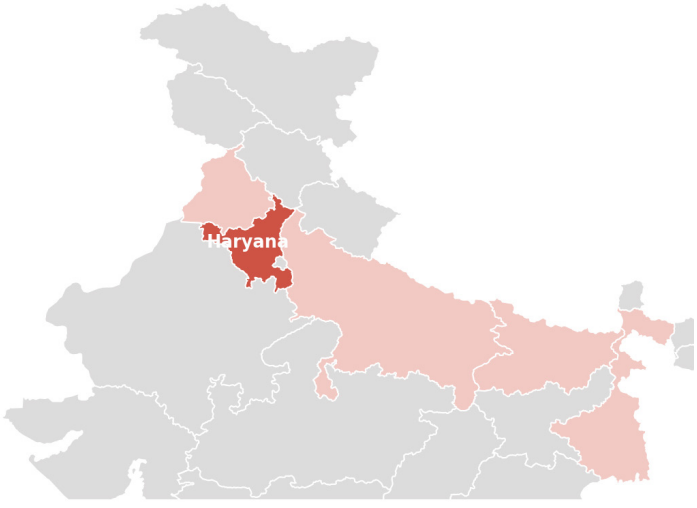
Key insights

Some sectors, such as thermal power plants and iron and steel, have fewer facilities but consume much more fuel and generate higher emissions which are majorly controlled in nature. Foundries and rolling mills are the largest consumers of coal among other industries (approximately 709,000 tonnes annually). The chemicals sector emerges as the largest non-power industrial source of black carbon (approximately 1,677 tonnes per year—23 per cent of total non-power emissions), followed by foundries and rolling mills (1,379 tonnes per year—19 per cent), the single largest coal-based industrial emitter outside the power sector, iron and steel (1,250 tonnes per year—17 per cent) and food processing (1,057 tonnes per year—15 per cent). Although individual facilities are generally smaller, the large number of units operating across the state results in a significant cumulative impact.

Haryana



10,422
Industrial facilities

44
Industry types

32,293 tonnes BC a year

Largest categories: brick kilns **4,247** facilities; textile units **1,257**; rice mills **786**; automobile units **507**; chemicals **384**; tanneries **382**; metal-based units **433**

Total fuel consumption: approximately **15.8** million tonnes of coal, **2.49** million kilolitres of petroleum products and 18.64 million tonnes of other fuels. Black carbon emissions are **4,539** tonnes per year under controlled conditions

Key insights

The fuel consumption profile indicates a strong dependence on both coal and other process fuels. The non-metallic mineral products sector is the largest consumer of coal (approximately 336,000 tonnes annually), while petroleum product consumption is dominated by the petrochemical and refinery sector (approximately 2.19 million kilolitres, nearly 88 per cent of the total). Excluding the power sector, the largest industrial source of black carbon is the chemicals sector (about 1,437 tonnes/year—28 per cent of total non-power emissions). The automobile sector is an important contributor (555 tonnes/year uncontrolled), followed by the non-metallic mineral products sector (503 tonnes/year) and basic iron and steel (464 tonnes/year).

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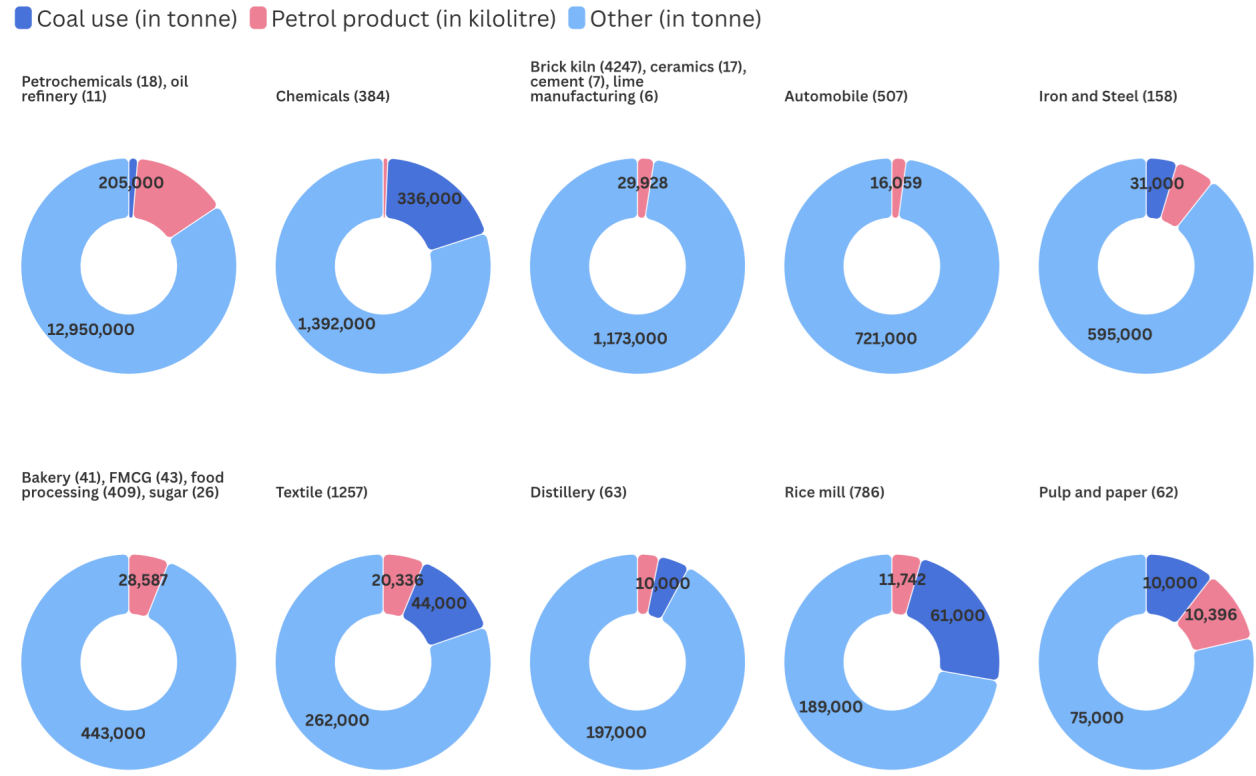
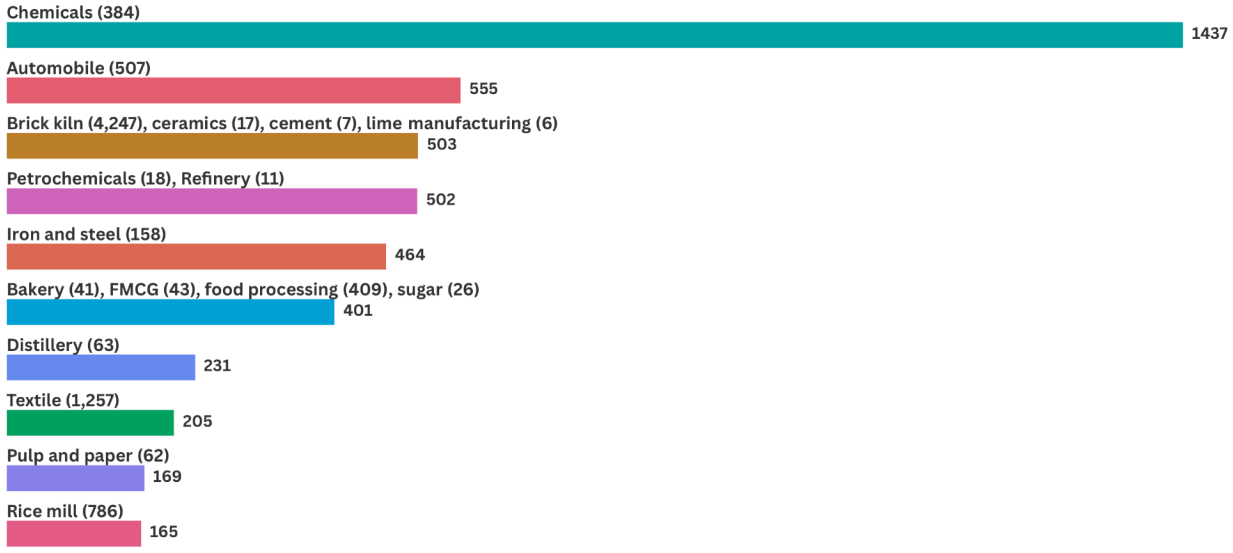
Graph 12: Sector-wise fuel usage in Haryana



Source: CSE analysis

Graph 13: Major black-carbon-emitting sectors in Haryana



Source: CSE analysis

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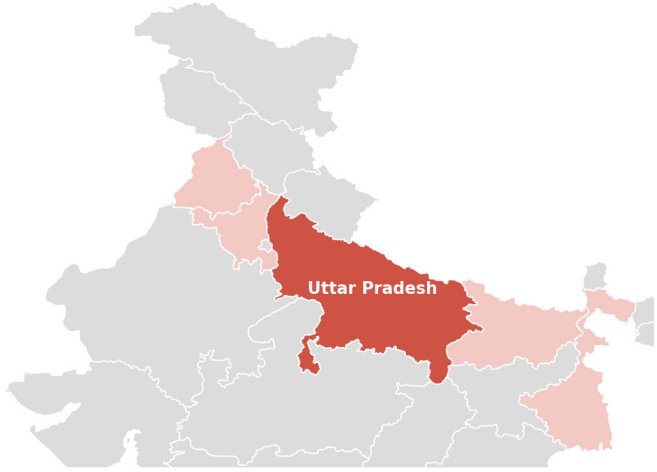
Uttar Pradesh



18,083
Industrial facilities

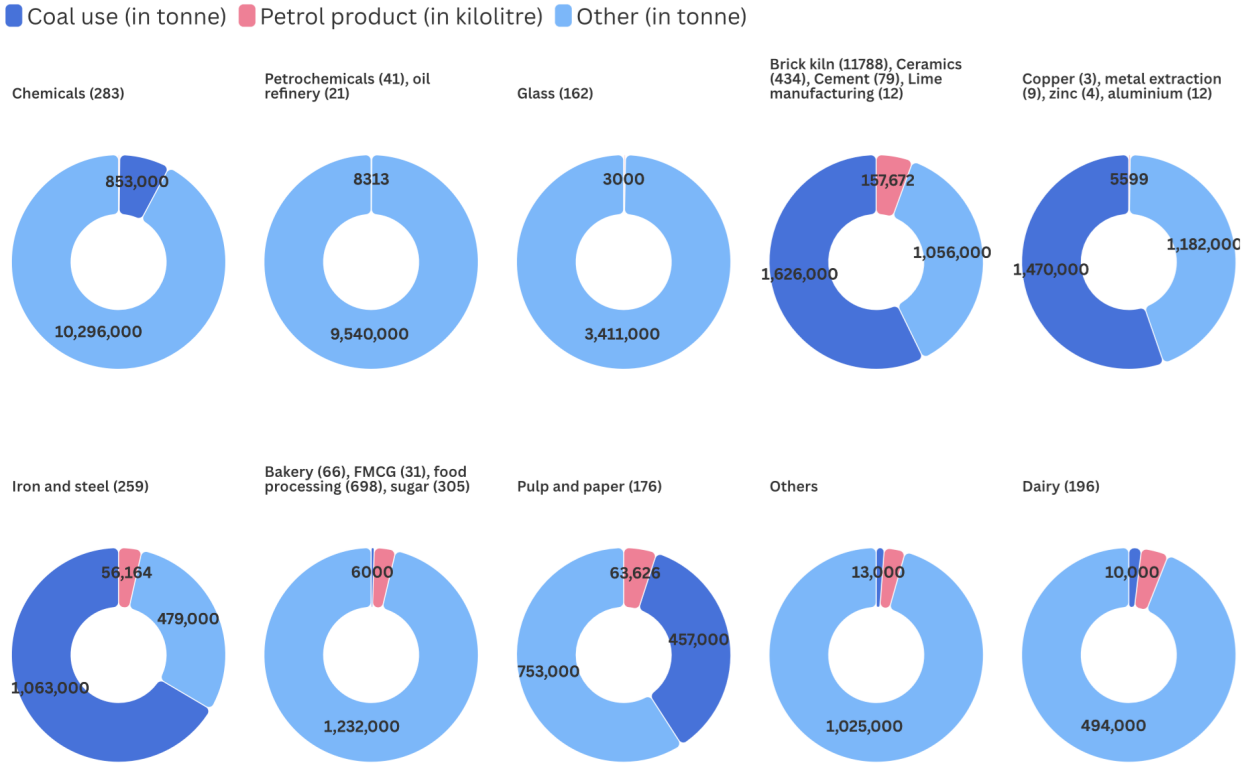
44
Industry types

182,812 tonnes black carbon a year

Largest categories: the non-metallic mineral products sector comprises **11,788** brick kilns, **434** ceramic units, **79** cement plants and **12** lime units; also **698** food-processing units, **337** tanneries, **305** sugar mills, **283** chemicals and **198** distilleries

Total fuel consumption: approximately **94.87** million tonnes of coal, **605,213** kilolitres of petroleum products and **30.78** million tonnes of other fuels. Black carbon emissions are **14,177** tonnes per year under controlled conditions.

Graph 14: Sector-wise fuel usage in Uttar Pradesh



Source: CSE analysis

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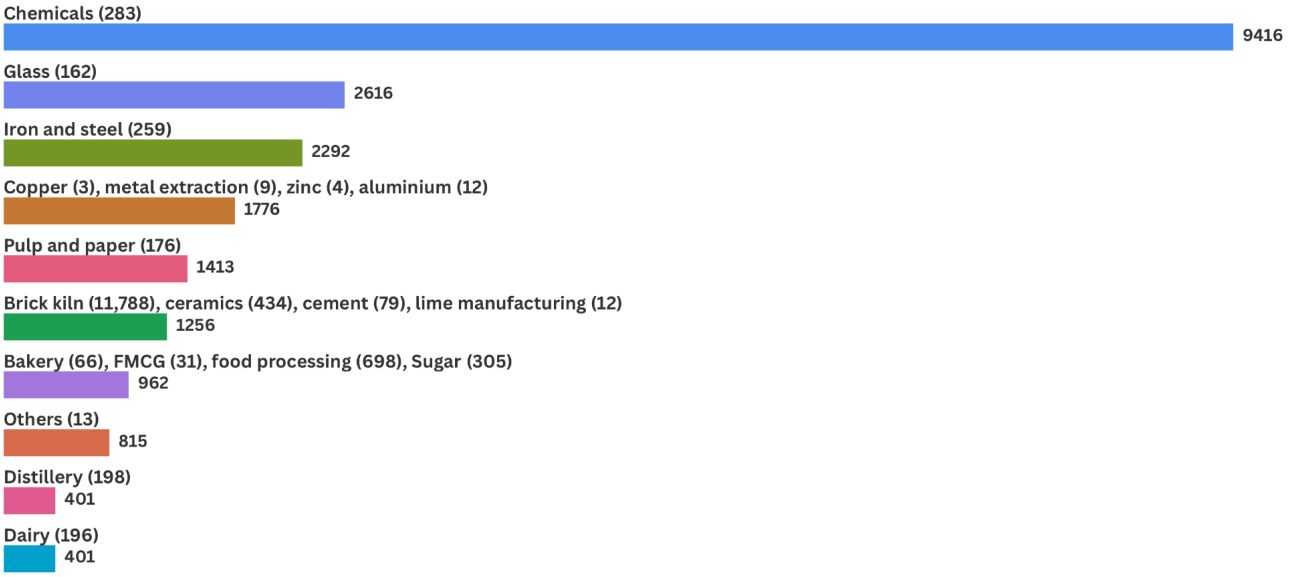
Graph 15: Major black-carbon-emitting sectors in Uttar Pradesh



Source: CSE analysis

Key insights

The chemicals sector is the largest industrial source, with approximately 9,416 tonnes per year—42 per cent of total non-power emissions—uncontrolled and 2,242 tonnes per year—12 per cent—controlled, driven largely by burning other fuels used in industrial processes and boilers. Glass manufacturing ranks second (approximately 2,616 tonnes per year), largely from high-temperature furnaces, followed by iron and steel (2,292—10 per cent), non-ferrous metals (1,776) and paper and pulp (1,413). The brick kiln, ceramics, cement and lime sector contributes approximately 1,256 tonnes per year under both uncontrolled and controlled scenarios: emissions remain largely unchanged because many brick kilns operate without advanced particulate control systems, making them a persistent source across the state.

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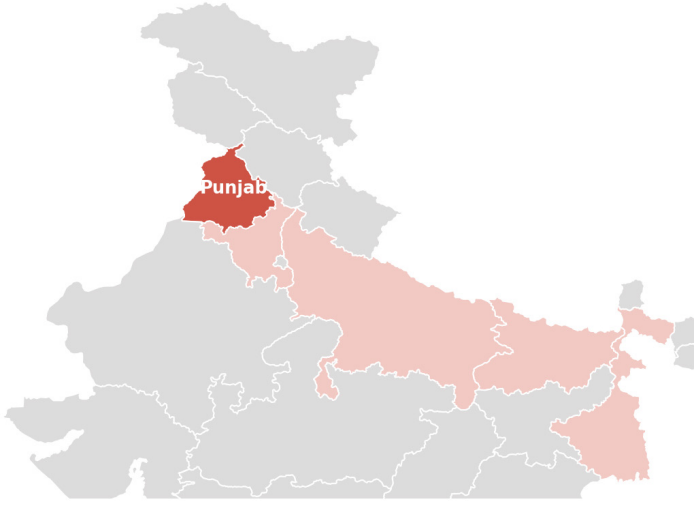
Punjab



9,832
Industrial facilities

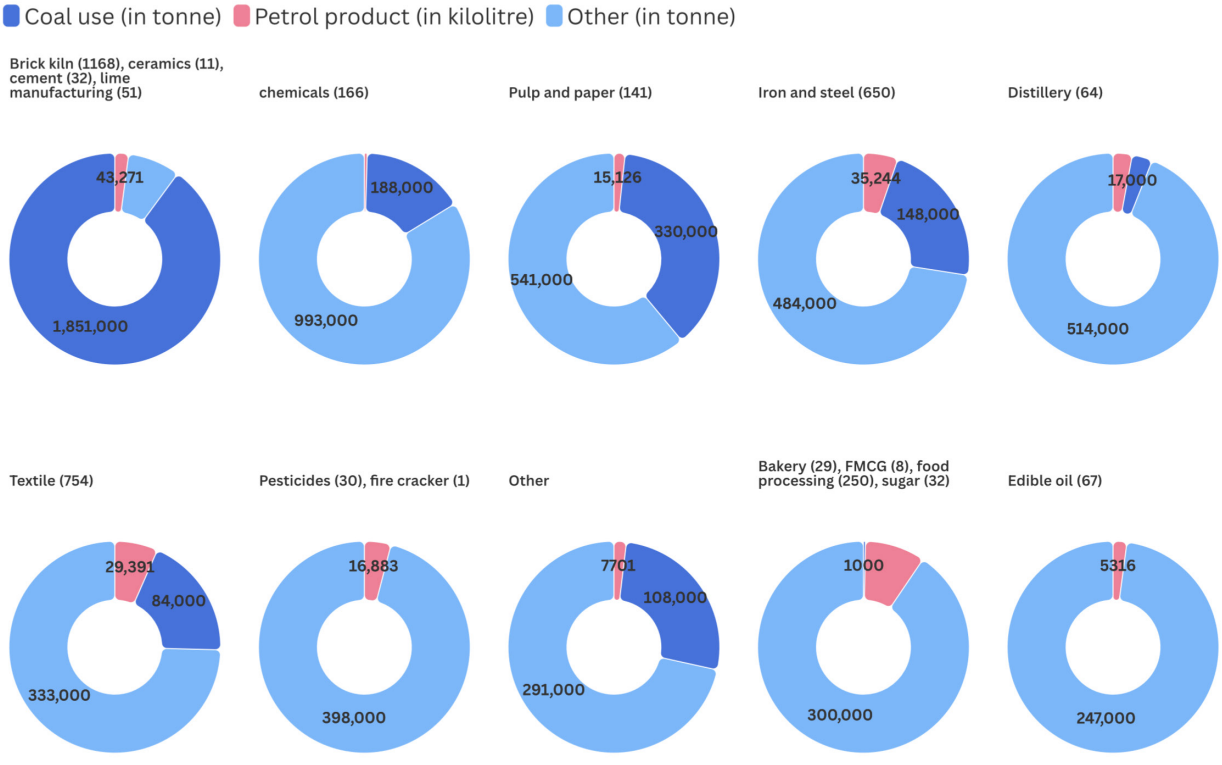
39
Industry types

44,025 tonnes BC a year

Largest categories: rice mills **4,604** facilities; brick kilns **1,168**; textile units 754; iron and steel units **650**; foundries **319**; food processing units **250**

Total fuel consumption: approximately **23.6** million tonnes of coal, **290,574** kilolitres of petroleum products and **4.9** million tonnes of other fuels. Black carbon emissions are **4,577** tonnes per year under controlled conditions

Graph 16: Sector-wise fuel usage in Punjab



Source: CSE analysis

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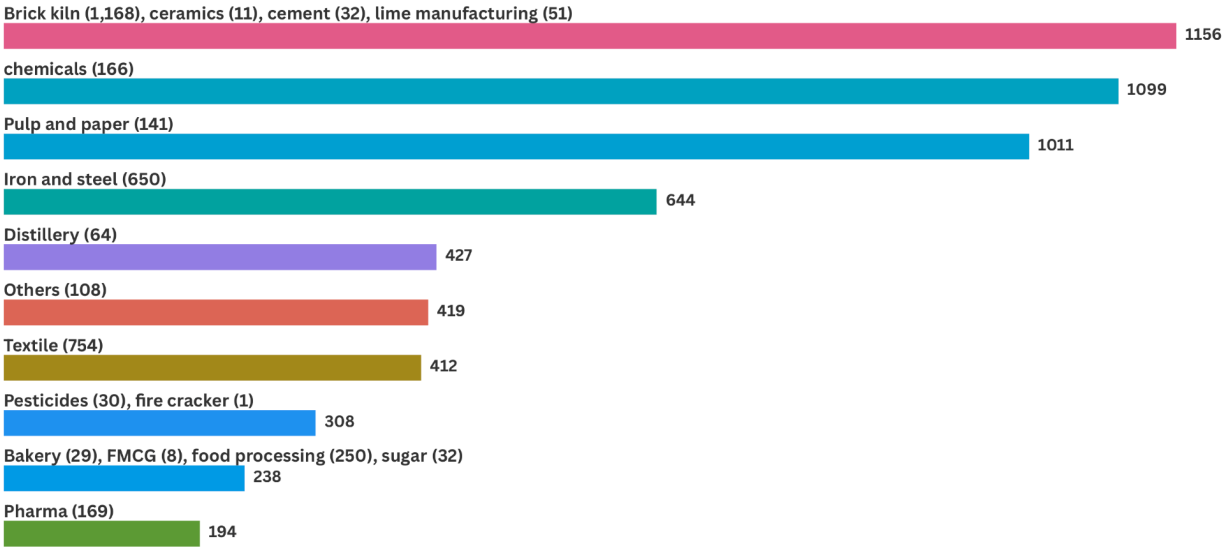
Graph 17: Major black-carbon-emitting sectors in Punjab



Source: CSE analysis

Key insights

The brick kiln, cement, ceramic and lime manufacturing sector is the largest coal consumer among non-power industries (approximately 1.85 million tonnes annually) and the largest industrial source of black carbon (approximately 1,156 tonnes per year—18 per cent of total non-power emissions). The chemicals sector is second (1,099 tonnes per year—17 per cent) and paper and pulp third (1,011 tonnes per year—16 per cent), followed by iron and steel (644), pesticide and firecracker manufacturing (308), food processing (238) and pharmaceuticals (194). Emissions are concentrated within a limited number of sectors, which offer the greatest opportunities for reduction through cleaner fuels, improved combustion efficiency, process modernization and adoption of advanced pollution control technologies.

Open burning of agri-residue

Crop-residue generation has reduced significantly from 620 million tonnes in 2008–09 to 500 million tonnes in 2019, and at present the country generates 350 million tonnes agricultural waste annually. While a significant portion of this generation is used as fodder, fuel, and for other domestic and industrial purposes, crop residue burning remains a major environmental concern across the IGP region, with major contributions from Punjab, Haryana, Uttar Pradesh, and West Bengal. In 2019, about 140 million tonnes of surplus residue remained, of

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which 92 million tonnes were burnt. Since no specific recent data is available for surplus residue or open burning, figures for 2025 were estimated by extrapolating historical state-wise generation and burning proportions based on the current available generation baseline of 350 million tonnes. Total residue burned in 2025 is estimated at 60 million tonnes, including 13 million tonnes each in Uttar Pradesh and Punjab, 6 million tonnes in Haryana, and 3 million tonnes in West Bengal, which forms the basis for black carbon emission calculations (see *Table 3: Agri-residue generation and quantity burned in major IGP states* and *Table 4: Black carbon emissions in IGP states from open burning of agri-residue*).

Table 3: Agri-residue generation and quantity burned in major IGP states

Category/state	2008–09	2019	2025 (estimated)
Total agri-residue generation (Mt)	620	500	350
Surplus residue (Mt)	NA	140	NA
Uttar Pradesh (UP) generation (Mt)	72	60	42
Punjab (PB) generation (Mt)	45	51	36
West Bengal (WB) generation (Mt)	37	—	21
Haryana (HR) generation (Mt)	25	—	14
Total quantity burned (Mt)	99	92	60
Uttar Pradesh (UP) burned (Mt)	22.25	—	13.4
Punjab (PB) burned (Mt)	21.32	—	12.8
West Bengal (WB) burned (Mt)	5.43	—	3.3
Haryana (HR) burned (Mt)	9.18	—	5.5

Source: CSE analysis

Table 4: Black carbon emissions in IGP states from open burning of agri-residue

States	Estimated agri-residue burned (tonnes)	Black carbon emissions (tonnes)
Uttar Pradesh	13,400,000	25,460
Punjab	12,800,000	24,320
West Bengal	3,300,000	6,270
Haryana	5,500,000	10,450

Source: CSE analysis

Based on the scientific study by IIT Bombay, funded by MoEFCC under the NCAP-COALESCE Project, the emission factor for straw with respect to black carbon has been derived.

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Issues and challenges

While research on black carbon in India has expanded considerably over the past two decades, significant challenges remain in understanding its full emission profile and integrating it into air quality and climate governance. Important gaps persist in measurement coverage, source-specific emissions data, inventory development, and institutional frameworks for monitoring and management. Beyond these foundational gaps, practical barriers also limit progress: industrial and informal-sector emissions remain poorly quantified, sector-specific pathways for reducing black carbon are yet to be defined, MSMEs lack the financing and technology needed to adopt cleaner alternatives, and shifting away from black-carbon-intensive fuels carries real economic and livelihood trade-offs that must be carefully managed.

i. No national framework for black carbon: India has established air quality systems that monitor pollutants such as PM2.5, PM10, sulphur dioxide and nitrogen oxides. Black carbon is physically present within these measurements, it is a component of fine particulate matter, but it is not tracked as a separate pollutant. No national standard exists for black carbon. No regulatory framework is developed to reduce it through targeted action.

ii. No standardized measurement practices: No standard protocol exists in India for black carbon stack/ambient measurement, and there is no regulatory requirement to report it. This means there is essentially no routine, comparable measurement of black carbon at industrial emission points as well as regional level anywhere in the Indo-Gangetic Plains. Without standardized protocols, results from different studies cannot be directly compared. This makes it very difficult to build long-term datasets or regional baselines that can track whether conditions are improving or worsening over time.

iii. Limited data availability: the core challenge for black carbon assessment in India: Existing studies in the Ganga basin, coalfields, industrial cities, and the Himalayas use aethalometers and atmospheric models to show that black carbon is persistent, regional, and driven by coal, diesel, and biomass combustion. But these methods only measure pollution already in the air; they cannot identify how much a specific brick kiln, boiler, or furnace emits, since source attribution relies on indirect estimations rather than direct measurement. The gap is worst for informal and small-scale industries, which report no fuel or emissions data to regulators.

iv. Incomplete industrial and informal sector coverage: A large share of black carbon emissions originates from MSMEs, brick kilns, diesel generators, metal

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melting and casting operations and other informal industries, but these sources remain poorly quantified. Most operate without fuel-consumption records, emissions reporting, or regulatory oversight, so their actual contribution to black carbon levels can only be estimated indirectly. This leaves a major blind spot in national emission inventories, since the informal sector is also where black-carbon-intensive combustion is most concentrated. For example, there is no data on the quantity of coal consumption in the about 10,000 metal melting and casting household units using pit furnaces in the Moradabad and Aligarh region in Uttar Pradesh.

v. Absence of sector-specific decarbonization pathways: Black carbon offers a rare opportunity for fast climate and air-quality gains because it stays in the atmosphere for only days to weeks, unlike long-lived greenhouse gases. However, India lacks a clear roadmap specifying which black-carbon-reducing technologies to deploy in which sectors, at what cost, and on what timeline. Without sector-specific pathways, mitigation efforts risk being scattered instead of focused on the biggest sources of emissions.

vi. Financing and technology adoption in MSMEs: MSMEs are significant contributors to black carbon emissions, driven by continued reliance on inefficient combustion technologies and high-emitting fuels such as coal, biomass and pet coke, notably in sectors like brick kilns, foundries and ceramics. Despite the potential co-benefits, they face limited access to capital, affordable clean technologies, and technical expertise needed to switch to lower-emission alternatives. Existing support is limited in scale and scope. The MSE-GIFT scheme, launched in December 2023 under the World Bank-supported RAMP programme with an outlay of Rs 478 crore, provides interest subvention and risk-sharing support for MSMEs adopting green technologies, but the absence of dedicated, scaled-up financing and technology-support mechanisms continues to slow the adoption of cleaner processes. The MSE-SPICE scheme does not directly address combustion efficiency or fuel switching.

vii. Socioeconomic trade-offs: Black-carbon-intensive fuels and technologies, such as coal and biomass, remain the cheapest and most accessible options for MSMEs and informal industries. Transitioning away from them without raising energy costs or disrupting livelihoods is a significant implementation challenge, particularly where alternative fuels or technologies are costlier or less readily available. Any plan to cut black carbon needs to balance these economic realities alongside the emissions goals.

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Recommendations and the way forward

Based on CSE's analysis, the hotspots and priority sectors for mitigation of black carbon emissions are the chemical sector (including basic chemicals, fertilizer and nitrogen compounds, plastics and synthetic rubber); non-metallic mineral industries, including brick kiln, ceramics, refractory, cement and lime manufacturing; iron and steel manufacturing; foundries and rolling mills; non-ferrous metal industries (copper, aluminium, zinc etc.); pulp and paper industries; glass; and food processing. These sectors combine high emission levels with significant opportunities for emission reductions through cleaner fuels, improved combustion efficiency, process optimization, and enhanced control technologies.

The study also finds that black carbon from industrial combustion in the IGP is a measurable, regionally significant, and inadequately governed emission problem. The inventory compiled covers 49,594 industrial facilities across 52 industry types. Even with air pollution control devices (APCDs) in place, thermal power plants handle such massive coal volumes that their emissions dominate the inventory, acting as an outlier that masks contributions from smaller sectors. Consequently, this study separates power generation from non-power industrial activities to deliver a clearer picture. Within the non-power category, the chemical sector produces the largest volume of uncontrolled black carbon emissions i.e. 13,631 tonnes per year, followed by the non-metallic mineral products sector which contributes 11,063 tonnes per year.Despite this scale, no national standard exists for black carbon, no regulatory body is assigned to measure it, and no routine stack-level black carbon measurements occur at any industrial facility in the IGP.

State-wise recommendations

The recommendations are based on the state profiles and CSE's estimated black carbon emissions from each sector, and highlight state-specific priorities including fuel switching, technology upgradation, combustion efficiency, electrification, common facilities and infrastructure.

Below, These plans are structured using a RAG (Red-Amber-Green) color-coded matrix, where Green indicates short-term, Amber indicates medium-term, and Red indicates long-term timelines.

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Work area	Specific action points	Indicators
1. Uttar Pradesh		
SOP development for monitoring methods and networks	Establish BC monitoring in three priority clusters: a brick kiln, a chemicals and glass cluster, and a metals cluster. Develop a standard protocol for measurements and data reporting.	Three clusters monitored; monitoring protocol developed
	Expand monitoring to additional industrial clusters. Publish an annual UP industrial black carbon inventory tied to consent data.	Additional clusters monitored; annual inventory published
Sectoral intervention	Assess combustion efficiency through audits in priority sectors chemicals, glass, iron and steel, non-ferrous metals, and paper and pulp and APCD verification. Brick kilns: Register and map brick kilns, identifying fuel use, kiln technology and pollution-control status. Set timelines for cleaner kiln designs and particulate control, prioritizing kilns near non-attainment cities.	Kilns upgraded; combustion audits completed; APCDs verified
	Update sector-wise emissions estimates using monitoring data and verified industrial fuel consumption. Glass and ceramics: Move furnaces towards gas or electric heating where supply allows, supported by cluster gas connectivity. Priority industrial clusters: Assess shared monitoring and technical service facilities.	Furnaces converted; shared facilities established
State government schemes and financing	Map eligible state schemes, MSME support and financing options for kiln conversion, furnace upgrades, APCDs and monitoring equipment.	Schemes and financing sources mapped
	Mobilize financing for cleaner furnaces, cluster gas connectivity and industrial technology upgrades.	Financing mobilized; projects funded
Agricultural residue management	Map crop-residue availability, potential industrial users and existing collection arrangements in priority districts.	Crop residue, industrial users and collection systems mapped
	Develop crop-residue supply chains linking farmers, aggregators and industrial boilers fitted with APCDs, with the agriculture department as lead.	Crop residue supplied; industrial boilers using residue
2. Punjab		
SOP development for monitoring methods and networks	Establish cluster-based monitoring for rice mills and measure BC at selected crop-residue-burning hotspots during the burning season.	Monitoring sites established; seasonal measurements completed
	Establish a regular monitoring programme and set sector-wise BC reduction targets in the Punjab chapter of the IGP action plan.	Monitoring programme established; sector-wise targets set
Sectoral intervention	Brick kilns: Verify zig-zag or equivalent technology, particulate controls and fuel quality. Paper and pulp: Audit boiler efficiency and verify APCD performance. Rice mills: Assess boiler fuel use and prepare fuel-switch plans using pelletized or briquetted biomass in controlled boilers.	Kilns verified; boiler audits completed; fuel-switch plans prepared
	Paper and pulp and other industrial boilers: Improve boiler efficiency and substitute coal with suitable processed biomass where feasible.	Boilers upgraded; coal substituted; cleaner-fuel projects implemented

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Work area	Specific action points	Indicators
State government schemes and financing	Identify state schemes and MSME financing for kiln upgrades, boiler improvements, APCDs and biomass-fuel conversion.	Schemes and financing sources mapped
	Mobilize financing for industrial boiler upgrades, fuel-switching infrastructure and biomass procurement systems.	Financing mobilized; projects funded
Agricultural residue management	Identify major paddy-straw-producing districts, collection systems and potential industrial buyers. Scale up ex-situ use of paddy straw in industries with controlled combustion.	Straw collection mapped; industrial users identified; straw utilized
	Establish reliable straw collection, storage and pricing arrangements so that straw displaces coal rather than adding to it.	Straw supply secured; coal displaced
3. Haryana		
SOP development for monitoring methods and networks	Initiate cluster-level BC monitoring, prioritizing chemicals, brick kilns and major industrial combustion sources.	Monitoring clusters established; fuel and flare data obtained
	Extend monitoring across textile and food-processing clusters and establish common monitoring infrastructure where feasible.	Additional clusters monitored; common monitoring infrastructure established
Sectoral intervention	Chemicals: Audit boilers and process heaters and verify continuous APCD operation. Automobiles: Verify combustion sources and the effectiveness of existing controls. Brick kilns: map and upgrade kiln technology and fuel usage, prioritizing NCR-linked areas.	Boiler audits completed; APCDs verified; kilns upgraded; estimates validated
	Identify textile and food-processing units with significant boiler-based fuel consumption. Textiles and food processing: Shift boilers to gas, electricity or processed biomass where feasible. Assess common boiler systems and shared monitoring infrastructure in textile clusters.	Boilers converted; common boiler systems assessed
State government schemes and financing	Identify financing for kiln upgrades, combustion audits, monitoring equipment and industrial pollution-control improvements.	Schemes and financing sources mapped
	Mobilise financing for boiler replacement, electrification, cleaner fuels and shared infrastructure.	Financing mobilized; projects funded
Agricultural residue management	Map crop-residue availability and existing supply chains in coordination with Punjab.	Residue availability and supply chains mapped
	Strengthen crop-residue collection and supply chains jointly with Punjab to address regional Black Carbon emission.	Residue collected; supply chains strengthened
4. West Bengal		
SOP development for monitoring methods and networks	Establish black carbon monitoring in foundry and steel belts. Develop cluster-level protocols for periodic industrial measurements.	Monitoring sites established; protocols developed
	Expand monitoring across major foundry and steel clusters and use the data to assess mitigation progress.	Additional clusters monitored

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Work area	Specific action points	Indicators
Sectoral intervention	Foundries and rolling mills: improve combustion efficiency through furnace audits, switch process fuels where feasible, and install or repair APCDs. Chemicals and iron and steel: Identify fuel types and audit combustion units.	Furnace audits completed; APCDs repaired or installed; boilers tuned
	Foundries and tanneries: Assess common facilities and shared technical services. Metal melting: Pilot gas or electric melting where grid capacity and gas supply permit. Rice mills and food processing: Extend boiler-efficiency and cleaner-biomass interventions. Identify clusters where shared infrastructure could reduce the cost of cleaner production and monitoring.	Common facilities assessed; melting pilots initiated; boilers upgraded
State government schemes and financing	Identify state and MSME financing options for furnace upgrades, APCDs, boiler improvements and cleaner-fuel adoption.	Schemes and financing sources mapped
	Mobilize financing for common facilities, electric melting equipment and industrial energy upgrades.	Financing mobilized; projects funded
Agricultural residue management	Identify crop-residue availability and potential rice-mill and food-processing users for controlled biomass combustion.	Residue availability assessed; industrial users identified
	Develop residue supply-chain pilots for rice mills and food-processing boilers, with arrangements for collection, storage and reliable fuel quality.	Supply-chain pilots implemented; residue supplied
5. Bihar		
SOP development for monitoring methods and networks	Use existing monitoring networks as a baseline for selecting new monitoring sites in brick kiln clusters. Develop standard monitoring and reporting protocols.	Monitoring sites selected; protocols developed
	Expand monitoring to rice-mill and food-processing clusters. Incorporate improved activity data into the state inventory.	Additional clusters monitored; inventory updated
Sectoral intervention	Brick kilns: Introduce phased benchmark conversion to cleaner kiln designs and particulate controls. Distilleries: Audit boiler efficiency, verify APCDs and establish biomass fuel-quality requirements. Iron and steel: Audit furnaces and APCD performance.	Kilns upgraded; boiler audits completed; APCDs verified
	Rice mills and food processing: Develop biomass-fuel and boiler programmes. Brick kilns: Establish technical service centres to support technology adoption, operation and maintenance.	Biomass and boiler programmes implemented; service centres established
State government schemes and financing	Identify state schemes and MSME financing for kiln conversion, boiler upgrades, pollution-control equipment and technical support for smaller operators.	Schemes and financing sources mapped
	Facilitate MSME credit for kiln operators and mobilize resources for technical service centres and equipment upgrades.	Credit mobilized; service centres funded
Agricultural residue management	Assess crop-residue availability and burning activity to establish the baseline for agricultural BC emissions.	Residue availability and burning assessed
	Develop a Bihar crop-residue estimate for inclusion in the inventory and establish supply arrangements for controlled industrial use where feasible.	Crop-residue estimate completed; supply arrangements established

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Stakeholder-wise recommendations

Clear, specific responsibilities and accountability of each stakeholder ensure that efforts to reduce black carbon emissions from industries proceed in parallel and mutually reinforce each other.

Regulatory bodies (MoEFCC, CPCB and state PCBs)

MoEFCC to develop a national framework for black carbon measurement, monitoring and reporting; establish standardized protocols for ambient and stack-level measurements; define reporting requirements for industrial facilities; and integrate black carbon mitigation into policy measures such as the National Clean Air Programme. CPCB to coordinate measurement protocols and technical guidance, support harmonized monitoring and reporting formats, and facilitate a publicly accessible national black carbon inventory. SPCBs/PCCs to integrate black carbon monitoring into existing ambient air quality monitoring infrastructure, initiate measurements in priority industrial clusters, develop industrial monitoring SOPs and coordinate state-level action plans. SPCBs should also develop policies mandating industries to switch to cleaner fuels, with fuel suppliers, electricity distribution companies, gas suppliers and biomass aggregators participating in the process.

Industries, industry associations and industrial development corporations

Industrial units in priority sectors to replace solid fuels with lower-emission alternatives where feasible; improve combustion efficiency through furnace and boiler upgrades, optimized air-to-fuel ratios, preventive maintenance and trained operators; and improve the operation of air pollution control devices (APCDs). Industry associations to conduct awareness programmes on black carbon emissions, disseminate cleaner-fuel and combustion-efficiency practices, and facilitate collective action on monitoring, technology adoption and compliance. Industrial development corporations/industrial estate authorities to facilitate shared infrastructure in industrial clusters, including common monitoring facilities, fuel-quality assurance, technical service centres and shared pollution-control infrastructure.

Think tanks, civil society organizations and research organizations

Research institutions to support the development and validation of monitoring SOPs, provide technical expertise on instruments and stack sampling, and assess mitigation technologies and their technical and economic feasibility. Think tanks/CSOs to participate in the development of monitoring protocols and

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support stakeholder sensitization, public awareness and independent scrutiny of monitoring and reporting systems. Regional and intergovernmental institutions may explore opportunities for regional data exchange and coordination on black carbon transport and mitigation across the Indo-Gangetic Plain and neighbouring countries.

Agricultural departments, farmer producer organizations and biomass aggregators

Agricultural departments and crop-residue management agencies to coordinate the development of crop-residue supply chains for industrial use in controlled environments, connect agricultural residue producers with potential industrial users, and support alternatives to open burning. Farmers and farmer organizations to participate in crop-residue collection and supply arrangements and explore opportunities to retain and sell residues instead of burning them, where viable collection and procurement systems exist. Fuel suppliers and biomass aggregators to supply consistent-quality lower-emission fuels and develop reliable procurement, processing, storage and distribution systems for suitable biomass fuels.

Financial institutions

Financial institutions and industrial financing agencies to identify financing mechanisms to support cleaner-fuel transitions, kiln and furnace upgrades, shared infrastructure and monitoring equipment, particularly for small and medium industrial units, and to enable dedicated, scaled-up financing and technology-support mechanisms to address combustion efficiency or fuel switching. Black carbon from industrial combustion in the Indo-Gangetic Plain (IGP) is a measurable, regionally significant, and inadequately governed emission problem. The inventory compiled for the report covers 49,594 industrial facilities across 52 industry types. Despite this scale, no national standard exists for black carbon, no regulatory body is assigned to measure it, and no industrial facility in the IGP conducts routine stack-level black carbon measurements.

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This scoping study examines industrial black carbon emissions across India's Indo-Gangetic Plains.

As a dangerous superpollutant, soot accelerates regional climate change, harms public health, and threatens Himalayan water security by accelerating glacial melt. Yet, black carbon from industry remains largely unmeasured and unregulated in India.

Soot at Site maps industrial black carbon emissions across the Indo-Gangetic Plains, identifies the sectors driving them, and charts a practical way forward.

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