UTTAR PRADESH CLEAN AIR PLAN

AIRSHED BASED AIR QUALITY ANALYSIS AND RECOMMENDATIONS

2024

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP

UTTAR PRADESH CLEAN AIR PLAN (UCAP)

AIRSHED BASED AIR QUALITY ANALYSIS AND RECOMMENDATIONS

2024

Prepared by

Department of Environment, Forest, and Climate Change
Government of Uttar Pradesh

CONTRIBUTORS

1. **Department of Environment, Forest and Climate Change (DoEFCC), Government of Uttar Pradesh**
   - Mr. Ashish Tiwari, Secretary, DoEFCC
   - Mr. Maneesh Mittal, Chief Conservator of Forests
   - Mr. Pranav Jain, Deputy Conservator of Forests
   - Mr. Mohd. Rahib, Assistant Director, DoE
2. **The World Bank**
   - Mr. Jostein Nygard, Senior Environmental Specialist
   - Ms. Karin Shepardson, Lead Environmental Specialist
   - Ms. Farah Zahir, Senior Economist
   - Ms. Ishaa Srivastava, Environmental Specialist
   - Mr. Sayantan Sarkar, Environmental Specialist
   - Ms. Neha Sharma, Consultant
3. **Technical Input**
   - Dr. Mukesh Sharma, Professor, IIT Kanpur
   - Dr. Sagnik Dey, Professor, IIT Delhi
   - Dr. Markus Amann, International AQM Consultant
   - Dr. Wolfgang Schöpp, International AQM Consultant
   - Mr. Zbigniew Klimont, Research Group Leader, IIASA
   - Dr. Pallav Purohit, Senior Research Scholar, IIASA
   - Dr. Fabian Wagner, Principal Research Scholar, IIASA
   - Dr. Gregor Kiesewetter, Senior Research Scholar, IIASA
   - Dr. Adriana Gomez Sanabria, Senior Research Scholar, IIASA
   - Dr. Parul Srivastava, Research Scholar, IIASA
   - Dr. Steinar Larssen, International AQM Consultant
   - Dr. Anju Goel, Associate Director, TERI
   - Mr. Nimish Singh, Fellow, TERI

Technical Review Committee

The Government of Uttar Pradesh constituted a committee to technically review the plan, comprising: Mr. Ashish Tiwari, Secretary, DoEFCC, Government of Uttar Pradesh; Mr. Pankaj Agarwal, Director, Central Pollution Control Board, Delhi; Mr. Sanjeev Kumar Singh, Member Secretary, Uttar Pradesh Pollution Control Board; Dr. Mukesh Sharma, Professor, Department of Civil Engineering, IIT Kanpur

World Bank Review Team

The World Bank technical review was carried out by: Mr. Ernesto Sanchez-Triana, Lead Environment Specialist; Mr. Arturo Ardila-Gomez, Lead Transport Economist; Mr. Sandeep Kohli, Senior Energy Specialist; Mr. Jonah Matthew Rexer, Economist

Acknowledgements

We gratefully acknowledge the institutional support of the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria; the Indian Institute of Technology (IIT), Delhi; and the Norwegian Institute for Air Research (NILU), Kjeller, Norway for their valuable contributions to air quality modelling and analysis.

Special appreciation is extended to Dr. Himanshu Lal, the late Dr. Bipasha Ghosh, Dr. Pallavi Joshi Lahari, Dr. Pratima Gupta, Ms. Kirtika Sharma, and Ms. Sanjukta Ghosh from IIT Delhi; Dr. Shashi Tiwari, Ms. Aishwarya Yadav, and Mr. Karanjeet Verma from TERI; Mr. Robert Sander, and Dr. Binh Nguyen from IIASA; Mr. Leif Marsteen, Mr. Philipp Scheider, Mr. Claudia Hak, and Mr. Franck Dauge from NILU; and Ms. Nitika Man Singh and Ms. Monika Devi Ingudam from the World Bank for their instrumental contributions to the development and publication of this plan.

Lastly, we acknowledge with gratitude the support and active participation of industry representatives and all stakeholders who contributed to the formulation of this plan.

Published by
Directorate of Environment
Vineet Khand-6, Gomti Nagar, Lucknow, Uttar Pradesh 226010

For more information
Directorate of Environment, Vineet Khand-6, Gomti Nagar, Lucknow, Uttar Pradesh 226010
Phone: 0522-2300541 | E-mail: doeuplko@yahoo.com | Website: http://upenv.upsdc.gov.in

CONTENTS

ABBREVIATIONS AND ACRONYMS

ACS	Additional Chief Secretary
AgNUE	Agricultural Nutrient Use Efficiency
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
AOD	Aerosol Optical Depth
AQ	Air Quality
AQM	Air Quality Management
AQS	Air Quality Standard
ARAI	Automotive Research Association of India
ARTO	Assistant Regional Transport Office
BAM	Beta Attenuation Mass (monitor)
BS	Bharat Standard
BSES	Bharat Stage Emission Standard
CAAQMS	Continuous Ambient Air Monitoring Station
CAFE	Corporate Average Fuel Efficiency
CAMPA	Compensatory Afforestation Fund Management and Planning Authority
CAQM	Commission for AQM in Delhi and Surrounding Jurisdictions
CBG	Compressed Biogas
CD	Construction and Demolition
CEMS	Continuous emission monitoring system
CEV	Construction Equipment Vehicles
CEEW	Council on Energy, Environment and Water
CH4	Methane
CLE	Current Legislation (in GAINS)
CMP	Comprehensive Mobility Planning
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CPCB	Central Pollution Control Board

DoA	Department of Agriculture
DoHUP	Department of Housing and Urban Planning
DoEFCC	Department of Environment, Forest and Climate Change
DoMSME	Department of Micro, Small and Medium Enterprises
DoUD	Department of Urban Development
DoT	Department of Transport
DoUT	Directorate of Urban Transport
EESL	Energy Efficiency Services Limited
EPA	Environmental Protection Act
EPR	Extended Producer Responsibility
ESP	Electrostatic Precipitator
EU	European Union
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
FCBTK	Fixed Chimney Bull Trench Kiln
FGD	Flue Gas Desulfurization
FMP	Freight Management Planning
GAINS	Greenhouse Gas-Air pollution Interactions and Synergies (model)
GBD	Global Burden of Disease (study)
GHG	Greenhouse gas
GoI	Government of India
HDB	Heavy Duty Buses
HDT	Heavy Duty Trucks
HDV	Heavy Duty Vehicle
HED	High-Efficiency De-dusters
I&M	Inspection and Maintenance
ICAR	Indian Council for Agriculture Research
IGP	Indo Gangetic Plain
IIASA	International Institute for Applied Systems Analysis
IIDD	Infrastructure and Industrial Development Department
IIT D	Indian Institute of Technology Delhi
IIT K	Indian Institute of Technology Kanpur
IOCL	Indian Oil Corporation
ISRO	Indian Space Research Organization

LPG	Liquified Petroleum Gas
MCC	Marginal Cost Curve
MFI	Multilateral Finance Institution
MNRE	Ministry of New and Renewable Energy
MoAEW	Ministry of Agriculture & Farmers' Welfare
MOEFCC	Ministry of Environment, Forest, and Climate Change
MoPI	Ministry of Power and Industry
MoPNG	Ministry of Petroleum and Natural Gas
MoSPI	Ministry of Statistics and Program Implementation
MSW	Municipal Solid Waste
MT	Million Tons
NABARD	National Bank for Agriculture and Rural Development
NAAQS	National Ambient Air Quality Standards
NBCI	National Biomass Cookstove Initiative
NAC	Non-Attainment City
NAM	National Air Quality Monitoring
NAMP	National Air Quality Monitoring Program
NAMS	National Air Quality Monitoring System
NBFC	Non-Banking Financing Corporation
NBOMP	National Biogas Organic Manure Program
NCAP	National Clean Air Program
NCR	National Capital Region
NCT of Delhi	National Capital Territory of Delhi
NEERI	National Environmental Engineering Research Institute
NFSM	National Food Security Mission
NGO	Non-Government Organization
NMAET	National Mission on Agricultural Extension and Technology
NH3	Ammonia
NILU	Norwegian Institute for Air Research
NRLM	National Rural Livelihood Mission
NOX	Nitrogen Dioxide
NRRI	National Rice Research Institute
NUE	Nutrient Use Efficiency

OCEMS	Online Continuous Emission Monitoring Stations
PCB	Pollution Control Board
PM	Particulate Matter
PM2.5	PM with a diameter of 2.5 micrometers or smaller
PM10	PM with a diameter of 10 micrometers or smaller
PMF	Positive Matrix Factorization
PMUY	Pradhan Mantri Ujjwala Yojana
PNG	Petroleum Natural Gas
PRANAM	PM program for Restoration, Awareness Nourishment and Amelioration of Mother Earth
PUC	Pollution Under Control
PWD	Public Works Department
QA/QC	Quality Assurance/Quality Control
RDD	Rural Development Department
RDSO	Research Designs and Standards Organization
RTO	Rural Transport Office
SATAT	Sustainable Alternative Towards Affordable Transportation
SAP	State Action Plan
SAU	State Agricultural University
SBM	Swachh Bharat Mission
SCAP	State Clean Air Plan
SCR	Selective Catalytic Reduction (SCR) engines
SDG	Sustainable Development Goals
SDV	Short Duration Varieties
SHG	Self-help Group
SNCRs	Selective non-catalytic reduction
SOP	Standard Operating Procedure
SOX	Sulphur Oxide
SO2	Sulfur Dioxide
SPCB	State Pollution Control Board
SPV	Special Purpose Vehicle
SRLM	State Rural Livelihood Mission
TA	Type Approval
TERI	The Energy and Resources Institute

TPD	Tons Per Day
TPP	Thermal Power Plant
UA	Urban Agglomeration
UCAP	Uttar Pradesh Clean Air Plan
UDD	Urban Development Department
ULB	Urban Local Body
UNECE	United Nation Economic Commission for Europe
UNFCCC	United Nation Framework Convention on Climate Change
UP	Uttar Pradesh
UP-CAR	Uttar Pradesh – Council of Agricultural Research
UP CAMPA	Uttar Pradesh Clean Air Management Program Authority
UPEIDA	Uttar Pradesh Expressway Industrial Development Authority
UPMTA	Uttar Pradesh Motor Transportation Association
UPNEDA	Uttar Pradesh New & Renewable Energy Development Agency
UPPCB	Uttar Pradesh Pollution Control Board
UP PM KUSUM	Uttar Pradesh Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan Scheme
UPSIDA	Uttar Pradesh State Industrial Development Authority
UPSRTC	Uttar Pradesh State Road Transport Corporation
UPSRLM	Uttar Pradesh State Rural Livelihood Mission
US	United States
UT	Union Territory
VSBK	Vertical Shaft Brick Kiln
VOCs	Volatile organic compounds
WHO	World Health Organization
XVFC	Fifteenth Finance Commission

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The Uttar Pradesh Clean Air Program (UCAP) presents an in-depth technical understanding of sources and causes of air pollution across Uttar Pradesh (UP) through application of a more comprehensive lens following an airshed based approach considering both primary and secondary sources of PM2.5. It has been based on a first state emission inventory that has been developed as inputs for modeling and will progressively be updated throughout implementation of the plan as part of a comprehensive decision support system (DSS) to be established.

UCAP's comprehensive baseline supports a forward-looking plan over the next 10 years based on the air quality levels, trends, and prominent sources. It also provides a source apportionment analysis and reviews baseline business as usual (BAU) policies as well as alternative policies and actions needed to further advance emission reductions in the state with the goal to achieve India's National Ambient Air Quality Standards (NAAQSs) to ensure cleaner air for the citizens of UP. Strategic objectives of UCAP in this context are (i) to develop pathways for achieving NAAQSs in UP; (ii) to promote pilots and standard operation procedures (SOPs) for all relevant sectors that contribute to air pollution, particularly focusing on those sectors and gaps within sectors that have not been addressed before, and **(iii)** align state-level interventions with the objectives of the National Clean Air Program (NCAP).

Background

Air pollution, particularly high levels of $PM_{2.5}$ in Indo-Gangetic Plain (IGP), poses significant health risks and impacts ecosystems. The IGP region that occupies 60 percent of India's total area, and 40 percent of its population, encompasses six States and two Union Territories and is a significant hotspot for air pollution. UP, located in the heart of the IGP, faces severe air pollution, with its population exposed to $PM_{2.5}$, leading to adverse health outcomes and economic losses.

UP's air quality is influenced by its geographical location and seasonal variations, with pollution exacerbated during winter due to stagnant air conditions. Despite some good improvements, many areas in UP, including 15 non-attainment cities (NACs) that did not meet the national air quality standards over a period of five years, continue to have air pollution levels far exceeding national standards. **To address this challenge, NCAP and the 15th Finance Commission (XVFC) program provide frameworks and funding for improving air quality.** NCAP aims to reduce key air pollutants by up to 40 percent by 2026, focusing on NACs. Additionally, the establishment of the Commission for Air Quality Management (CAQM) for the National Capital Region (NCR) and adjoining areas reflects India's commitment to a multi-sectoral approach to tackle pollution.

Various government schemes and initiatives promote cleaner technologies, sustainable transportation, energy efficiency, and waste management to mitigate air pollution. However, further improvements require a holistic airshed management approach, acknowledging that pollution sources often transcend city and state borders. UP, being the most populous state in India, plays a crucial role in addressing air pollution in the IGP. Despite challenges, concerted efforts at the national and state levels, along with regional cooperation, are essential to achieving cleaner air and safeguarding public health and the environment.

Key Considerations when developing UCAP

A plan that considers the dynamics of an airshed - both of UP and the IGP.

	Integrate findings and recommendations of already developed Clean Air Action Plans (CAAPs).
	Ongoing work by the Central Pollution Control Board (CPCB) in developing *"Guidelines for Finalization of State Action Plan (SAP)".*
	That the plan contributes to achieving targets set in the NCAP.
	That progress is measured according to the standards outline in the NAAQs.
	The effect of both (i) recent and current Air Quality Management (AQM) policies and measures and (ii) additional AQM policies and measures must be put in place to reach targets.

Air Quality Landscape

Thorough reviews of ground level monitoring sources reveal that there is some progress in the average and range of concentrations measured at both continuous ambient air quality monitoring stations (CAAMS) for PM2.5 (Figure ES2) and National Ambient Monitoring Program (NAMP) stations for PM10. (Figure ES1). Additional utilization of satellite-based optical measurements enables the assessment of aerosol optical depth (AOD) in the atmosphere, which can be translated into surface concentrations of aerosol particles, particularly PM2.5. Like with the data from the NAMP and CAAQMS stations, some lower concentrations in AOD - driven PM2.5 data are noted. Notably, high AOD values, signifying elevated PM concentrations, are evident in eastern UP and particularly pronounced in regions surrounding New Delhi, with slightly lower but still significant levels along the Ganga River.

FIGURE ES1: SECTOR SHARES TO THE PM2.5 PRECURSOR EMISSIONS IN UTTAR PRADESH, 2020

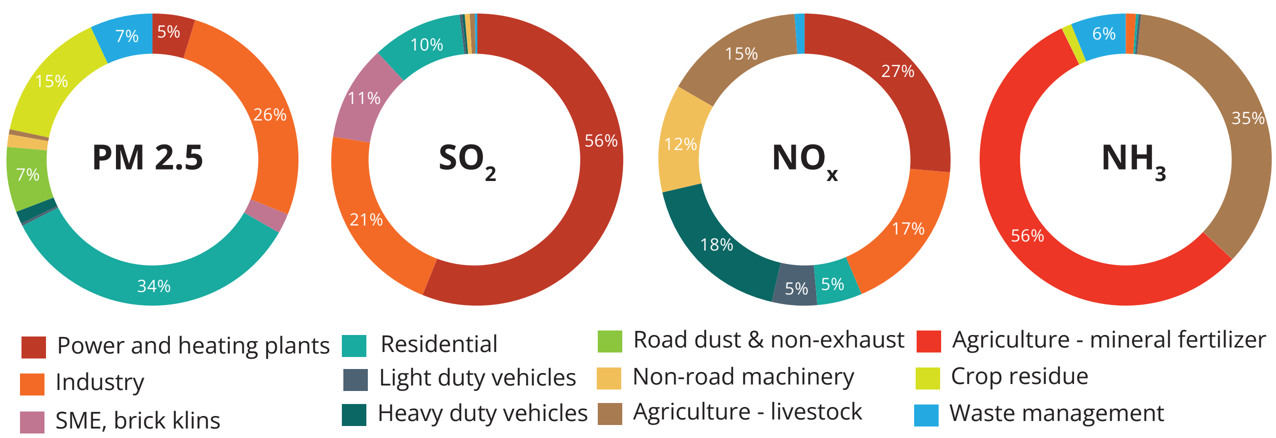
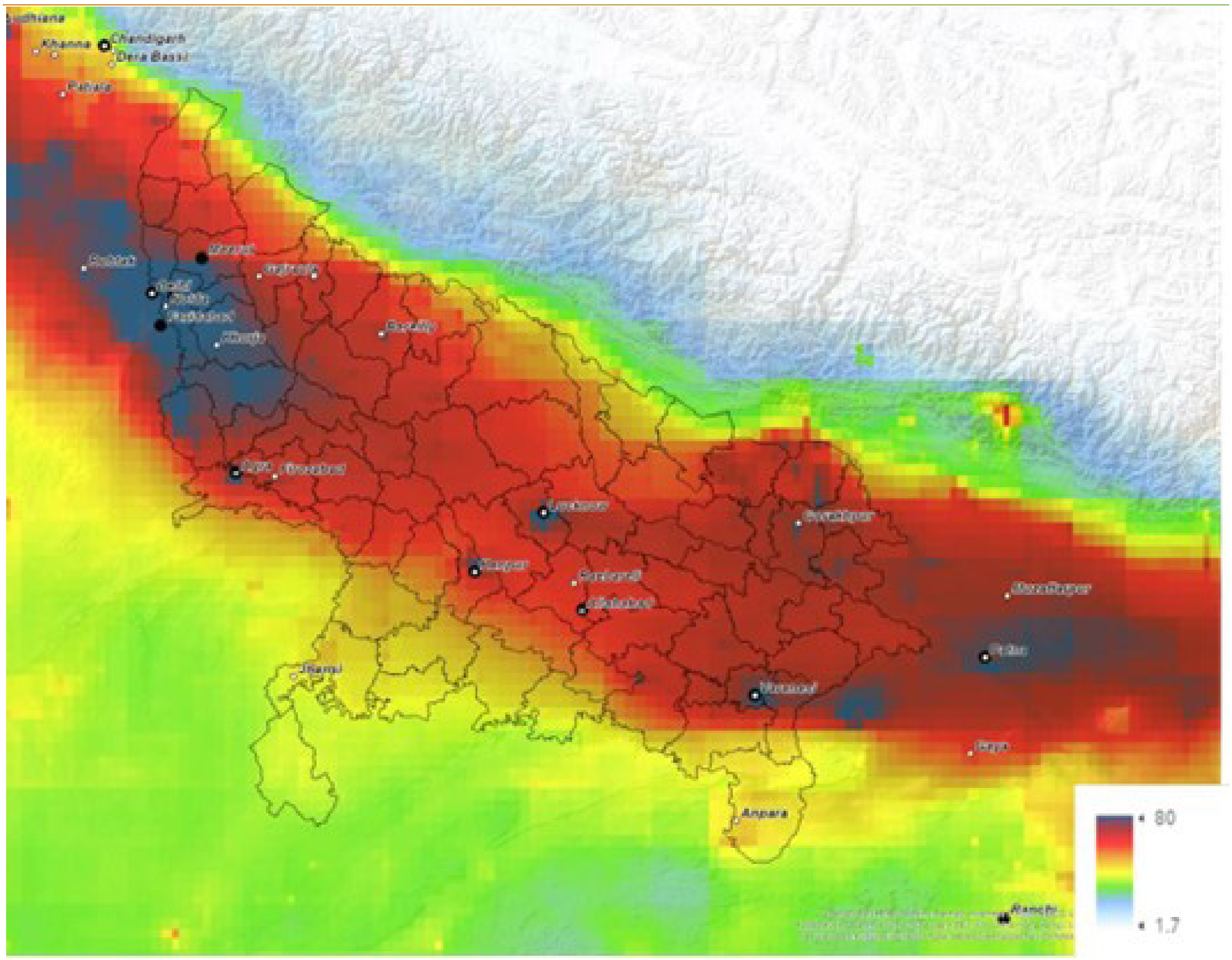


FIGURE ES2: TIME TREND OF PM2.5 CONCENTRATION (2017-2022)



Sources of Air Pollution

Based on GAINS-IGP analyses, the situation in UP in 2020 is depicted in Figures ES3 & 4, with the spatial origins of PM2.5 exposure depicted on the horizontal axis: (i) natural emission sources, i.e., soil dust; (ii) from other countries; (iii) from other regions in India except the neighboring states of UP; (iv) from the neighboring state; and (v) from UP itself. Sector contributions are indicated by the vertical bars. The left panel shows contributions broken down by source sector. **About 40 percent of total PM2.5 exposure in UP consists of secondary PM2.5 out of which 60 percent is contributed from outside the state. Secondary PM which is formed in the atmosphere from precursor emissions of oxide of nitrogen (NOx), oxide of sulfur (SO2), ammonia (NH3) and volatile organic compounds (VOCs).**

is intricately linked to various sectors, each contributing differently to its concentration in ambient air throughout UP. Based on source contribution information tailored for UP, using both geographic origin of sources (US 3 and 4) and hotspot information (fig. ES5), the key sectors and geographic focus for interventions are:

Residential Sector: Solid fuel combustion in households, primarily for cooking, contributes about 31 percent (20 $\mu g/m^3$) to PM2.5 levels. With highest concentrations in Eastern and some fewer in Western districts, this source poses a significant health risk, especially in low-income communities.

Transport Sector: Transport-related emissions contribute 14 percent (9.1 $\mu g/m^3$) PM2.5 concentrations, with road dust and vehicle emissions being primary contributors. Urban centers experience hotspots of elevated

FIGURE ES3: TOTAL CONTRIBUTIONS (PRIMARY AND SECONDARY PM2.5

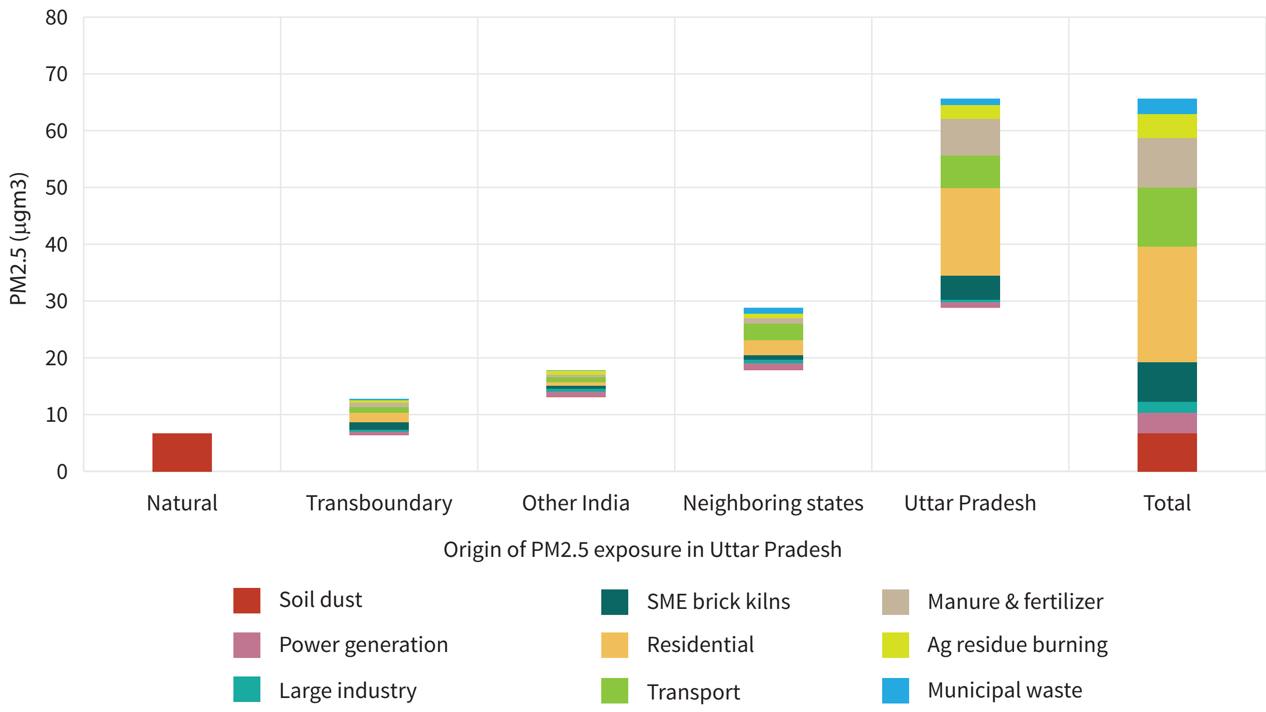


FIGURE ES4: SECTORAL CONTRIBUTIONS OF PRIMARY PM2.5 AND CONTRIBUTIONS OF SECONDARY PM2.5

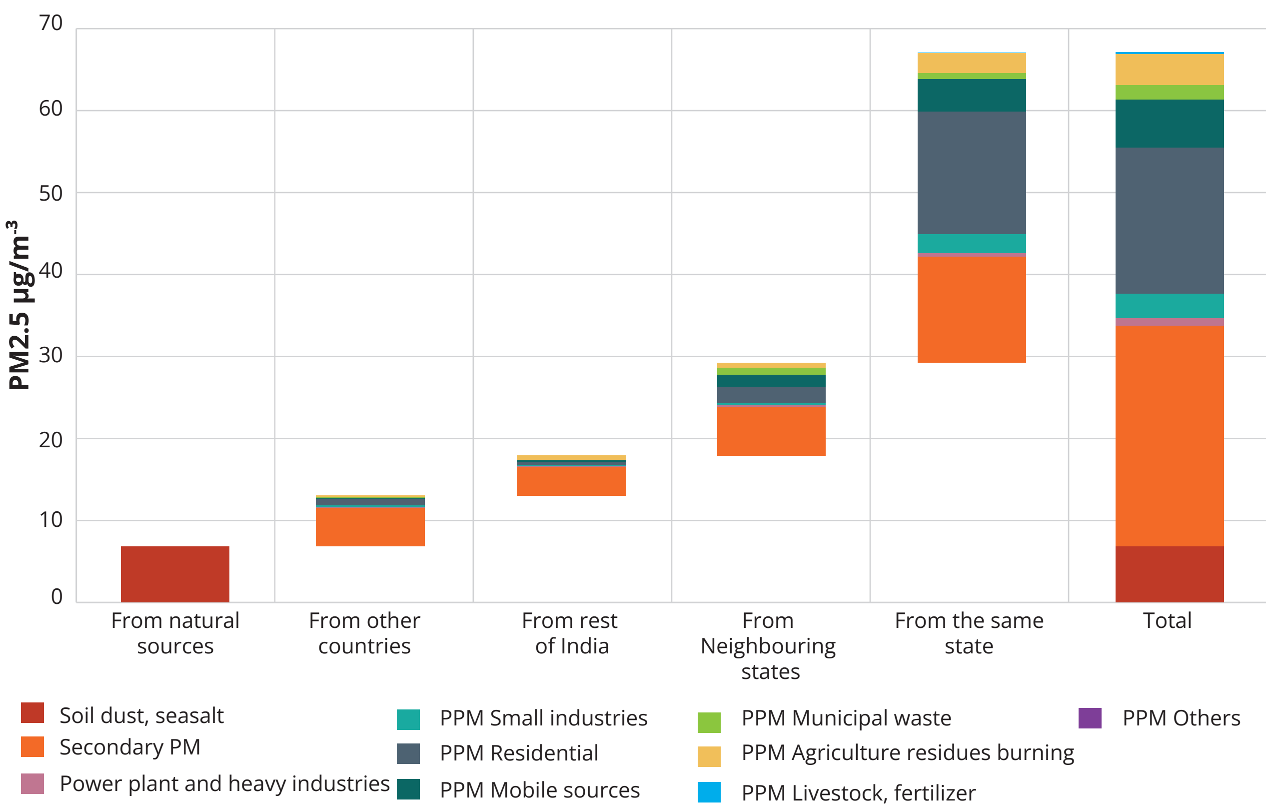
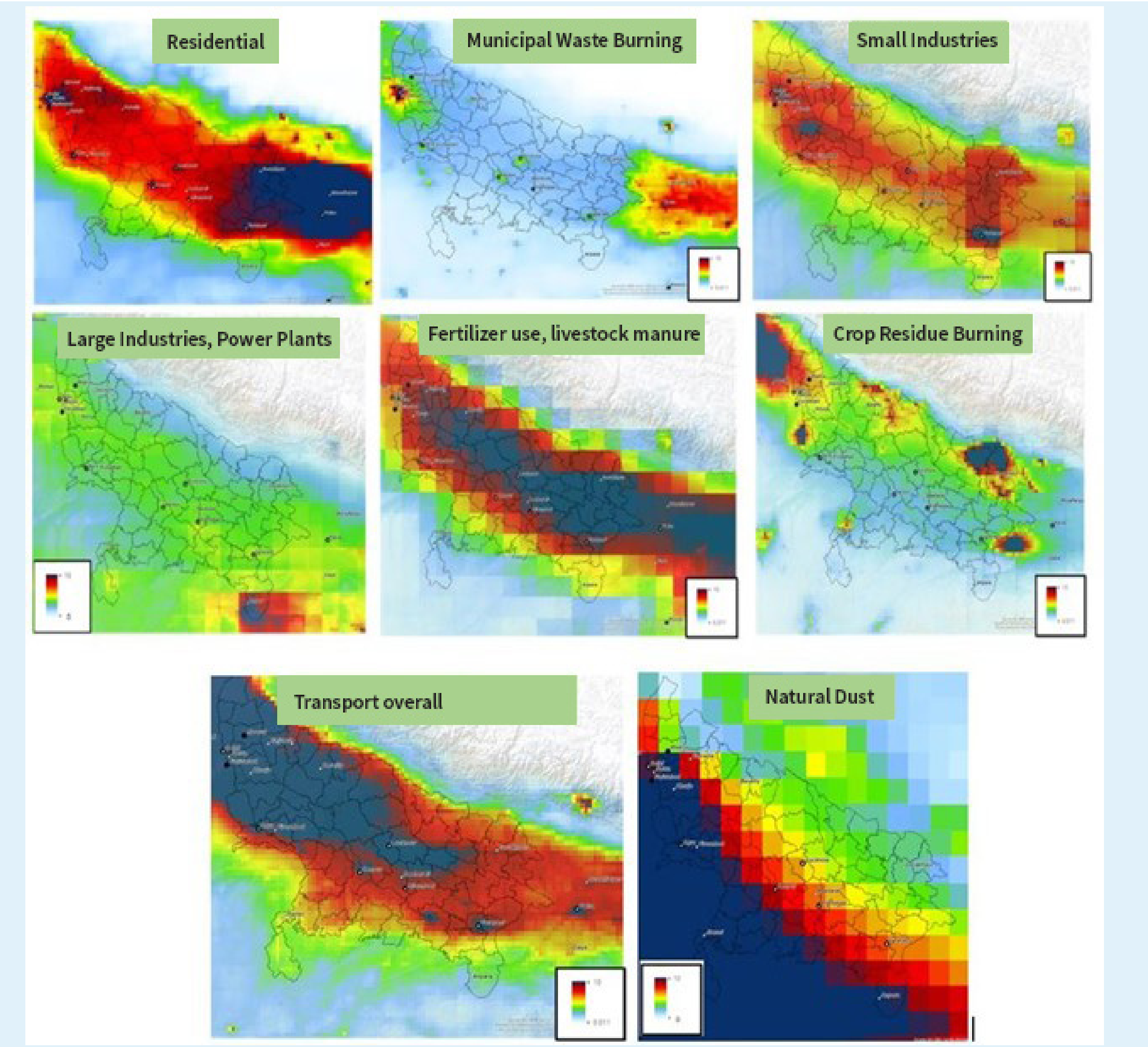


FIGURE ES5: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN THE AMBIENT AIR IN UP FROM EMISSIONS FROM SEVEN MAIN SECTORS AND NATURAL DUST. (ALL SCALE: 0.01-10 MG/M³ EXCEPT RESIDENTIAL: 0.01-25 MG/M³).



PM2.5 levels due to vehicular activity. Strong contributions to high PM2.5 concentrations in particularly NCR and towards the East and major urban areas throughout UP.

Industrial Activities: Particularly SMSM industries and partly large-scale industries and power plants, contribute 16 percent (10.6 µg/m³) to PM2.5 levels throughout UP, with significant emissions originating from sources both within and outside UP. Small-medium enterprises, including brick kilns, also play a substantial role in air pollution, particularly in the NCR and surrounding areas and in the "Gorakhpur-Varanasi axis" in the east.

Agricultural Practices: Agricultural activities, such as residue burning and fertilizer application, contribute 19 percent (12.4 µg/m³) to PM2.5 concentrations. While remaining crop residue burning are largely localized, particularly in the North-East of UP, high ammonia emissions from fertilizer and livestock manure are contributing to high secondary PM2.5 concentrations are prevalent throughout UP.

Municipal Waste Management: Municipal waste burning contributes 4 percent (2.7 µg/m³) to PM2.5 concentrations, with localized hotspots around urban centers. Improving waste management practices is essential for reducing emissions from this sector.

Pathways to Reduce Air Pollution in Uttar Pradesh

Prioritized interventions based on both (i) $PM_{2.5}$ reduction potentials and (ii) CPCBs guidelines for formulation of state action plan (SAP) and a pathway for reaching NAAQSs (current 40 μg/m³) and help to further reach 35 μg/m³ have been outlined. In figure ES6, the PM2.5 reduction potential both from measures under current polices (**blue** parts) and further potentials from measures under additional policies (**orange** parts) have been outlined. As outlined in Table ES1, full implementation of current policies can largely retain a status quo situation over the next 10 years, while implementation of additional measures under new policies that is not part of the current AQM policy matrix in UP, must be substantively implemented to substantively improve the air quality situation in UP and achieve both current (40 μg/m³ for PM2.5) and future NAAQSs.

FIGURE ES6: PM2.5 EXPOSURE REDUCTIONS IN UP IN 2035 EMERGING FROM THE POSSIBLE EMISSION CONTROLS IN THE VARIOUS ECONOMIC SECTORS WITHIN UP (RANKED BY DECREASING POTENTIALS FOR FURTHER EXPOSURE REDUCTION

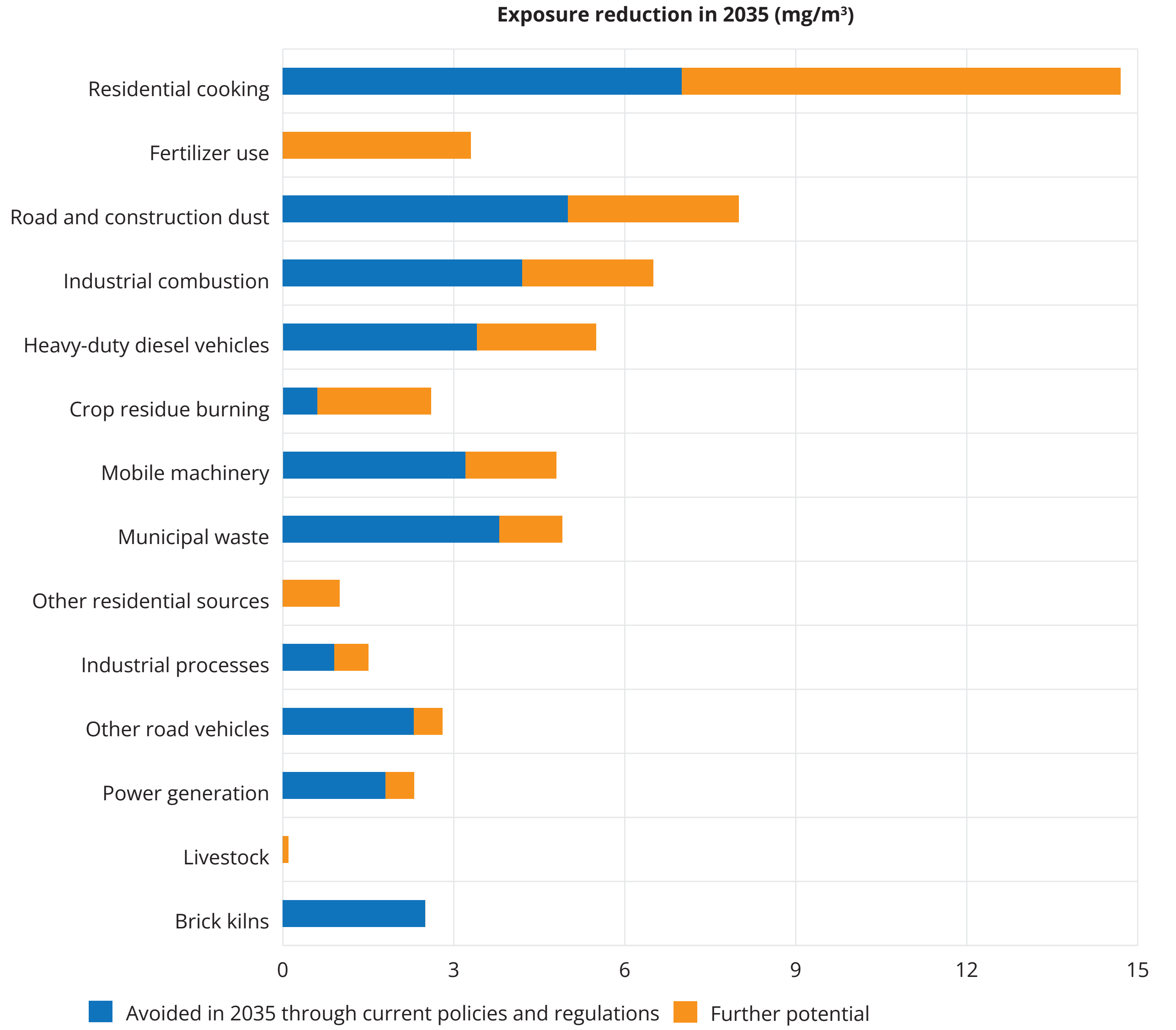


TABLE ES1: PROJECTED PM2.5 EXPOSURE REDUCTIONS IN UP IN 2030-35 THROUGH UCAP.

Measures to be applied	Potential $PM_{2.5}$ exposure reduction in UP over a 10-years period	$PM_{2.5}$ exposure in UP (PWE)
Base year 2020 with already implemented emission control measures		65 µg/m³
Baseline project for 2035 assuming an increase of GDP by a factor of 2.7 and full implementation of current policies and regulations		67 µg/m³
Implementation of measures with largest reduction potentials: – Clean energy in households and improved heating – Efficient urea fertilizer use – Control of construction and road dust – Ban on open burning of crop residues – Enforced inspection and maintenance programs for heavy-duty vehicles – PM control at industrial sources (mostly MSMEs) – Improved solid waste management – Enhanced emission standards for mobile machinery (e.g. construction machinery)	24 µg/m³	
Common measures applied in other IGP states	~8 µg/m³	
Key measures in UP combined with common measures applied in other IGP states	~32 µg/m³	35 µg/m³

Meeting National Clean Air Program (NCAP) Goals

To align state level interventions in AQM with the objectives of the NCAP following steps must be considered in period of 10 years (2025-2035) divided into two parts:

- **First part**: By continuously focusing on getting current and additional PM2.5 policies implemented, NCAP targets (40 percent reduction in 2026 or 2017/19) will be reached by all NACs in UP. As outlined in figure ES7, this will be achieved through a combined implementation of measures focusing on particularly road dust and more advanced household energy use but also agriculture and municipal waste management.
  - Establish needed implementation capacity and technical and managerial knowledge in state-wide priority sectors.
  - Carrying out demonstrations and pilots to gain needed experience and tailor technology and management practices to local economic conditions.
  - In parallel, a first phase of strong implementation (e.g. of existing SAAPs) to be continuously carried out and accelerated.
- **Second Part:** Full-scale implementation of all the prioritized state-wide sectors in UCAP (both current and additional measures) may be considered by the state to be enforced in full capacity.
- **To align with NCAP time scale**, PM10 impacts are focused on 2030. This reflects source-specific emission factors for PM10 that reflect the impact of the considered emission control measures on PM10 emissions. (Note that removal efficiency for PM10 size fraction is in many cases different from the efficiency for smaller particles such as PM2.5).

Summary and Conclusion

Air pollution in UP significantly impacts human health and economic productivity, with the annual PM2.5 concentration exceeding the Indian air quality standard. The UCAP identifies key sources of air pollution and proposes measures for its reduction, including a robust, comprehensive, and collaborative state-wide implementation plan. UCAP delivers several key lessons that provide useful insights into the formulation of priority activities:

KEY TAKEAWAYS

1 The analysis clearly reveals measures in nine set of additional measures (see orange matrix below) in five key sectors as indispensable for achieving substantial air quality improvements in UP in the coming decade: (i) residential/commercial; (ii) agriculture; (iii) transportation and dust; (iv) MSMEs; and (v) municipal waste. From a technical perspective, measures in these sectors seem like both most for reducing PM2.5 exposure in UP.

2 With effective governance and supporting implementation mechanisms, measures adopted within UP could bring down PM2.5 exposure over a 10-year period by about 23 $\mu g/m^3$ (2025-35).

3 In addition, cooperation with neighboring states could lower the inflow of pollution into UP and thereby reduce background concentrations by about 7 $\mu g/m^3$. Together, such actions could align average PM2.5 exposure in UP with 40 $\mu g/m^3$ (current NAAQC) and help going further to reach 35 $\mu g/m^3$ (ref. Table ES1).

4 Given that these air quality improvements seem attainable within a 10-year period or beyond, the date of achieving current NAAQS of 40 $\mu g/m^3$ target and potentially 35 $\mu g/m^3$ will critically depend on the starting point of the proposed measures.

5 International experience shows that regulations without proper enforcement mechanisms are costly but ineffective. Full adoption of the envisaged emission controls will be critical for success of the action plan. This requires a careful design and proper piloting of policy interventions, possibly with a temporally staged transition pathway, with clear end-dates for the intermediate steps.

6 To retain a target of 40 $\mu g/m^3$ and possibly help going further to reach 35 $\mu g/m^3$ for PM2.5 and to enable sufficient time to provide essential financial resources, develop strategic knowledge, build technical, managerial and coordination capacities, and carry out demonstration and pilot programs in sectors that needs further experience before larger-scale programs are applied, it is suggested that implementation of UCAP be carried out over a 10-year period. This would enable capacities to be built and demonstrate that gradual full-scale implementation of all prioritized measures to reach NAAQSs throughout Uttar Pradesh.

OUTLINING PATHWAYS FOR ACHIEVING NAAQSS - EFFECTIVELY ENFORCING CURRENT POLICIES

(blue table):

1. Expansion of AQ monitoring network, real-time emission source monitoring, enhancing the institutional capacities for monitoring and implementation of AQM measures, green skill development to support the operation & maintenance of air pollution control systems and most importantly, a state of the Science Evidence - Based DSS fully backed up by the monitoring infrastructure.
2. Achieving Bharat standards to level VI (both HDVs and LDVs), control of CNG-powered vehicles.
3. Mopeds, agricultural and construction machinery all reach (EU) stage 3 controls.
4. Moderate PM control (ESPs) and effective desulfurization are achieved in large power plants.
5. Almost 80 percent of households have applied electric or LPG cooking while basic PM control (cyclones/ESP1) are applied in most industries.
6. Moderate PM controls (ESO2) are applied in large-scale and heavy pollution industries like cement and fertilizer.
7. Achieving enhanced compliance for non-energy related emissions from industrial processes including MSME and brick kiln.

To be able to "bend the curve" the following additional measures must be brought into play (green table):

To reach current NAAQSs (40 µg/m³ for PM2.5), which will further help to move towards 35 µg/m³, the following nine additional measures must be activated and put into full play:

1. Full application of clean energy in all households that use traditional cookstoves today by applying a set of clean /advanced technology (that includes LPGs, improved cookstoves, induction cookstoves where electricity supply exists, apply localized household-base biogas digesters and solar-powered energy sources).
2. Promoting the use of neem-coated fertilizer and increase the NUE in all major cropping areas in each agro-ecological zone in UP.
3. Develop management models for reduced ammonia emissions from livestock manure, particularly in large cowsheds (Gaushalas).
4. Paving roads and apply water spraying, street washing etc. to reduce road dust and apply water spraying and construction curtains to reduce dust generation at construction sites.
5. More efficient application of PM filters to reduce fuel combustion in industries and achieve almost 100 percent efficiency in larger industrial plants.
6. Apply enforced inspection and maintenance systems for HDVs, particularly for HD trucks.
7. Enforce a ban on CRB and collection and energetic recycling of municipal waste material.
8. Reduce emissions from non-road sources.
9. Full integration of waste generation, avoidance, collection, separation, recycling, treatment and waste disposal.

For each of these additional measures, specific SOPs must be developed in the 2025-30 timeframe. Responsible agencies for preparing the SOPs involve (i) Department of Rural Development for clean energy in households, (ii) DoA and UP-CAR for increased NUE, (iii) Animal Husbandry Department for livestock manure management, (iv) Directorate of Urban Local Bodies, for paving roads, apply water spraying and street washing, (v) UPPCB for full application of PM filters in industries, (vi) DoT for enforced inspection of HDVs, (vii) DoA for ban on CRB, (viii) DoT for reducing emissions form non-road sources and (ix) Urban Development Department for full integration of SWM.

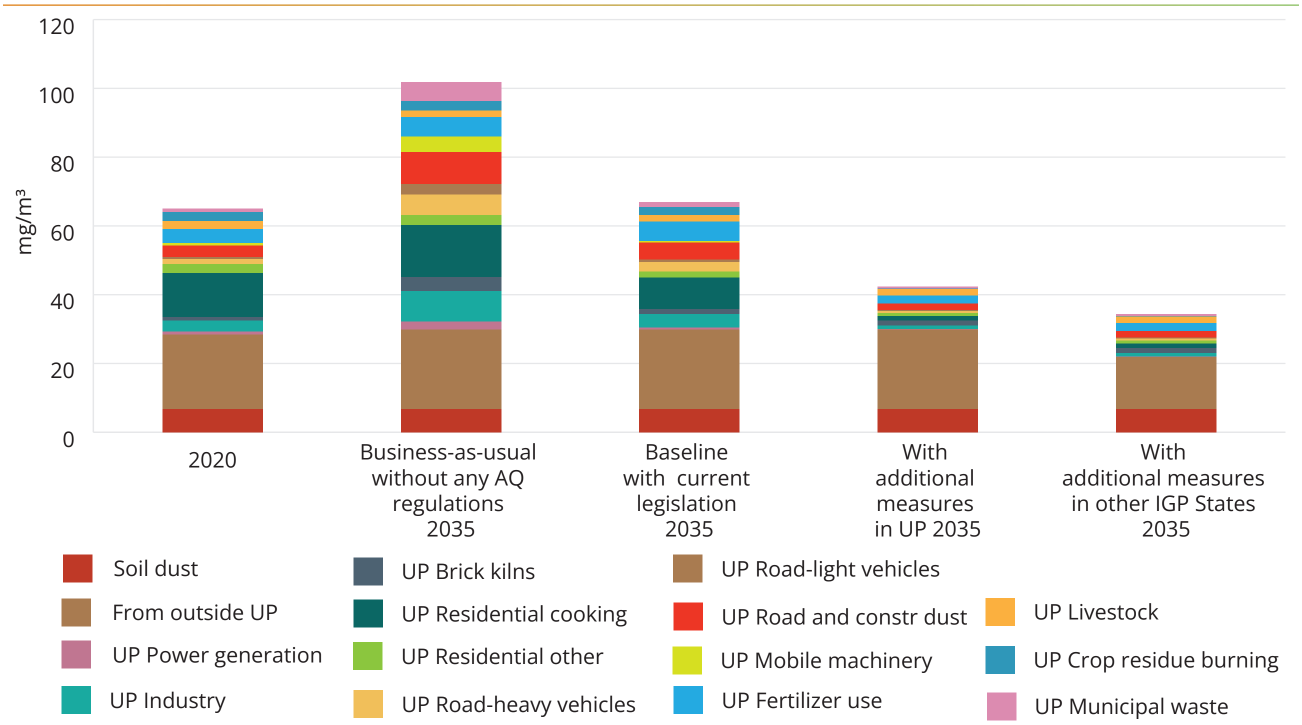
Key Findings of the UCAP Analysis

Despite some progress in recent years in improved air quality, full implementation of existing air quality policies and regulations in UP and India as applied to UP, will maintain PM2.5 concentrations at current levels (~65 μg/m³) over the next decade despite significant economic growth. Without current policies, regulations and measures, current air quality situation in UP would be around 75-80 μg/m³) and projected air quality over the next 10 years would increase to above 100 μg/m³). (Ref. Fig. ES8).

Nine measures in five key sectors have been identified as critical for the achievement of substantial air quality improvements in UP. These include residential/commercial biomass burning (clean energy in household), agriculture (fertilizer, crop residue burning, management of livestock manure), transportation, non-road vehicular sources and dust, medium and small industries, and municipal waste burning.

Unilateral implementation of a full set of additional measures within UP could reduce PM2.5 exposure by about 26 μg/m³ by 2035, but this would still result in exposure levels above the desired medium to longer-term levels. Cooperative airshed management with neighboring states could further reduce PM2.5 exposure in UP, potentially bringing it down to 40 μg/m³ (current NAAQS) and also help in reaching 35 μg/m³ and avoiding the need for the most expensive measures within UP. The analysis indicates that UP on its own would hardly be able

FIGURE ES7: CONTRIBUTIONS BY SECTORS IN 2020 AND PROJECTED SECTOR CONTRIBUTIONS FOR DIFFERENT SCENARIOS TO 2035 (YEARLY AVERAGE PM2.5 IN PWE).



to reduce PM2.5 exposure to 40 µg/m^3, nor fully help in reaching 35 µg/m^3, but cooperative action with other IGP states could make this target attainable.

Using international AQM practices, UCAP includes an initial attempt on cost-effectiveness analysis for further work in the future as a separate annexure which needs refinement/customization before it to be of use, as called for in the new CPCB "Guidelines for Formulation of State Action Plans" (sections 2.2 and 2.2.7), which indicates UP can achieve significant exposure reductions at substantially lower costs by prioritizing measures based on their cost-effectiveness in addition to their exposure reduction potential. Measures with moderate costs could reduce PM2.5 exposure by about 16 µg/m^3 but would not be sufficient to approach the national air quality standards for PM2.5. It also shows that following an implementation plan based on cost-effectiveness and regional cooperation would involve substantively lower costs to the UP economy.

Rapid implementation of identified additional measures for PM2.5 will also decrease PM10 concentrations in UP, aligning with the National Clean Air Program (NCAP) target of a 40 percent reduction of PM10 concentrations by around 2026. By continuously applying on PM2.5 targets and applying measures that is prioritized based on PM2.5 reduction potentials, PM10 targets set in NCAP will also be met.

KEY RECOMMENDATIONS STEMMING FROM UCAP

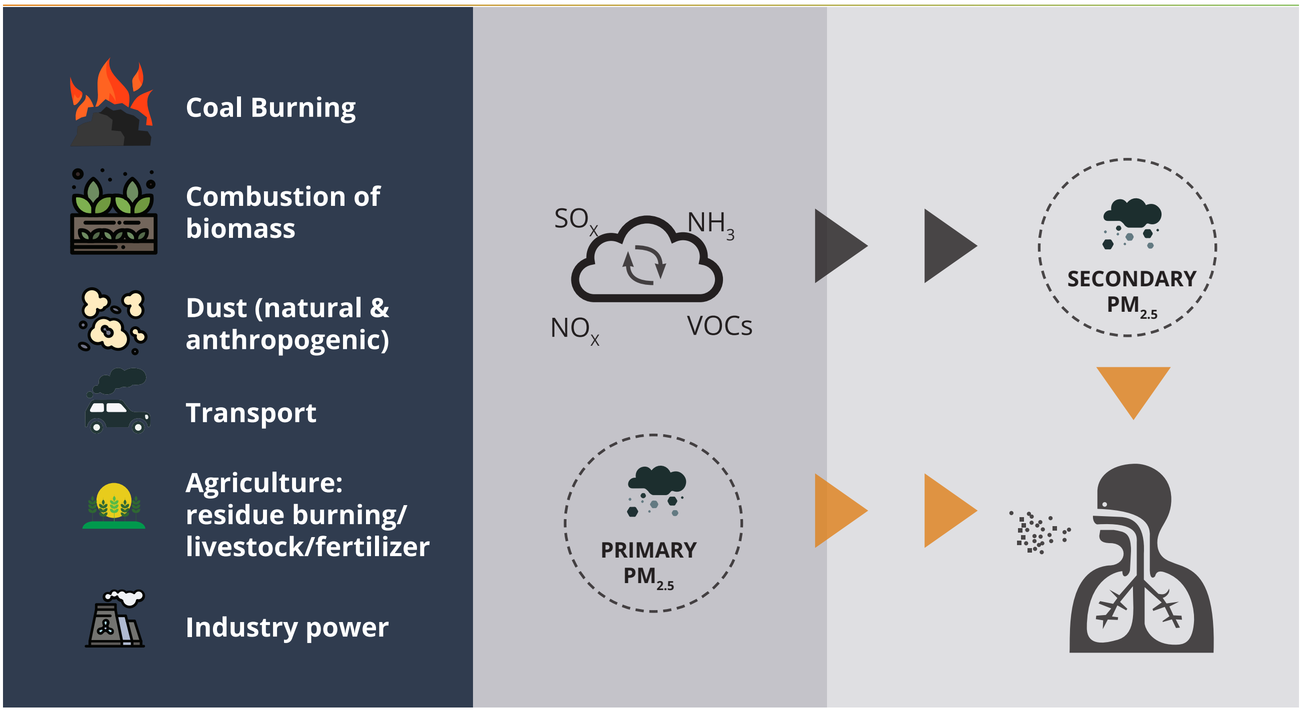
1. Strengthen the capacity for implementation of existing air quality policies and regulations to maintain current PM2.5 levels despite economic growth.
2. Implement additional measures within UP to further reduce PM2.5 exposure, focusing on pathways for emission reductions through nine additional set of measures in five key sectors identified.
3. Engage in cooperative airshed management with neighboring states to achieve further reductions in PM2.5 exposure and meet air quality targets.
4. Prioritize funding for measures across sectors based on technical analysis of source information to achieve significant exposure reductions.
5. Enhance the capacity of regulatory bodies for effective monitoring and enforcement of air quality policies.
6. Expand the air quality monitoring network to cover more representative areas of UP, including rural/village settings.
7. Improve data quality procedures and operational practices to maximize the benefit from the extensive air quality monitoring effort.
8. Establish a dynamic emission inventory and decision support system to inform air quality management and policy decisions.
9. Build a "green" workforce to implement effective monitoring systems and conduct studies on the effects of air pollution.
10. Form a Special Purpose Vehicle (SPV) for focused management of air pollution in UP and oversight for implementation of UCAP.

INTRODUCTION & BACKGROUND

Air pollution is a widespread global environmental hazard that poses significant threats to both human health and the Earth's ecosystems. This complex issue spans multiple sectors and is closely tied to various economic activities. Unfortunately, efforts to control and manage emissions have often fallen behind the pace of economic development and growth. To address this pressing concern, comprehensive solutions are needed across multiple sectors and spanning across administrative boundaries. These solutions should encompass a transition towards cleaner air across diverse sectors of the economy, supported by strategic investments and essential behavioral changes.

In the past, specific sectors like transportation, large industrial sources, crop residue burning, and municipal waste incineration have been acknowledged as major sources of air pollution in India, particularly in densely populated urban regions. However, there is growing awareness that rural areas also significantly contribute to and are recipients of air pollution. One challenge is the continued use of traditional cookstoves (both by wood and cow dung burning in particularly low-income rural areas). Other challenges are small and medium-sized industrial enterprises generating largely primary PM but also through agricultural practices that often generate ammonia emission due to imbalanced fertilizer use and from livestock manure across the country that play a crucial role in PM2.5 pollution. These practices are often overlooked. Other largely primary PM sources in often rural areas includes micro, small and medium industries.

FIGURE 1: AIR POLLUTION IS A MULTI-SECTOR CHALLENGE



Note: SOx: Sulphur Oxides; NOx: Nitrogen Oxides; NH3: Ammonia; VOCs: Volatile Organic

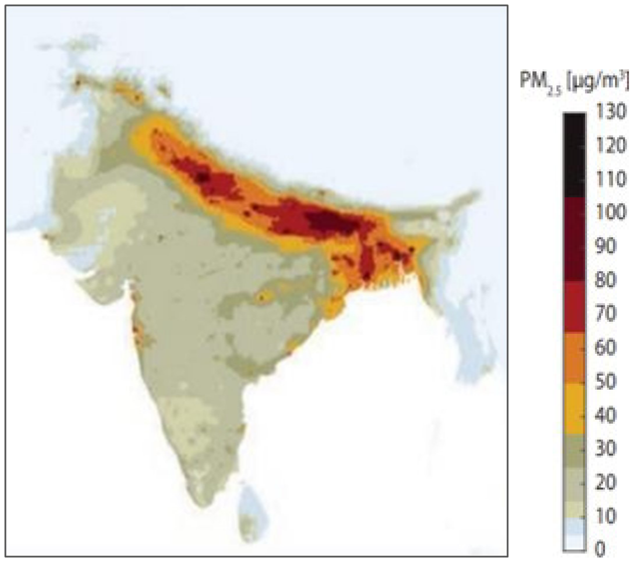
Despite certain air quality improvements over the last years, fifteen of UP's Non-Attainment Cities (NACs) range among the cities with higher PM2.5 concentrations in India, with PM2.5 levels often **twice above India's current air quality standard (40 µg/m³)[1].** A variety of contributing factors is responsible for the high pollution load, including UP's location in the center of the IGP region surrounded by states with high emissions, and the local meteorological conditions of the IGP. However, UP is also characterized by high emission densities within the State, which add to the unfavorable situation.

The key to addressing air quality issues involves reforming numerous practices at the "airshed" level. This strategy allows the government to combat emissions in urban, industrial, residential, energy, transportation, and agricultural/rural sectors, all of which significantly contribute to deteriorating ambient air quality across broad geographical expanses. In India, like in most other parts for Asia, a major component of PM2.5 also arises from "secondary" emissions, resulting from the mixing of gases from diverse sources to create PM2.5 particles (Figure 1). These particles then disperse far from their original sources, often crossing city and district boundaries. Nearly half of the PM2.5 emissions affecting Indian urban areas are classified as secondary particulate matter (PM), illustrating the sub-regional, national, and at times, international scale of the air pollution challenge faced by certain Indian states.

Ambient $PM_{2.5}$ Exposure: A Growing Burden

Air pollution is the largest environmental risk factor for public health and ecosystems. Exposure to fine particulate matter (PM2.5) in ambient air, which is particularly high in the IGP (Figure 2), is a key driver of the deleterious health effects of air pollution. There is strong scientific evidence on the public health burden of PM2.5 attributable to long-term exposure to

FIGURE 2: PM2.5 CONCENTRATIONS IN SOUTH ASIA, 2020

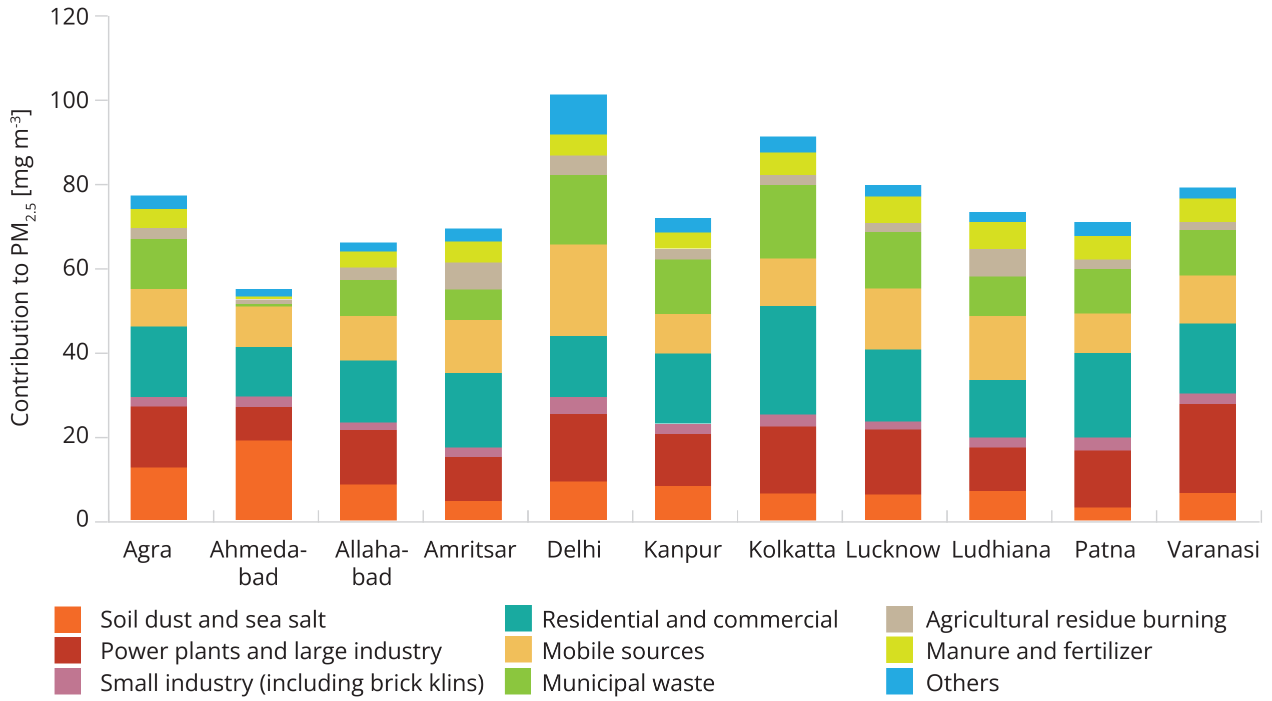


PM2.5 including ischemic heart disease, lung cancer, chronic obstructive pulmonary disease (COPD), lower-respiratory infections (such as pneumonia), stroke, type 2 diabetes, and adverse birth outcomes, amongst others. Air pollution is projected to account for 2.1 million premature deaths in 2030 in five South Asian countries alone, including Bangladesh, India, Nepal, Pakistan, and Sri Lanka[1]. Deaths attributed to PM2.5 account for a significant fraction of total deaths in each country: 20 percent in Bangladesh, 15 percent in India, 18 percent in Nepal, 17 percent in Pakistan, and 11 percent in Sri Lanka.

Like with other states in the Indo-Gangetic Plain, UP's entire population is exposed to ambient particulate matter and in certain locations up to 20 times higher (around 100 µg/m³). With rapid economic growth to meet the needs of a burgeoning population, it is facing a unique and urgent development concern because of deteriorating air quality due to its widespread transboundary health impacts. Apart from adverse health outcomes, there is burgeoning evidence that air pollution also adversely impacts affects yield productivity in its agriculture sector loss to India's Gross Domestic Product (GDP) from

[1] World Bank report "Striving for Clean Air in South Asia" (World Bank 2023a)

FIGURE 3: SPATIAL ORIGIN OF POPULATION-WEIGHTED FINE PARTICULATE MATTER EXPOSURE IN CITIES IN IGP, 2018



Source: Calculations using GAINS-IGP model developed by the International Institute for Applied Systems Analysis, in collaboration with IIT-Delhi (World Bank 2023a).

premature deaths, worker productivity[2], and solar power generation output[3,4].

Finally, air pollution and climate change are also closely linked; policies and programs to improve air quality will bring significant co-benefits for climate change mitigation and will contribute to India's net-zero targets. In several sectors, the sources that generate the local pollutants that contribute to poor air quality, such as particulate matter (PPM2.5 PM2.5) and such gasses as sulfur dioxide (SO2), nitrogen oxides (NOx), and ammonia (NH3), are often the same sources that generate greenhouse gasses (GHGs) such as carbon dioxide and short-lived climate pollutants like black carbon (part of PM2.5) and methane (CH4). Hence, air pollution reduction can generate important climate co-benefits by reducing GHGs along such air pollutants as PM2.5 (driving reductions of both primary and secondary PM reductions through reactions of SO23 with SO2 or NOx) and ground-level ozone (mostly driving CH4 reductions).

National Initiatives to Tackle Air Pollution

India is committed to create a clean environment. The commitments and obligations to environmental conservation and protection within the ambit of the targeted goals on environmental sustainability under the Sustainable Development Goals (SDGs) is manifested in several administrative and regulatory measures, including a separate statute on air pollution that have been under implementation since long.

---

2 Impact of air pollution on labor productivity: Evidence from prison factory data. https://www.sciencedirect.com/science/article/pii/S2666933121000216#bbib7

3 Large Reductions in Solar Energy Production Due to Dust and Particulate Air Pollution https://pubs.acs.org/doi/10.1021/acs.estlett.7b00197

4 Cleaner air would enhance India's annual solar energy production by 6–28 TWh. https://iopscience.iop.org/article/10.1088/1748-9326/ac5d9a/pdf

There is a strong legal and regulatory framework to address air pollution in the country. The Air (Prevention and Control of Pollution) Act (the "Air Act"), enacted in 1981 (amended in 1987), the Environment (Protection) Act (EPA) (1986), and the National Clean Air Program (NCAP) provide the legislative and strategic underpinning for India's Air Quality Management (AQM) policies and programs. The Central Pollution Control Board (CPCB) at the national level and the State Pollution Control Boards (SPCB) at the state level are statutory bodies whose roles and responsibilities are outlined by the Air Act overseeing the implementation of the AQM policies and programs.

In January 2019, the Government of India (GoI) took steps to prioritize air quality within the country. NCAP, launched by the Ministry of Environment, Forest, and Climate Change (MoEF&CC), brought several initiatives together with a concentrated focus on air pollution management. Since the establishment of NCAP, GoI has continued to strengthen its air quality management governance. Linking in relevant national missions and other sector policies and programs, the NCAP consolidates fragmented AQM efforts into one national program with an ambitious goal. Initially, the program set for first time in India a timebound target of reducing key air pollutants PM10 and PM2.5 by 20-30 percent in 2024 taking the pollution levels in 2017 as the base year. In 2023, NCAP was strengthened with the goal of achieving a reduction of up to 40 percent or – in certain cases - meeting the National Ambient Air Quality Standards (NAAQS) for PM10 concentrations by 2025-26. 82 cities under NCAP have been provided annual target of 3-15 percent reduction of PM10 levels to achieve overall reduction of air quality up to 40 percent PM10 levels. It is currently focused on 131 NACs where air pollution standards are not being met; all NACs have been asked to prepare air quality action plans to achieve air quality standards and to meet targets of NCAP. It is worth noting that the NCAP framework also encourages the formulation of regional and transboundary plan for effective control of pollution, more specifically with reference to the Indo-Gangetic Plain region (IGP).

In 2020, the government's 15th Finance Commission (XVFC) allocated INR 12,139 crores (1.6 billion US$) in performance based fiscal transfers to India's 49 cities with a population over 1 million to fight air pollution over 5 years (2021-26). 49 cities under 15th Finance Commission air quality grant, have been given an annual target of 15 percent reduction in annual average PM10 concentrations and improvement of good air quality days (Air Quality Index < 200). Sixteen (about 40 percent) of these mega-cities are in the IGP region with seven in Uttar Pradesh. Subsequently, in August 2021, a law has established the Commission for AQM for the National Capital Region and NCR and adjoining areas (CAQM) to handle different aspects of poor air quality for Delhi and 5 surrounding states and urban territories which includes parts of Uttar Pradesh (Ghaziabad, Gautam Buddha Nagar and Baghpat). This put into effect India's first multi-sector, multi-jurisdictional airshed approach to tackle pollution.

Finally, various initiatives and schemes have been launched by the Government of India (GoI) which have strong co-benefits for improving air quality. These initiatives span across different sectors and include measures including (not limited to): (i) tightening vehicular emission and fuel quality standards, (ii) promoting electric vehicles through incentives, (iii) implementing emissions standards for industries, (iv) regulating the use of pet coke and furnace oil, (v) adopting cleaner technologies in various industries, (vi) establishing air quality early warning systems, (vii) promoting energy efficiency, (viii) providing LPG for cooking through Pradhan Mantri Ujjwala Yojana (PMUY), (ix) encouraging sustainable transportation alternatives, (x) promoting the production and usage of Compressed Bio Gas (CBG) through the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme, (xi) promoting cleanliness through the Swachh Bharat Mission, and (xii) implementing measures for better waste management and agricultural practices. These efforts are intended to mitigate air pollution and enhance overall air quality (ref. Table 1).

TABLE 1: CENTRAL GOVERNMENT INITIATIVES TAKEN TO COMBAT AIR POLLUTION

Vehicular Pollution Control

- Leapfrogging from BS-IV to BS-VI norms for fuel and vehicles since April 2020.
- Network of Metro rails for public transport is enhanced and more cities are covered.
- Development of Expressway and Highways are also reducing fuel consumption and pollution.

- Introduction of cleaner/alternate fuels like CNG, LPG, ethanol blending in petrol.
- Faster Adoption and Manufacturing of Electric Vehicles (FAME) -2 scheme has been rolled out
- Permit requirement for electric vehicles has been exempted.
- Promotion of public transport and improvements in roads and building of more bridges to ease congestion on roads.

Industrial Pollution Control

- Stringent emission norms for Coal based Thermal Power Plants (TPPs).
- Pet coke and furnace oil have been banned as fuel in Delhi and NCR States.
- Industrial units shifting to PNG.
- Installation of on-line continuous monitoring devices in highly polluting industries.
- Shifting of Brick kilns to zig-zag technology for reduction of pollution.

Waste Management

- Notifications of 6 waste management rules covering solid waste, plastic waste, e-waste, bio-medical waste, C&D waste and hazardous waste.
- Setting up infrastructure such as waste processing plants.
- Extended Producer Responsibility (EPR) for plastic and e-waste management.
- Ban on burning of biomass/garbage.

Crop Residue Management

- Under Central Sector Scheme on 'Promotion of Agricultural Mechanization for in-situ management of Crop Residue in the States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi', agricultural machines and equipment for in-situ crop residue management are promoted with 50 percent subsidy to the individual farmers and 80 percent subsidy for establishment of Custom Hiring Centers.

Monitoring of Air Quality

- Expansion of air quality monitoring network under National Air Quality Monitoring Program (NAMP).
- Implementation of Air Quality Early Warning System for Delhi. The system provides alerts for taking timely actions.

Moving from City to Airshed-focused Air Quality Management

National initiatives such as the XVFC program for larger cities and NCAP for smaller non-attainment cities have been critical in advancing AQM. However, it is acknowledged by both National authorities (MoEFCC) and state authorities (like UP) that further air quality improvements require AQM management across larger airsheds like throughout the IGP. In the IGP, UP has been in the forefront of advocating for airshed management, emphasizing that a large share of the air pollution concentrations originates outside cities and even outside the state borders (up to 50 to 60 percent of the sources).

It has also been acknowledged that ambient air quality can be very polluted in rural areas as well, and in some cases reach similar concentration levels as in the cities.

UP is the largest state in India (in terms of population) with over 230 million inhabitants and is situated in the heart of the IGP region. The state is more populous than any other state/province in South Asia and worldwide. UP consists of 75 districts and 312 sub-districts with 17 percent of India's total population spread over a geographic area of 243,290 sq. km.

The quality of air has remained dangerously poor in many parts of the IGP region, including in Uttar Pradesh. Ambient air pollution in UP is significantly influenced by its location in the center of the IGP region. Nestled between the Himalayas bordering on the north and smaller Vindhya Range and plateau region in the south, the state experiences high aerosol load of both primary and secondary PM. Additionally, it also faces high seasonal fluctuations in air quality from summer through the late- monsoon and winter seasons. In the winter season, the cold air frequently settles over the state and gets trapped under a layer of warm air. Due to this temperature inversion, pollution builds in the cold air throughout the inversion.

Hence, due to often poor pollution dispersion conditions (low wind speeds and shallow atmospheric boundary layers) and a high population density, the state experiences not only city-wide but high regional air pollution as described in the World Bank report "Striving for Clean Air in South Asia" (World Bank 2023a), the state becomes part of the IGP-wide airshed including neighboring states Delhi, Haryana, Punjab, and Bihar.

Despite certain air quality improvements over the last years, fifteen of UP's NACs are among those with the higher levels of air pollution in India, often more than twice and up to four times of India's current air quality standards for PM10 and PM2.5 (60 and 40 µg/m3, as annual averages)[5].

Considering both concentrations and exposure to PM in air

The NCAP program focuses on concentrations of PM10 and PM2.5 in the air and sets targets for their reduction, where the assessment of target fulfilment is based upon the concentrations of PM measured at the designated monitoring stations in urban areas. This accords with what have been and still is a common practice around the World.

At the same time, worldwide epidemiological evidence indicates that **long-term population exposure to PM2.5** is the most powerful predictor for adverse health impacts by considering the entire population of the area in question, such as in the whole of UP.

Whereas monitored concentrations represent the spatial point where the monitoring station is located, the exposure metric considers the average of concentrations across the entire area. The metric is calculated as the product of PM concentration and the population number in

[5] It is understood that India is in the process of revising its air quality standards by tightening the annual PM2.5 standard to 35 µg/m^3 (ref. The Economic Times "Panel Suggests Improving 2009 Air Quality Standards").

each of the network grids covering the area, then it averages across all grids. This is made possible using air quality models. The exposure to PM that the entire population experiences is covered by this metric, thus considering the health aspects of air pollution of the whole population.

The Uttar Pradesh Clean Air Plan (UCAP)

An airshed-based AQM approach along with a focus on developing state-level air quality action plans needs to be adopted to complement actions initiated under the NCAP, 15th Finance Commission and various national and state programmes. While the government has taken many steps to improve India's air quality in general and in IGP specifically, the current AQM planning framework continues to be limited:

1. **Sources within a city's administrative boundary may account for limited proportion of the pollution impacting it, while substantive air pollution sources may come from regional sources** Hence, there is a need for AQM planning at a multi-jurisdictional and multi-sector scale. It is critical to formulate a state plan to become the basis for not only city-wide but state level collaboration. Current City Air action plans (CAAPs) can be integrated into the larger state-wide plan for Uttar Pradesh. Hence, there is a need for AQM planning at a multi-jurisdictional and multi-sector scale. It is critical to formulate a state plan to become the basis for not only city-wide but state level collaboration. Current City Air action plans (CAAPs) can be integrated into the larger state-wide plan for Uttar Pradesh.

2. Second, there is a need **to formalize a multi sector dialogue for sequenced prioritization of** actions and enable optimized funding across various departmental levels in the state.

3. Third, **the financial resources available for clean air actions are quite significant but fragmented**. There is a need to deploy a comprehensive financing strategy to leverage existing funding channels (15th Finance Commission air grants, National Clean Air Program (NCAP) funds, central and state funding schemes, etc.) and explore funding gaps to design a strategic investment framework.

The Central Pollution Control Board (CPCB) in spring 2024 has updated its "Guidelines for Formulation of State Action Plans" (SAPs) recognizing the important role of States for executing air quality management actions and policies to address the persistent public health challenge of air pollution. These guidelines promote holistic and integrated air quality management policies based on strong scientific insights derived through data analysis, the identification and prioritization of sources to help define actions and policies, utility of SAPs to help set pathways and achieve targets through enforcement, monitoring, and incentives, and execution of clear governance arrangements under the National Clean Air Program. UCAP is pioneering India's first SAP aligned with this new vision that calls for a more comprehensive state plan based on a comprehensive state emissions inventory inclusive of all urban and rural areas and sources to help integrate and synergize actions at the national, regional airshed (IGP in this case), state, and local levels.

The guidelines also suggest state plans should identify necessary policy changes including for the convergence of activities with various ongoing programs and schemes and provide an indicative template of items to include while suggesting state should tailor the SAP to its specific situation and conditions. In this context, UCAP provides an early model of the scientific rigor possible to inform airshed based planning especially through application of the GAIN-IGPs modelling tool to help UP also work in collaboration with other states of the same IGP airshed to analyze, understand and prioritize interactions and benefits of working on common measures better. UCAP as an early mover will be a "living" SAP that will be reviewed and updated regularly. A World Bank supported Clean Air Management Program (UP-CAMP) will be implemented in parallel during its first six years to support the priority actions and set pathways for the states ongoing implementation of UCAP.

Strategic Objectives of UCAP

The GoUP's Department of Environment, Forest, and Climate Change is spearheading India's first state-level strategy – The Uttar Pradesh Clean Air Plan (UCAP) – to ensure cleaner air, emphasizing the adoption of an airshed approach in planning and implementing measures for air quality improvement.

The strategic objectives of the UCAP are:

1. To develop pathways for achieving National Ambient Air Quality Standards (NAAQSs) in Uttar Pradesh.
2. To promote pilots and standard operation procedures (SOPs) for all relevant sectors that contribute to air pollution and particularly those sectors that have not been addressed adequately yet.
3. To align state level interventions with the objectives of the NCAP.

UCAP Development Process

The UCAP has been developed by the Department of Environment, Forest, and Climate Change (DoEF&CC), GoUP and Uttar Pradesh Pollution Control Board (UPPCB), with IIT Kanpur and the World Bank as the lead technical partners. On behalf of the DoEF&CC, a working group was created (led by the World Bank and IIT Kanpur) and comprised select AQM national/international organizations and experts. This working group was tasked with the conceptualization and overall development of the UCAP.

Members of the working group comprised the following institutions: World Bank, Indian Institute of Technology, Kanpur (IIT K), Indian Institute of Technology, Delhi (IIT D), Norwegian Institute for Air Research (NILU), French National Institute for Industrial Environment and Risks (INERIS), International Institute for Applied Systems Analysis (IIASA), and the National Environmental Engineering Research Institute (NEERI). Additional technical support was provided by The Energy Research Institute (TERI).

This report is based on extensive technical modelling outcomes incorporating global best practices with the aim of assisting Uttar Pradesh in achieving its clean air objectives.

Sector Prioritization

This report addresses the following aspects that emerge from the technical analyses conducted for the UCAP:

1. **Air Quality**: Characterization of the air quality throughout the state by analyzing and providing an overview of air quality monitoring systems through Continuous Ambient Air Quality Monitoring (CAAQM) and the National Manual Air Monitoring Program (NAMP) network covering entire State including Urban Agglomerations (UAs), Cities (both Non-Attainment Cities/NCAs and attainment cities) and in rural areas to understand both general air quality trends and status. The analysis of air quality is supported by and compared with satellite-based Aerosol Optical Depth (AOD) data.
2. **Air Pollution Sources:** Determination of varied sources throughout the state using GAINS-IGP modelling that determines both air pollution source sectors and geographic origin of the sources. The source sectors, represented geographically on state maps developed through UCAP, include large, small, and medium industrial emissions, power plants, vehicular pollution both from agricultural activities (fertilizer, livestock manure and crop residue burning), construction, and residential cooking and heating. Modelled results for UP are further compared with source apportionment results in selected cities. The approach allows for a targeted and data-driven strategy to mitigate air pollution in UP, facilitating informed decision-making for policymakers and environmental authorities to substantively

improve air quality and public health in the region.

3. **Priority Interventions:** Based on GAINS-IGP modelling, possible sector interventions are ranked by their potential reduction in PM2.5 exposure.

4. **Activities and Measures Matrix**: Based on a comparison of all source contributors and the PM2.5 reduction potentials for each measure, a comprehensive action matrix has been developed that go across both priority sectors[6] and already included measures in the current state air action plan (SAAP). By analyzing current SAAP and Central and State sector schemes and polices, current challenges and gaps in reaching targets and maximizing emission reduction in the sectors are outlined. Initial work outlines policy framework, key challenges, key interventions, institutional and implementation arrangement for the following sectors:

   i. Domestic and commercial sources (biomass burning).

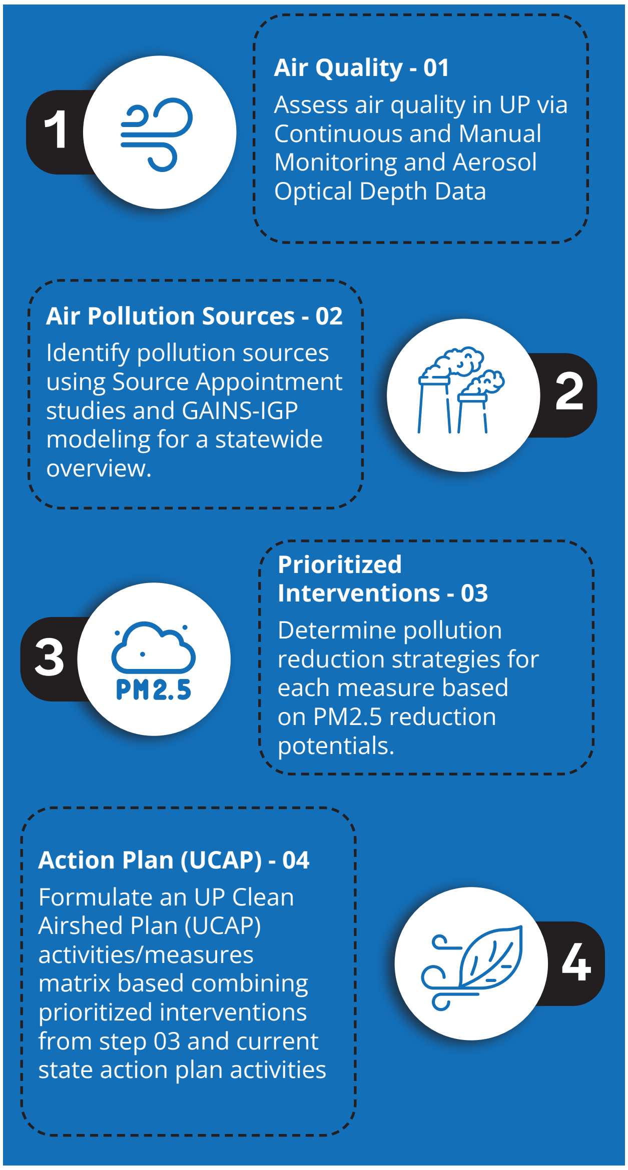
   ii. Agriculture (Fertilizer application and Livestock manure (both are ammonia sources), and crop residue burning.

   iii. Transport sector (mobiles sources and dust).

   iv. Industry (Medium and Small Industries (MSMEs), Large Industry and Power Plants).

   v. Waste burning.

FIGURE 4: STRUCTURE OF UTTAR PRADESH CLEAN AIR PLAN (UCAP)[7]



This report assesses the overall air quality of UP using data collected by continuous ambient air quality monitors and satellites (Chapter 3), quantifies the various sources of pollution that contribute to exposure of the UP population to PM2.5 (Chapter 4), and identifies priority measures that would enable effective improvements of air quality based on potential for reducing PM2.5 concentrations

[6] This analysis emphasizes key prioritized sectors. However, as the economy of any geographic area expands, the structure of sources and emissions at specific points might fluctuate across seasons and years. Future UCAP plans could encompass these changes.

[7] Cost effectiveness as part of component 3 is presented in annex 5. The request for identifying cost-effective measures" to improve air quality and public health are outlined in section 2.2. of CPCBs "Guidelines for Formulation of State Action Plan".

and outlines an activity and measures matrix that combines the existing state clean air plan and additional policies and measures (Chapter 5). As a way forward, using GAINS-IGP modelling “cost- effectiveness to the society” of the different activities is also attempted as a matter of preliminary exercise which needs to be customized for India in general and UP in particular before making any formal reference (Annex 5).

This UCAP structure (from executive summary to chapters 1-5) follows largely the recommended component structure in the CPCB “Guidelines for Formulation of State Action Plan” and the guiding principles (setting targets, achieving NAAQSs as a goal, development of action plan, involving institutions constituted under NCAP etc.) outlined in the guidelines.

APPROACH, METHODOLOGY AND DATA

The Airshed Management Approach

Based on the planning framework provided by the National Clean Air Program (NCAP), UP's focus on managing air quality has been primarily on its 17 non-attainment cities (NACs) within the NCAP. However, air pollution is a long-range and thereby often a transboundary phenomenon, not confined to administrative borders - it is transported throughout the region, based on wind directions and other meteorological and topographical characteristics. Thus, air quality in the cities is strongly affected by other emissions of the same airshed, i.e., from the surrounding semi- urban and rural areas, from other states and from other countries, where pollution is equally found to be above national and international air quality standards and deteriorating due to various sources[8].

An airshed is defined as a geographic area within which air pollution is freely and routinely transported and that is influenced by shared sources of pollutants, weather, and terrain.[9] The airshed management approach recognizes that poor air quality is often the result of the cumulative impact of a multitude of activities and emission sources (both regulated and unregulated) and that the situation is usually exacerbated by topographical as well as meteorological conditions which prevent pollutant dispersion.

The airshed management framework has been developed and applied around the world as a practical approach that helps to **understand the contributions of air pollution from within cities, from the surrounding region as well as from sources in other states and neighboring countries.** The framework brings together comprehensive regional and state level emission inventories and source apportionment studies based on state-of-the-art scientific and modelling methods and tools. It further emphasizes the use of cost-effectiveness analysis to prioritize a set of control measures that provide the highest pollution reduction benefit at the lowest cost.[10] It also highlights the role of effective coordination amongst local, regional, state, and federal authorities to determine pathways to effective regulatory and scientific cooperation across authorities and sectors. Evidence from across the world shows that urban areas such as the greater Los Angeles, Mexico City and Beijing areas that have used the airshed approach have seen significant reductions in priority pollutant emissions while simultaneously experiencing an increase in population and economic activities.

---

8 Prakash, J., Choudhary, S., Raliya, R., Chadha, T. S., Fang, J., & Biswas, P. (2021). Real-time source apportionment of fine particle inorganic and organic constituents at an urban site in Delhi city: An IoT-based approach. Atmospheric Pollution Research, 12(11), 101206.

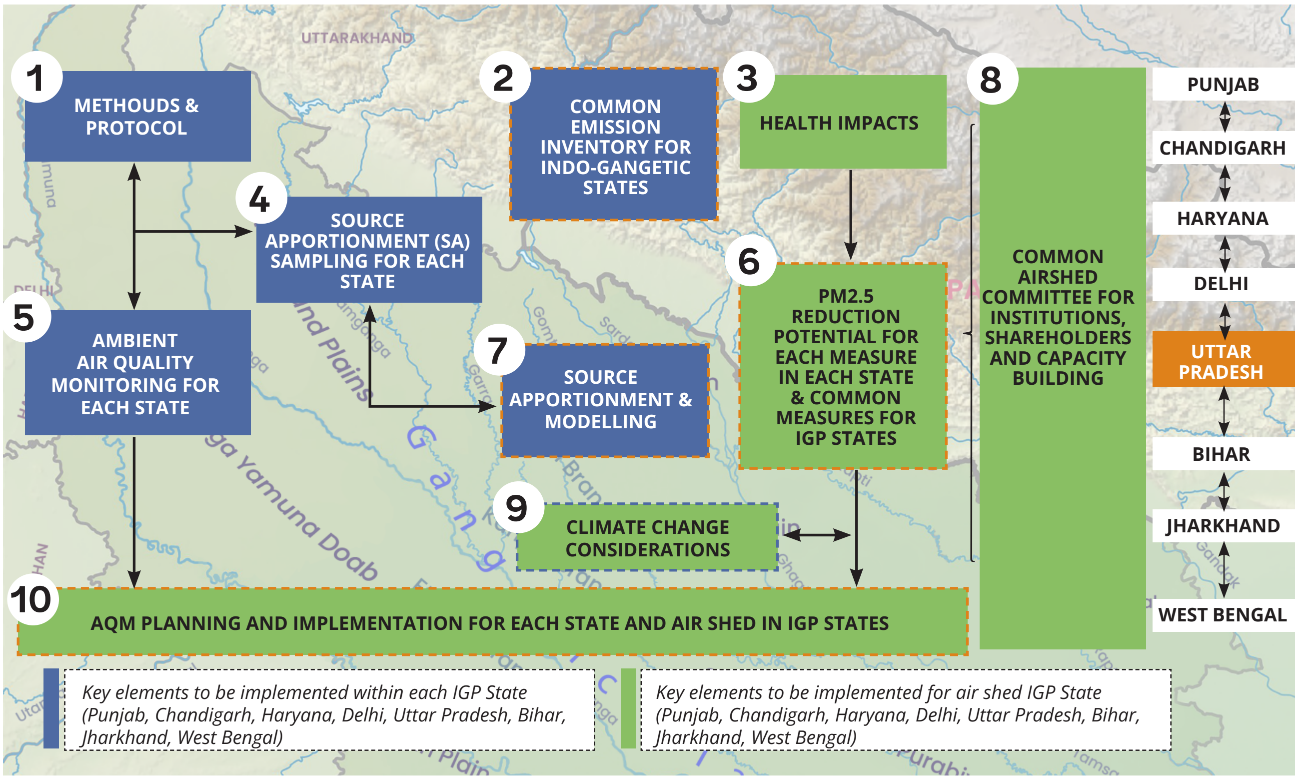
9 EPA, 2015. Identification of airsheds in India and South Asia overall have been further made in World Bank (2023a)

10 Pollution Management and Environmental Health Program (PMEH), The World Bank

The Airshed Approach of the Clean Air Program for UP

The preparation of the Uttar Pradesh Clean Air Program (UCAP) followed the airshed management framework (Figure 5). It assessed the overall air quality in UP based on observations obtained by the manual and continuous ambient air quality monitoring stations (CAAMS) and satellite data, developed emission inventories and source apportionments, quantified the potential exposure reductions that could be achieved by the various available measures in and outside UP, and examined priorities measures for implementation. To facilitate development of a multi-sector air quality management plan, consultation workshops were organized with stakeholders.

FIGURE 5: BUILDING BLOCKS OF THE AIRSHED MANAGEMENT FRAMEWORK FOR UP [11]



Note: The red line indicates the elements addressed in this report for UP.
Source: Pollution Management and Environmental Health Program (PMEH), The World Bank

The UCAP analysis focuses on fine particulate matter (PM2.5) as the primary pollutant of concern due to its overwhelming dominance over the health impacts from other pollutants. It examines the contributions that originate from the direct (primary) emissions of PM2.5 as well as from the chemical processes that generate (secondary) PM2.5 in the atmosphere, especially from the gaseous precursor emissions sulfur dioxide (SO2), nitrogen oxides (NOx), and ammonia (NH3). For each of these pollutants, the analysis identifies the sectoral origin as well as the locations where they are emitted and where they have impact on PM2.5 concentrations. Emissions of volatile organic compounds (VOCs) are considered, although they are not discussed in detail.

[11] For step 6, cost effectiveness considerations have been added in annex 5.

With a focus on public health, annual average population weighted exposure to PM2.5 in UP is adopted as the key metric for air quality. This indicator is chosen because it puts emphasis on long-term exposure - the greatest predictor of health impacts - and on regions where people live, hence where exposure takes place. Note that this is different from other frequently used air quality indicators, such as air quality standards expressed as the highest (annual mean or daily) concentration of PM2.5 measured at a monitoring site in the city (for example, next to an industrial complex or a busy street crossing). While the latter metric is practical for administrative and legal compliance purposes, it is poorly related to overall population exposure and the pollution burden on public health.

The technical analysis for this report assesses the current air quality in UP, combining data from ground level monitoring stations and the remote sensing of AOD. Data sources were made available by UP-PCB and CPCB.

Subsequently, the analysis examines how alternative clean air policy interventions could improve air quality and PM2.5 exposure in Uttar Pradesh in the next decade. This quantitative assessment employs the GAINS (Greenhouse gas – Air Pollution Interactions and Synergies) model, a well-established model framework tailored to the IGP in general and to UP in particular. Based on the available national and local statistics, this report estimates for 2020 the PM2.5 precursor emissions from all relevant sources that contribute to PM2.5 exposure in UP surrounding areas in the IGP. The GAINS model then calculates, for the base year 2020 the PM2.5 concentration distribution throughout UP, which is checked against the monitored concentrations, data from the CAAQMSs and from PM2.5 derived from satellite AOD data. With 2020 as the base year, it extrapolates emissions over 15 years to 2035 considering the likely impacts of economic and social development on the levels of emission generating activities as well as the effects of already implemented pollution control regulations. Subsequently, the analysis examines the air quality improvements in UP that could be achieved through implementation of about 1,100 different emission control options and identifies the source categories within and outside UP for which conceivable emission control measures could deliver the largest reductions in PM2.5 exposure in UP.

Finally, the model results inform the development of priority actions based upon their potential to reduce PM2.5 emissions that could deliver the largest air quality improvements in UP. Actions distinguish near-term priorities, especially those stated in the UP's existing state clean air plan (SCAP - 2020), and additional actions that emerge from the UCAP process, extending air quality management in UP to a wider and more comprehensive airshed approach.

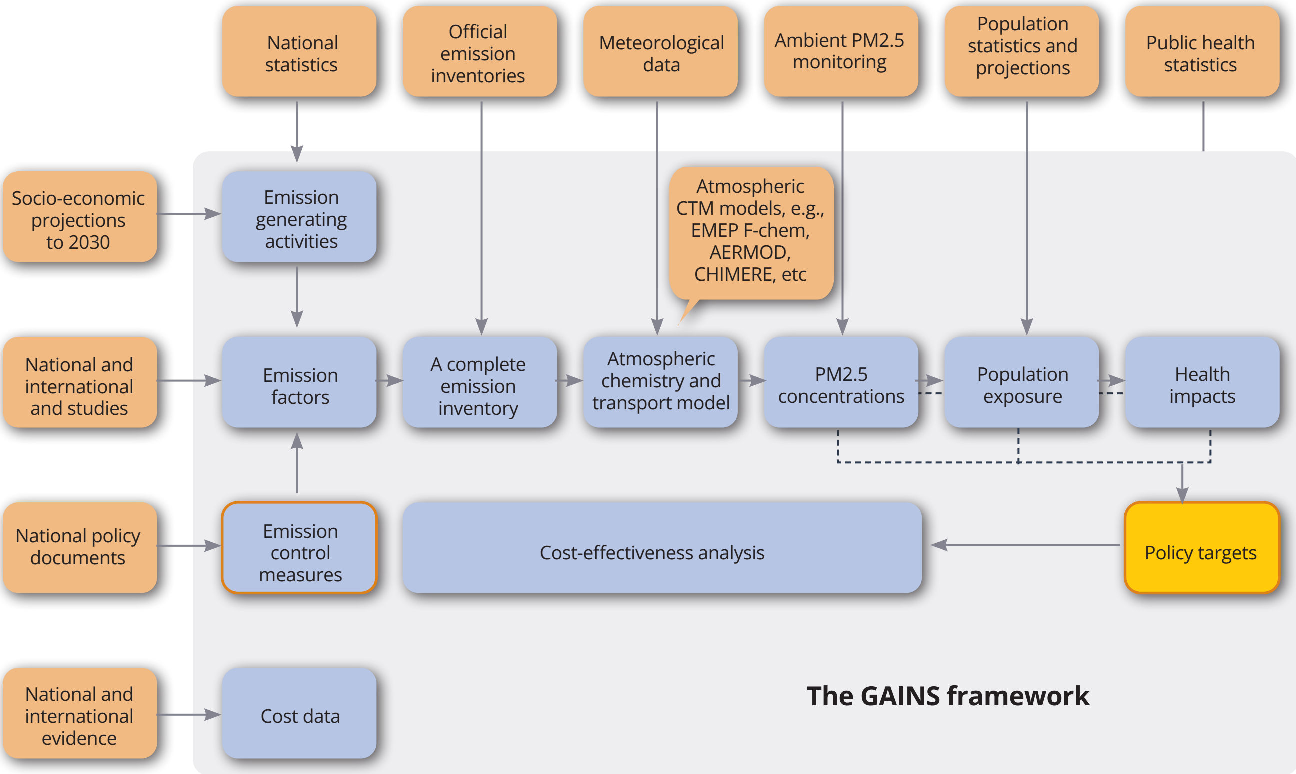
The GAINS modelling tool

To provide airshed management with a good understanding of where pollution is currently coming from and how pollution can be reduced most effectively in the future, the UCAP analysis employs the well-established GAINS-IGP model framework that has been tailored to the IGP.

The GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model (Amann et al. 2011), developed by the International Institute for Applied Systems Analysis (IIASA) and tailored to IGP together with IIT-Delhi, explores the (cost-) effectiveness of policy interventions to reduce population exposure to pollution and/or of greenhouse gas emissions (Figure 6). Building on robust scientific understanding and quality-controlled local data, GAINS analyses have informed decision makers and stakeholders in the selection of measures that delivered the effective air quality improvements in, inter alia, China, South Africa, Vietnam, the European Union, and the parties to the Convention on Long-range Transboundary Air Pollution (LRTAP).

For the UCAP, a regional version of the GAINS model for the Indo-Gangetic Plain (IGP) region of India was adapted for the state of UP (the GAINS-IGP model). Starting from an implementation of the GAINS model for the

FIGURE 6: INFORMATION FLOW IN THE GAINS-IGP MODEL ANALYSIS[12]



Source: International Institute for Applied Systems Analysis (IIASA)

South Asia that has been developed by IIASA for the World Bank report on airshed management in the South Asia (World Bank 2023a), the Indian Institute of Technology – Delhi (IIT-Delhi) has updated and fine-tuned the input data for the state of UP and the other IGP states based on present published statistics and other data sources.

The GAINS-IGP model quantifies the spatial distribution of observed pollution concentrations in ambient air by bringing together information on the sources of emissions and their socio- economic drivers with advanced modelling of atmospheric chemistry and transport of pollution (the blue boxes in Figure 6). Based on given projections of future economic, energy and agricultural development, GAINS-IGP then determines for each source the future improvements in air quality and population exposure that are offered by, in the case of IGP state, 1,100 proven emission control options and the costs that would occur to the overall economy of, for example, UP. To inform decision making about the cost-effectiveness of alternative policy intervention options, GAINS-IGP explores cooperative multi-sectoral portfolios of measures that achieve given air quality and/or climate policy targets at least cost to the economy (the red box(es) in Figure 6). A host of local statistics, measurement data and policy documents are used to compile the input data to the GAINS-IGP model that enable a reliable localized application for UP (the orange boxes in Figure 6).

Emission estimates

The GAINS-IGP model[13] distinguishes about 400 emission source categories, for which it estimates the annual emissions of primary PM2.5, and the precursor emissions that

[12] Cost-effectiveness analysis is presented in annex 5.
[13] http://gains.iiasa.ac.at

generate secondary PM2.5 in ambient air. It estimates the precursor emissions that are responsible for PM2.5 in ambient air (i.e., primary PM2.5, sulfur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3) and volatile organic compounds (VOC) and the six Kyoto greenhouse gases. For each source category *i* and year, annual emissions of pollutant *p* are estimated considering activity levels (*act*), (uncontrolled) emission factors[14] (*emfact*), as well as the removal efficiencies (*effm,p*) and application shares *appm* of a control measure *m*.

$$em_{i,p} = \sum_m act_i * emfact_{i,p} * (1 - eff_{m,p}) * app_m$$

~ (Equation 1)

Activity rates *acti* (i.e., the quantities of emission-generating activities) are derived from relevant local statistics or, if unavailable, estimated based on experience from other countries/states with comparable conditions. Emission factors *emfacti,p* are primarily derived from local measurements that are deemed representative for the specific sources in the region (i.e., in South Asian countries), and local emission inventories to the extent they are available. The plausibility of local data robustness is validated with international literature. In total, GAINS-IGP considers about 1,100 proven emission control options *m*, for which the emission removal efficiencies are derived from world-wide literature considering the local conditions in UP. Application rates *appm* reflect the share of total activities to which a given measure *m* is applied at a given time.

Total emissions of a given source category in an administrative unit are spatially distributed based on statistics for large point sources and using appropriate surrogate data for distributed sources (e.g., maps of population distribution, road networks, land-use data, agricultural statistics). Region-specific diurnal and seasonal time profiles as well as the heights at which emissions occur are considered for the emissions of each source category.

The potentials for emission and exposure reductions in the future

Based on given projections of future economic, energy and agricultural development, GAINS- IGP then determines for each source likely future emissions of PM2.5 precursors, their impact on PM2.5 concentrations in ambient air and how this affects population exposure in the IGP. On this basis, the potential improvements in air quality and population exposure that are offered by the referred 1,100 proven emission control options in IGP are then estimated. Emission removal efficiencies of the control options are derived from world-wide literature considering the local conditions in UP, and for each measure a maximum application potential is defined that reflects local circumstances, such as the applicability of measures to large or small sources, the possibilities of retrofitting existing installations, and social constraints. Thereby, for each of the available emission control measures, their simultaneous impact on the various precursor emission substances is quantified and the consequences on PM2.5 concentrations in ambient air and resulting population exposure throughout the IGP is estimated. In addition, as a futuristic approach, initial work on the cost effectiveness concept for emission control measures is described in Annex 5 which needs to be further validated.

PM2.5 concentrations and population exposure

With the resulting emission fields of all PM2.5 precursor emissions, annual mean concentrations of PM2.5 in ambient air are computed at a 10 km x 10 km spatial resolution throughout South Asia. The GAINS-IGP model uses reduced-form source-receptor relationships that have been derived from the European Monitoring and Evaluation Program

[14] Hypothetical emission factor without any emission control measure

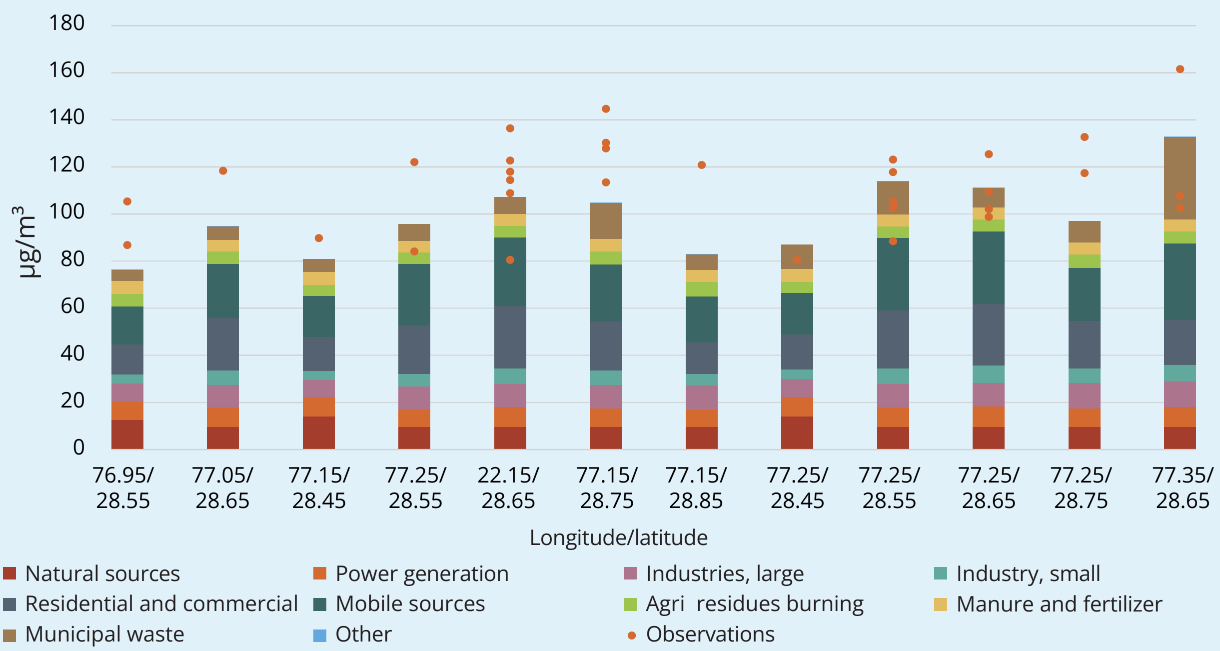
(EMEP) atmospheric chemistry-transport model distinguishing the release heights of the different emission sources. (Simpson et al.,2012). The underlying computations of the full EMEP model have been performed at hourly time steps for the full year, employing the meteorological conditions in the IGP of 2018 and considering for all emission sources the characteristic seasonal and diurnal time patterns. The chemical formation and atmospheric transport of secondary PM2.5 in ambient air from the emissions of the relevant precursor emissions (i.e., SO2, NOx, NH3 and VOC) are modelled with a $0.5^0 \times 0.5^0$ longitude–latitude resolution (Kiesewetter et al. 2015).

Although public attention and legislative air quality management focuses on episodic concentration peaks at pollution hot spots, worldwide epidemiological evidence indicates long-term exposure to PM2.5 as the most powerful predictor for adverse health impacts. With a focus on public health, hourly results are aggregated to annual mean concentrations as the most relevant metric associated with public health impacts. Also, to facilitate air quality management at the airshed level, ambient concentrations occurring in the target region (i.e., Uttar Pradesh) are aggregated to a population exposure metric, computed as

Box 1. To inform efforts to protect public health in an economically effective way, this report employs as the central metric the annual average population-weighted mean exposure to ambient PM2.5. However, it should be noted that mean population exposure is lower than the highest concentrations measured at hot spots, which are relevant for establishing compliance with ambient air quality standards (Figure 7b).

This report computes grid average PM2.5 concentrations throughout the model domain with a 10 km × 10 km spatial resolution. These can be compared with monitoring data for the various monitoring stations (Figure 7b) and combined with population statistics to compute the mean population exposure for each grid cell. With these data, the mean population exposure over the entire population in an administrative region can be computed.

FIGURE 6A: MODELLED AVERAGE PM2.5 CONCENTRATIONS FOR THE 10 KM × 10 KM GRID CELLS OF DELHI** AND ESTIMATED SECTORAL SOURCE CONTRIBUTIONS), COMPARED WITH RESULTS FROM THE MONITORING STATIONS THAT ARE LOCATED WITHIN THE GRID CELLS.



***Note: There are not sufficient monitoring stations in UP cities for a similar analysis* a sum of the products of grid average PM2.5 concentrations and population in the grid cell. (Box 1).

The GAINS-IGP model

The GAINS-IGP analysis for the UCAP builds on a regional version of the GAINS model which has been originally developed by the International Institute for Applied Systems Analysis (IIASA) for the World Bank report on airshed management in the South Asia region (World Bank 2023). Subsequently, this model was further adjusted by the Indian Institute of Technology – Delhi (IIT-Delhi) to the six states of the IGP, i.e., Bengal, Bihar, Haryana, Jharkhand, Punjab, UP as well as Delhi city (defined as the GAINS-IGP model[15]). The PM2.5 emissions inventory was established using local statistics, measurements, and emission factors, considered representative for South Asia, India, and specifically Uttar Pradesh. Data analysis ranged from 2019 to 2020, with occasional references to 2018 data in special cases, as outlined in Annex 2. For instance, for assessing cooking energy demand, household fuel use pattern is taken from MoSPI (2018), being the latest available data at the time of analysis. The availability of data at the required granularity necessitated certain assumptions. Further details on data sources by sector in Uttar Pradesh are available in Annexes 2 and 3.

As part of this validation process, TERI carried out an extensive assessment of the GAINS-IGP database on activity statistics, measures for controlling emissions, and the emission inventory pertaining to the base year 2020. TERI recommended further enhancements in line with the most up-to-date publicly available information. Subsequently, GAINS-IGP activities, including fuel consumption in the transport (MoPNG, 2022) and industry (MoSPI, 2021) sectors, and efficiency of cookstoves were updated. Data concerning road dust emissions was revised using data from CPCB (2022).

The modeling teams presented the Working Group (WG) with GAINS-IGP activity data, projections, and the penetration of control strategies, both at the sectoral and sub-sectoral levels. The experts of the WG were also given information regarding methodology, data sources, and key assumptions. Considering the inputs and data shared by the WG, specific adjustments were made to the activity data for Uttar Pradesh. These refinements were associated with various sectors and involved updating factors such as the count of brick kilns and their annual brick production, waste generation in both rural and urban areas, fertilizer consumption, and the use of bagasse in sugar mills. Furthermore, the implementation of emission control measures was aligned with the insights provided by the experts of the WG. Further details on data sources by sector in Uttar Pradesh are available in Annexes 2 and 3.

The updates in UP input data of the GAINS-IGP model led to some changes in the source contributions of the various emission categories to PM2.5 concentrations and exposure (Figure 8):

- The agricultural contributions to PM2.5 concentrations (from fertilizer, livestock manure and crop residue burning) increased due to (i) higher fertilizer use and a larger livestock population compared with original data.
- Substantive reduction in the emissions of burning of municipal solid waste due to a rather low average consumption figure for UPs population (around ½ kg per day).
- An increase in contribution from road transport sources due to higher fuel consumption estimates for both heavy duty vehicles and light duty vehicles.
- Lower contributions from household cooking due to an estimated increase in the uptake of LPGs by 2020 (implying a slightly lower number of households using traditional cookstoves).

[15] See: https://gains.iiasa.ac.at/gains/IGP/index.login?logout=1&switch_version=v0

- An increase in the contributions from MSME industries due to higher fuel consumption data particularly in the brick kiln sector and due to a higher number of non-converted brick kiln manufactures than earlier anticipated.

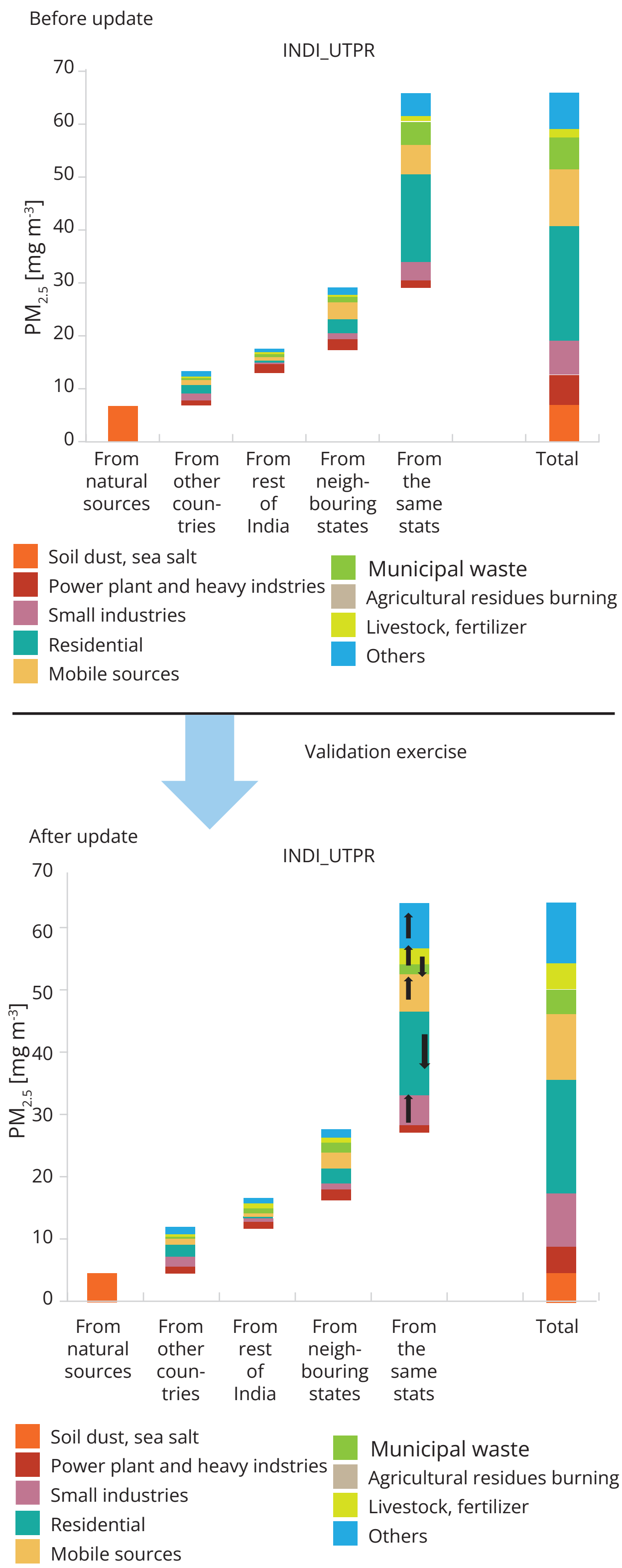
As a result, the modeling framework is fine-tuned to the best available data for UP for the base year 2020. These estimates serve as input for simulating ambient PM2.5 concentrations in 2020. The accuracy of these simulations is confirmed by comparing them to data from ambient PM2.5 monitoring (see above). As for future years, such as 2030 and 2035 in this report, activity data is projected using specialized sector-specific models, like those for energy, agriculture, waste, and transportation. Further details are provided in Chapter 4 of the report. The modeling of future emission control measures incorporates all policies that were put into effect up to the year 2020 (Chapter 5 and part of Annexes 2 and 3).

Model validation of PM2.5 concentrations

Based on the emission inventory that has been developed jointly with international and Indian experts and considering the emissions from outside sources, the GAINS-IGP model computes for 2020 a population weighted average PM2.5concentration of about 66 ug/m³ in Uttar Pradesh (see Chapter 3). However, there are discussions among experts about the accuracy and completeness of the estimated emission inventory, *inter alia*, about emissions from the waste sector, especially whether informal waste management in rural areas is fully accounted for (see section below about data input). The waste sector in fact could contribute something like 5 μg/m³ higher concentrations than what is now in the model. If that is the case, that would bring the GAINS-IGPPM2.5average up to about 71 ug/m³.

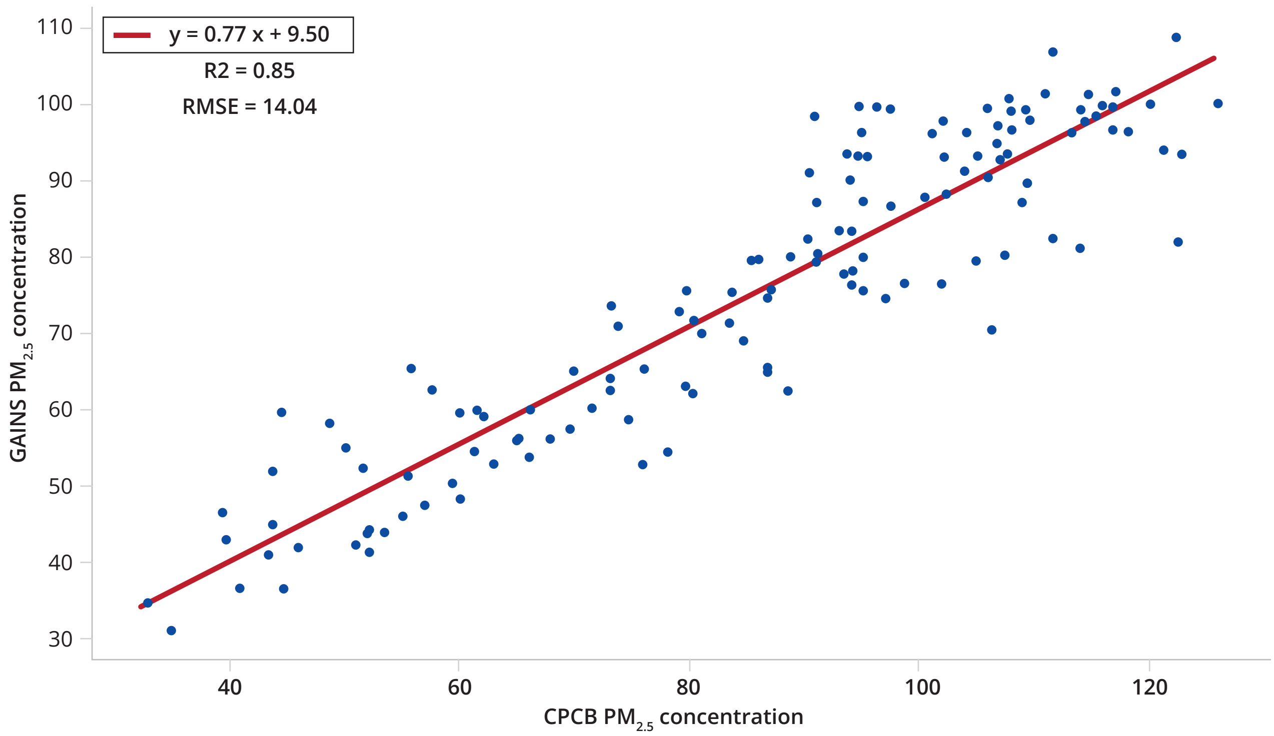
Observed PM2.5 values from 104 continuous ambient air quality monitoring stations and 37 manual stations in the IGP region provided by India Central Pollution Control Board's (CPCBs) data portal PM2.5 concentrations

FIGURE 7: THE RESULT FROM UPDATING THE GAINS-IGP DATABASE FOR UP IN BASELINE YEAR 2020



have been compared with grid-average PM2.5 concentrations computed with the GAINS-IGP model for the 10x10 km grid cells. The resulting R^2 value of 0.84 demonstrates a

FIGURE 8: VALIDATION OF ANNUAL MEAN PM2.5 CONCENTRATIONS OBSERVED IN 2020 AT SPECIFIC LOCATIONS IN THE IGP AGAINST MODELLED PM2.5 CONCENTRATIONS IN THE SURROUNDING 10X10 KM GRID CELLS.



Data source: IIT-Delhi, CPCB data 2023

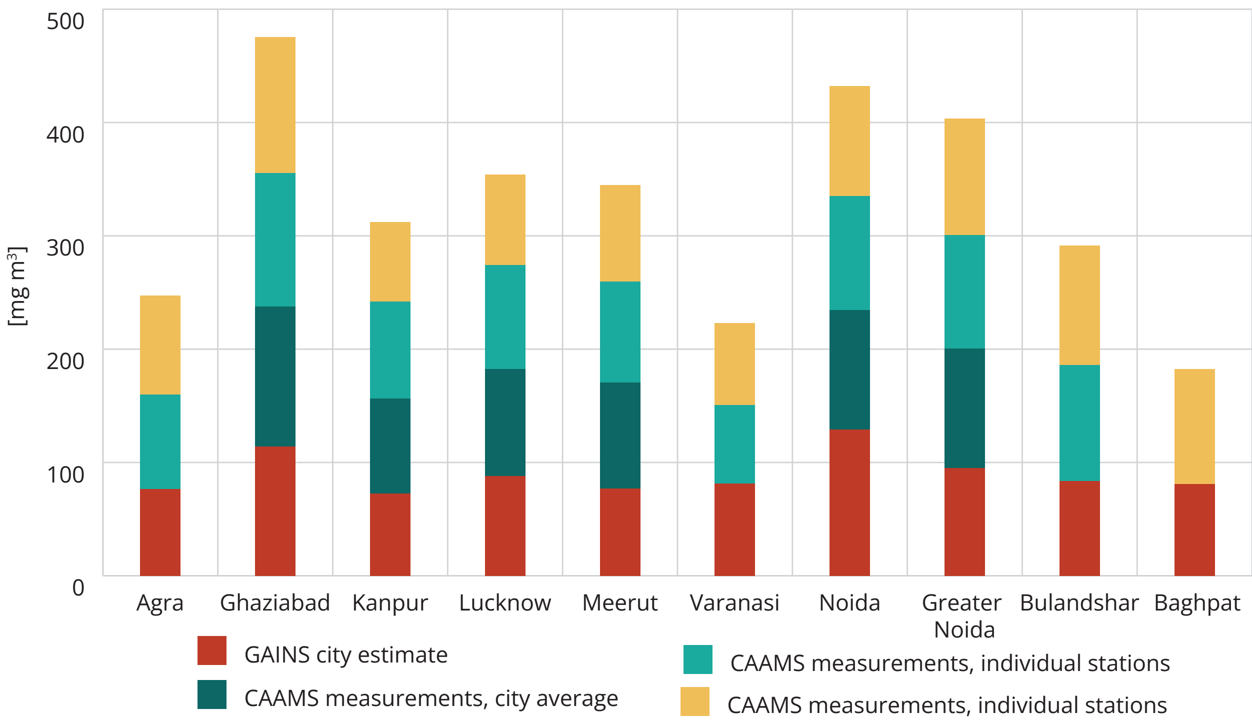
high degree of correlation between modelled and observed PM2.5 data, given the prevailing genuine uncertainties in modelling and observations The regression coefficient of 0.77 (less than 1:1) reflects that the GAINS-IGP modeled concentrations represent the average concentration in 10 km x10 km grid cells (which does include the urban zones where the monitoring stations are located), while the observations in this case represent concentrations at continuously monitoring air quality stations (CAAMS). These represent local point measurements in urban areas, sometimes hotspot locations in streets, sometimes less exposed but still urban locations, such as in residential areas. The computed values for 10 km x10 km grid cells are 23 percent lower than measurements at urban spot values is to be expected.

A special validation for Uttar Pradesh has compared annual mean PM2.5 concentrations measured in 2020/2021 at 25 CAAMS stations in 13 cities with GAINS-IGP estimates. Model results have been adjusted for local concentrations increments within 10 km x10 km grid cells that are caused by the local emissions of transport and residential sources at the sub-grid scale. For cities with sufficient monitoring data, there is a remarkable fit of the population-weighted concentrations computed by the GAINS-IGP model and the range of CAAMS observations of the various monitoring sites (Figure 10). Disagreements for individual cities are likely to be caused by the uncertainties of local emission inventories (e.g., missing industrial locations) or by the paucity of representative monitoring sites.

A comparison of GAINS-IGP results of PM2.5 concentrations with the PM2.5 estimates derived from the aerosol optical depth (AOD) observations from satellite data (Chapter 3) show similarities and differences.

While the AOD map indicates a rather uniform PM2.5 level throughout the central areas of the state, the GAINS-IGP map which is derived from the estimated emission inventory (ref. Chapter 3) shows definite spatial variations, such as lower PM2.5 levels in the center

FIGURE 9: COMPARISON OF ANNUAL MEAN PM2.5 CONCENTRATIONS DERIVED FROM CAAMS MEASUREMENTS IN UP CITIES WITH GAINS-IGP ESTIMATES 2019-2021



area of the state, possibly related to the low estimate of emissions from municipal waste management. The agreement of the GAINS-IGP and AOD-derived maps of PM2.5 concentrations provides a plausible picture of the spatial distribution of PM2.5. However, the AOD-based estimates suggest substantially higher PM2.5 concentrations than GAINS-IGP results, while the available ground-level monitoring data supports the GAINS-IGP results regarding the state-wide average PM2.5 level (see Chapter 3), in good agreement with the comparison results shown in Figure 9 above for all IGP stations. In conclusion, PM2.5 concentration levels calculated by GAINS-IGP is supported by CAAMS measurements, and the spatial distribution aligns with AOD data, thereby providing a plausible picture of the state-wide air pollution in Uttar Pradesh.

Confidence intervals of GAINS-IGP modeling results

Related to modeling results presented in chapter 5, the emission and air quality projections of the GAINS-IGP model include complex model calculations involving several 1000s of input data, each of them associated with their own uncertainties. Identifying the existence of uncertainty is not intended to discredit the validity of emissions and air quality forecasts, nor is it intended to impinge upon their ability to provide decision-support to policy makers. Despite the existence of uncertainties of the complex model calculations, such uncertainties are typical in many decision- making problems and are not prohibitive for the development of robust policy decisions.

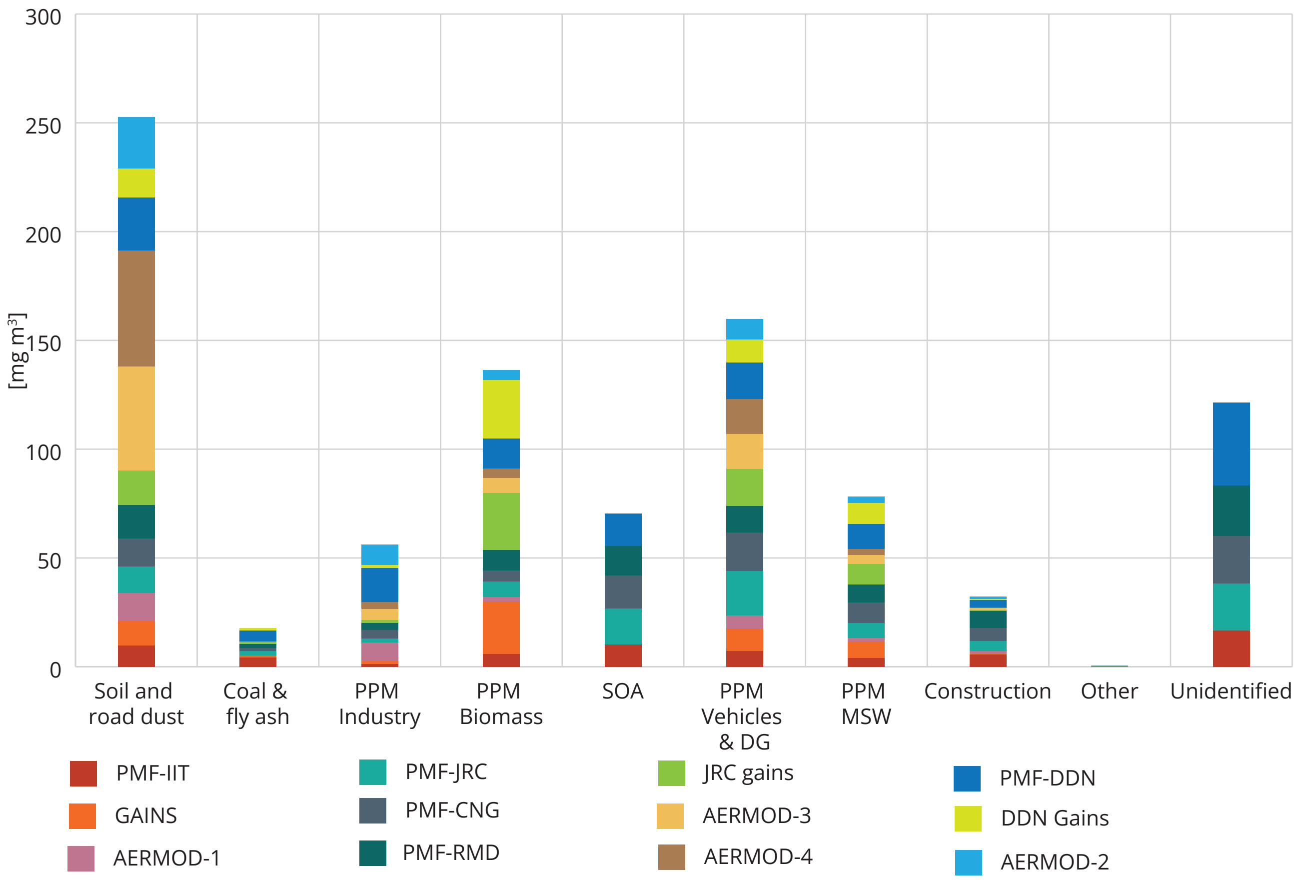
In general, it has been found useful to distinguish statistical uncertainties (i) for which the confidence intervals of the uncertain input parameters cannot be quantified on a robust basis and for which, in absence of a solid quantitative basis, often symmetric ranges around a central estimate are specified (e.g., the uncertainties of future economic projections, the general unpredictability of the future (e.g., geo-political conditions, epidemics), meteorological variability, statistical uncertainties in monitoring data or cost information, etc.), and (ii) uncertainties that lead to systematic biases in model results. While symmetric uncertainty ranges of input parameters lead, in general, to symmetric probability distributions of results, the understanding of uncertainties that can result in systematic biases of model outputs is critical for the interpretation of model results. For emission projections future compliance with emission control legislation has been found to be of dominant importance for future emission levels. However, in many cases it proved difficult to develop unequivocal quantifications of the confidence in future compliance regimes. To this end, the UCAP analysis presents two alternative options (scenarios) of future air quality by outlining the consequences of two extreme assumptions on the enforcement of existing air quality legislation. (For further information see annex 6).

Validation of source apportionment results

To further validate the GAINS-IGP model results against locally prepared studies, a special analysis for Kanpur (World Bank 2023c) compared the findings of the source apportionment study conducted by IIT-Kanpur under the SDC-MOEFCC cooperation program on AQM for Four Indian cities with estimates derived from the GAINS-IGP model (Sharma 2022b). To establish comparability, results obtained with the three different methods (i.e., the positive matrix factorization (PMF) method based on chemically speciated PM2.5 monitoring in ambient air, the AIRMOD model of the dispersion of primary PM2.5, and the GAINS-IGP model for primary and secondary PM2.5) have been converted into a common sectoral, spatial and temporal metric. Also, based on the likely chemical fingerprints of the various emission sources, the unexplained residual fraction emerging from the PMF method has been attributed to the source categories. Note that this comparison was conducted before the data upgrade by the UP-CAMP team, i.e., it

FIGURE 10: COMPARISON OF THE CONTRIBUTIONS TO ANNUAL MEAN (PRIMARY AND SECONDARY) PM2.5 LEVELS AT THE MONITORING SITES IN KANPUR, PMF AND GAINS-IGP.

FIGURE 11: COMPARISON OF THE ESTIMATED CONTRIBUTIONS TO ANNUAL MEAN PRIMARY PM2.5 LEVELS AT THE MONITORING SITES IN KANPUR.



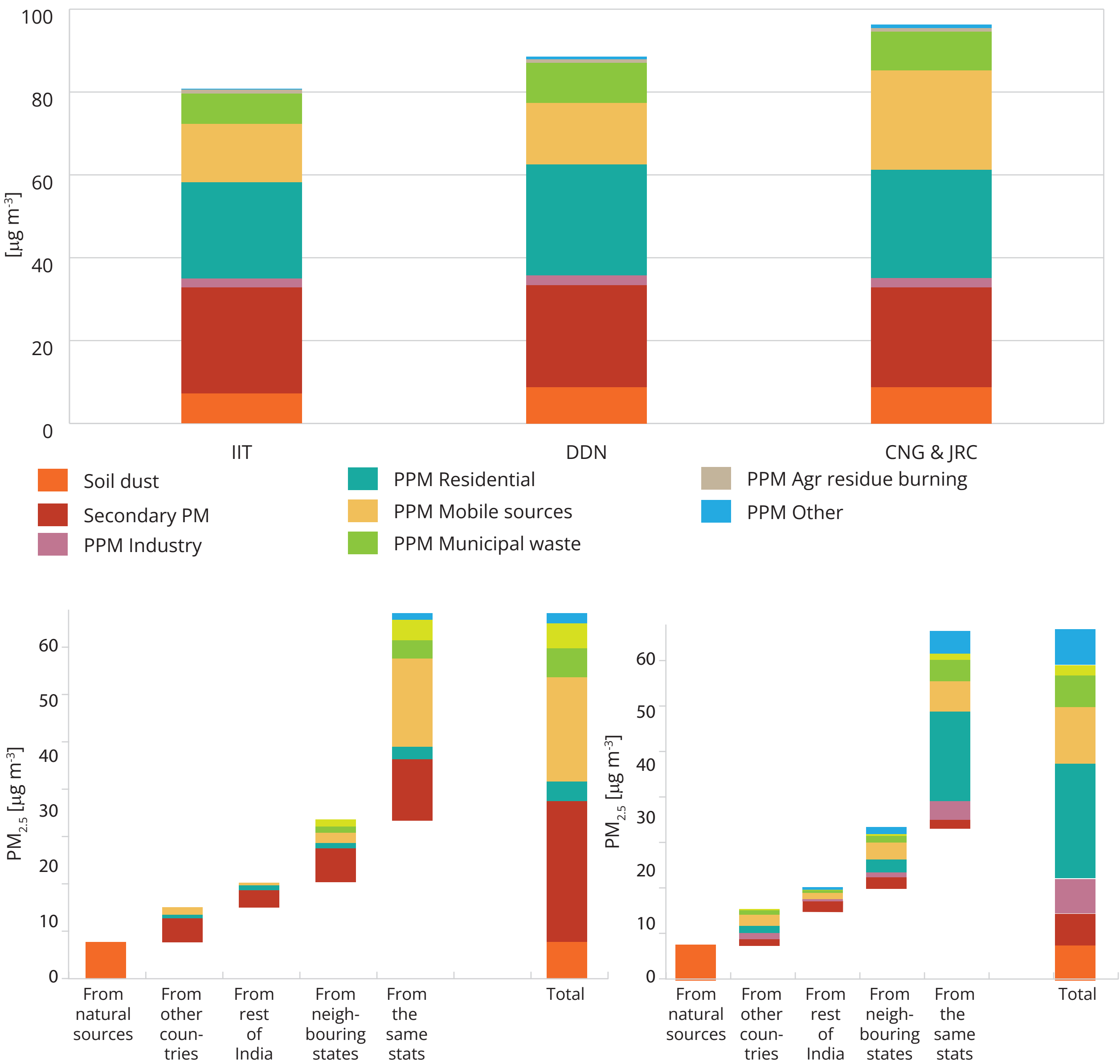
is still based on the original and much higher estimates of emissions from municipal waste management which have been lowered during the data update.

Overall, Figure 11 shows close agreement about the sectoral contributions between the PMF results and the GAINS-IGP estimates, considering that the GAINS-IGP does not resolve variations within the 10 km x 10 km grid cells. An exception is grid cell 80.25/26.35, where the available emission inventory does not include an important near-by industrial emission source.

Overall, for the stations in Kanpur, PMF and GAINS-IGP agree on the high importance of residential biomass burning, vehicles, municipal waste management and solid and road dust for annual mean concentrations of PM2.5. Also, there is a strong agreement about the importance of secondary inorganic aerosols. It is further noteworthy that the key sources that emerge from these three studies are within the range also identified by other studies for other cities in IGP (Guttikunda et al. 2023). Comparisons of the estimated contributions of primary PM2.5 show a good match of the AERMOD results for the vehicles and municipal waste management (Figures 11 and 12).

Furthermore, GAINS-IGP source apportionment estimations show very similar modeling results between three different source locations in Kanpur (IIT, DDN and CNG & JRC) and UP overall (three city locations in upper part and UP overall in lower part of figure 13), although the ratio between the main sources may differ a little between the city readings (higher PM2.5 concentrations with higher primary PM readings) and UP overall readings (lower PM2.5 with higher secondary PM2.5 readings). This shows that secondary PM2.5 must be controlled at the regional level both within the states and between the states.

FIGURE 12: GAINS-IGP SOURCE APPORTIONMENTS FOR THREE DIFFERENT MONITORING SITES IN KANPUR (UPPER PANEL) AND FOR ALL OF UTTAR PRADESH (POPULATION-WEIGHTED, LOWER PANEL)



AIR QUALITY IN UTTAR PRADESH

This chapter explains the present air quality situation in Uttar Pradesh. It provides the basis for showing the need for improvements in the air quality, especially related to PM concentrations in the air. Additionally, it implies the scale of concentration reductions required and consequent emissions reductions essential for attaining the NAAQS and achieving the objectives outlined in the NCAP and other NCAP-related programs like the 15th Finance Commission through this UCAP (ref. chapter 5).

The contents and assessments presented in this section on the air quality situation in Uttar Pradesh are based on the data coming from the extensive AQ monitoring network in Uttar Pradesh, covering the period from 2017 to 2022. Data for 2017-2021 from the UP-Pollution Control Board (UPPCB) was shared with the Norwegian Institute for Air Research (NILU) and individual experts for analysis, evaluation, and presentation. This work is presented in a separate background report from NILU[16]. Additional data for some stations for 2021-22 has been transferred directly from the CPCB database, to enable a broader analysis of the recent air quality (PM) trends. All figures and tables and evaluations, analyses, and summaries of the air quality-related data in the present Chapter 3 are extracted from and/or based upon the contents of the NILU report and the additional data that has been transferred directly from the CPCB data base of UP data. UPPCB's extensive work on data provision and NILU's evaluation showed that there is an extensive base of AQ data from Uttar Pradesh. Initial air quality data screening was done for assessing the present air quality situation and developments in Uttar Pradesh.

This assessment centers on the year 2020, the base year of the UCAP. Because of the extent of availability of data from a sizeable number of monitoring stations, the actual time period selected here is from October 2020 to September 2021. The period 2017-2022 is used to analyze and show the trend in PM concentrations in UP during recent years.

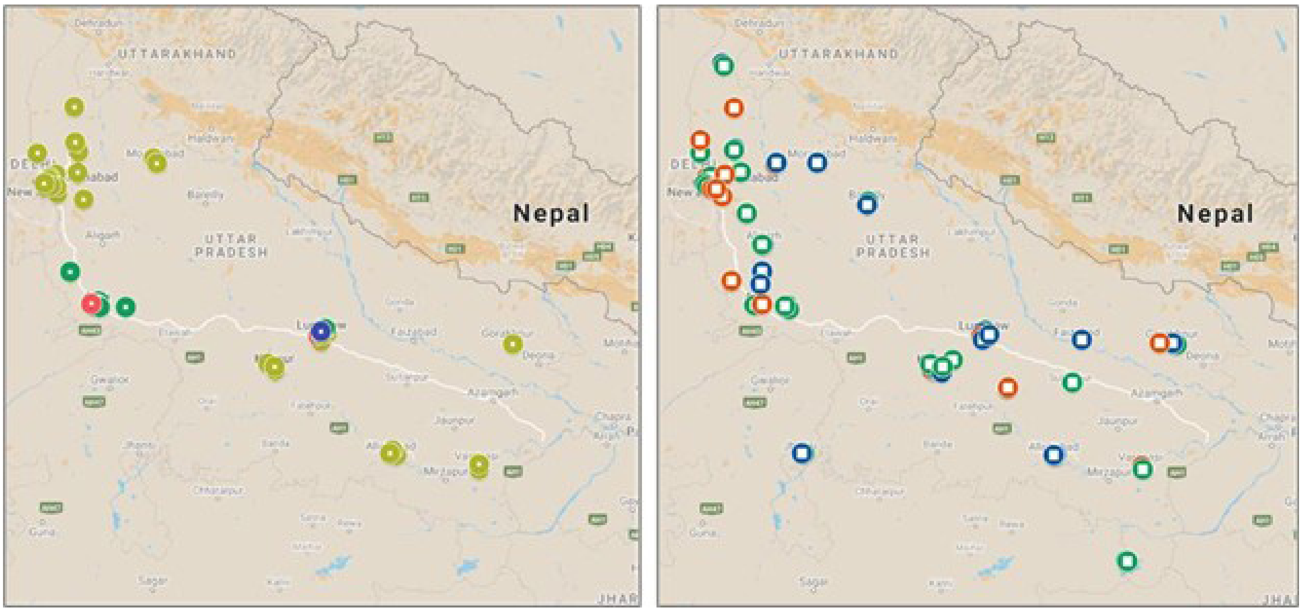
Air quality monitoring networks and selection of data series for an overview assessment of PM concentration levels in UP

Air quality data were made available from 45 continuous monitoring stations (CAAMS) and from 79 manual sampling (NAMP) stations with data from January 2017 to September 2021. Stations were started up at various points in time, some starting in early 2017. The actual period covered varies much from station to station. Details about the monitoring networks and period of measurement, as well as the basis for the selection of stations and data used for this assessment, including information about the additional data downloaded for the 2021-22 period, can be found in Annex 4. The cities with CAAMS and NAMP monitoring stations are shown in maps in Figure 14.

The UP-air quality monitoring network data does not cover the areas in Uttar Pradesh outside the larger cities and more rural/village areas. Rural/village areas will need to be covered in an expanded monitoring network in the future, so it can be used to assess by monitoring the

[16] Hak C., Schneider P., Shetty S.: Technical Support for Air Quality Management Plans for Uttar Pradesh and Bihar. Task 1: Evaluation of air quality (PM) data from Uttar Pradesh and Bihar. NILU Report 15/2022. Lillestrøm, Norway.

FIGURE 13: CAAMS (LEFT PANEL) AND NAMP (RIGHT PANEL) STATIONS IN UTTAR PRADESH



Note: Green: Residential area stations, blue: Commercial area stations, red: Industrial area stations, dark yellow: Mixed area stations

population-averaged PM concentration in Uttar Pradesh as a basis for assessing the impact of the PM pollution level on the population.

In total, there are 30 for PM2.5 and 53 stations for PM10 with *acceptable* data quality for continuous (CAAMS) and manual (NAMP) stations that enable a reliable assessment of the present air quality situation in UP (Table 2).

TABLE 2: NUMBER OF DATA SERIES FROM UP CITIES USEDFOR THIS ASSESSMENT OF PRESENT UP PM CONCENTRATION LEVELS

	CAAMS stations	NAMP stations
PM2.5	25	5
PM10	22	31

For CAAMS stations, ´present´ refer to the period October 2020 - September 2021. Regarding manual stations, the ´present´ period depends upon the availability of (almost) full consecutive monthly time series during the last 12 months before the end of the available data series, towards September 2021. All manual ´present´ data series are within the period from January 2020 to September 2021.

PM concentrations in UP for UCAP in 2020

The overall assessment of the PM air quality in Uttar Pradesh for the UCAP base year (here October 2020-September 2021) is around 95-100 µg/m³ using the average PM2.5 level in 13 cities, and the PM10 concentration is around 200 ug/m³, based on an average for 11 cities. These levels are about 2.5 and three times higher than the Indian AQ standard for PM2.5 and PM10 respectively. PM2.5 and PM10 concentrations measured at these stations are shown in Table 3 and Table 4.

Key observations from the tables below covering the selected time series, are as follows:

1. The averaged PM2.5 concentration is 94 µg/m³ across all 25 CAAMS stations and 113 µg/m³ across the five NAMP stations. These concentrations exceed the National Indian Air Quality Standard (AQS) by 2-4.5 times at almost all the 30 monitoring stations.
2. The averaged PM10 concentration is 216 ug/m³ for 22 CAAMS stations and 187 ug/m³ for 31 NAMP stations. These concentrations exceed the AQS by 2-4.5 times at almost all the 53 monitoring stations.

3. The average and range of concentrations measured at the CAAMS and NAMP stations, with some in the same cities and some in different cities, show that they are at roughly the same level.

4. Because of a lack of monitoring stations outside urban areas, this assessment does not cover the PM pollution situation in rural/ village/agricultural/small town areas where a substantial portion of the population lives. The monitoring system should be extended with some stations in such areas.

TABLE 3: PM2.5 AND PM10 CONCENTRATIONS AT CAAMS STATIONS IN UTTAR PRADESH

City	Station name/ Nos.	Site type	PM2.5 (µg/ m^3)	Range (µg/ m^3)	PM10 (µg/m^3)	Range (µg/ m^3)
Ghaziabad	4 stations	M	123.5	113.5-140.4	253.6	240.6-280.7
Lucknow	4 stations PM10 3 stations PM2.5	M/C/I	94.2	71.4-122.3	200.4	179.5-234.8
Noida	4 stations	M	105.5	96.8-113.5	223.3	216.3-233.4
Greater Noida	2 stations	M	105.7	103.0-108.3	240.5	212.5-268.4
Bulandshahr	Yamuna Puram	M	105.8		210.5	
Baghpat	New Collectorate	M	101.2		233.0	
Meerut	3 stations	M	92.3	85.1-100.3	205.4	188.5-227.3
Kanpur	2 stations	M	83.8	70.3-97.2		
Agra	Sanjay Palace	M/C	87.3			
Muzaffarnagar	New Mandi	M	83.1		199.1	
Moradabad	Lajpat Nagar	M			198.6	
Varanasi	Ardhali Bazar	M	72.2		168.6	
Hapur	Anand Vihar	M	39.6		141.6	

Note: Annual average for 2020/21 (Oct 2020 – Sep 2021). Ranked by highest to lowest annual PM2.5

TABLE 4: PM2.5AND PM10 CONCENTRATIONS AT NAMP STATIONS IN UTTAR PRADESH (MG/MS)

City	Station name	Site Type	PM2.5 (µg/m^3)	Range (µg/ m^3)	PM10	Range
Ghaziabad	4 stations	M	123.5	113.5-140.4	253.6	240.6-280.7
Lucknow	4 stations PM10	M/C/I	94.2	71.4-122.3		
	3 stations PM2.5			200.4		

City	Station name	Site Type	PM2.5 (µg/m³)	Range (µg/ m³)	PM10	Range
Noida	4 stations	M	105.5	96.8-113.5	223.3	216.3-233.4
Greater Noida	2 stations	M	105.7	103.0-108.3	240.5	212.5-268.4
Bulandshahr	Yamuna Puram	M	105.8		210.5	
Baghpat	New Collect.	M	101.2		233	
Meerut	3 stations	M	92.3	85.1-100.3	205.4	188.5-227.3
Kanpur	2 stations	M	83.8	70.3-97.2		
Agra	Sanjay Palace	M/C	87.3			
Muzaffarnagar	New Mandi	M	83.1		199.1	
Moradabad	Lajpat Nagar	M			198.6	
Varanasi	Ardhali Bazar	M	72.2		168.6	
Hapur	Anand Vihar	M	39.6		141.6	

Note: Annual values for 2020/21 (Oct.-Sep.) except where otherwise noted. Ranked by highest to lowest.

PM concentration variations across seasons and time-of-day

Seasonal PM concentration variations are strong in Uttar Pradesh. Winter concentrations (Nov-Feb) are typically more than four times higher than in summer months. This can be seen in Figure 15 for examples of PM2.5 and PM10seasonal variations in Noida and Ghaziabad. Monthly averages in winter reach as high as over 400 µg/m³ and 300 µg/m³ for PM10 and PM2.5 respectively. The reasons for the high winter concentrations are both increased emissions from some sources during winter as well as meteorological conditions being less favorable for the dispersion of pollutants.

Typical urban diurnal variations show a morning pollution peak and an evening peak that extends through the night hours (Figure 16**).** The extended evening/night peak shows the effect of poor pollution dispersion (ground level cold and calm), while the quite low mid-day level shows that, despite continuing large emissions from traffic and other sources throughout the daytime, the effect of typical good dispersion conditions (warm air, wind) lowers the pollution level substantially.

These seasonal and diurnal variations cause sometimes extremely high PM levels at peak periods mostly during winter months. In many cities in Uttar Pradesh, highest 24-hour average concentrations are over 400 µg/m³ and 800 µg/m³ for PM2.5 and PM10 respectively, (see Annex 4 for details). These are extremely high levels and much above any AQ standard. For the protection of the health of the population, measures to reduce air pollution concentrations need to also consider sources with high emissions during such peak periods.

FIGURE 14: SEASONAL VARIATION OF PM2.5 (TOP) AND PM10 (BOTTOM). TYPICAL EXAMPLES FROM CAAMS STATIONS IN NOIDA AND GHAZIABAD RESPECTIVELY (AVERAGE AND 1 STD. DEV. BANDS)

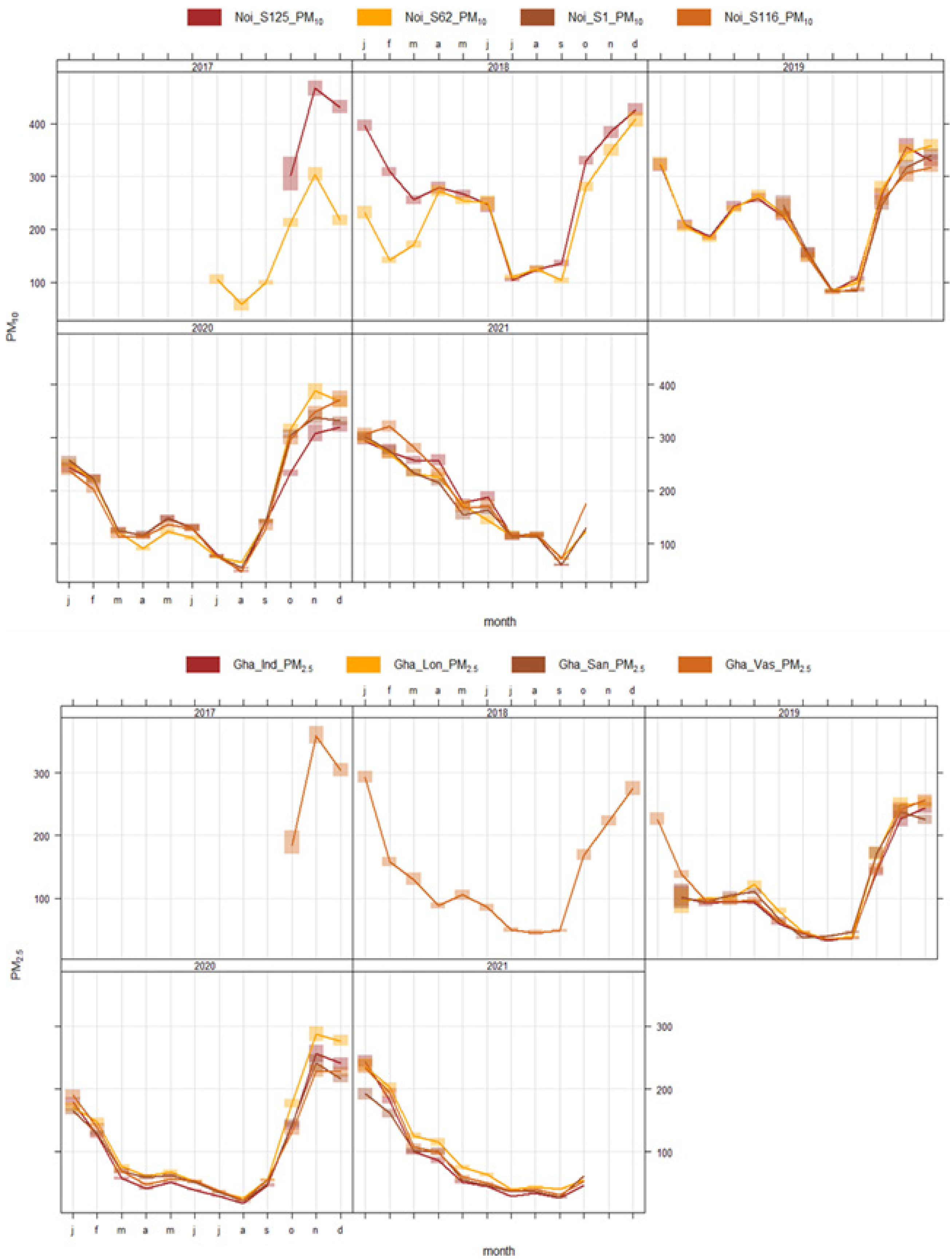
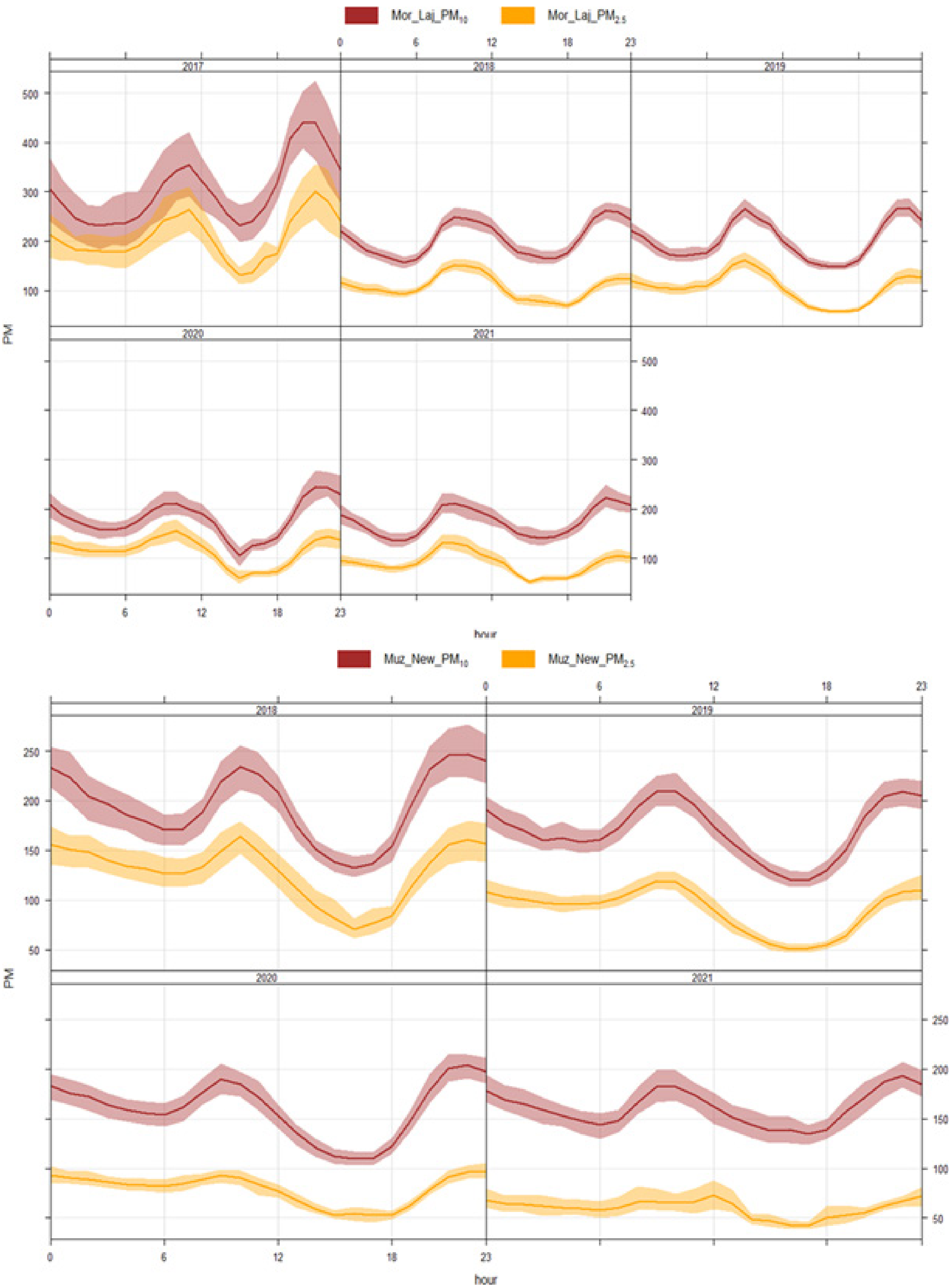


FIGURE 15: AVERAGE DIURNAL VARIATION OF PM10 AND PM2.5. TYPICAL EXAMPLES FROM CAAMS STATIONS, MORADABAD (TOP) AND MUZAFFARNAGAR (BOTTOM). (AVERAGE AND 1 STD. DEV. BANDS)



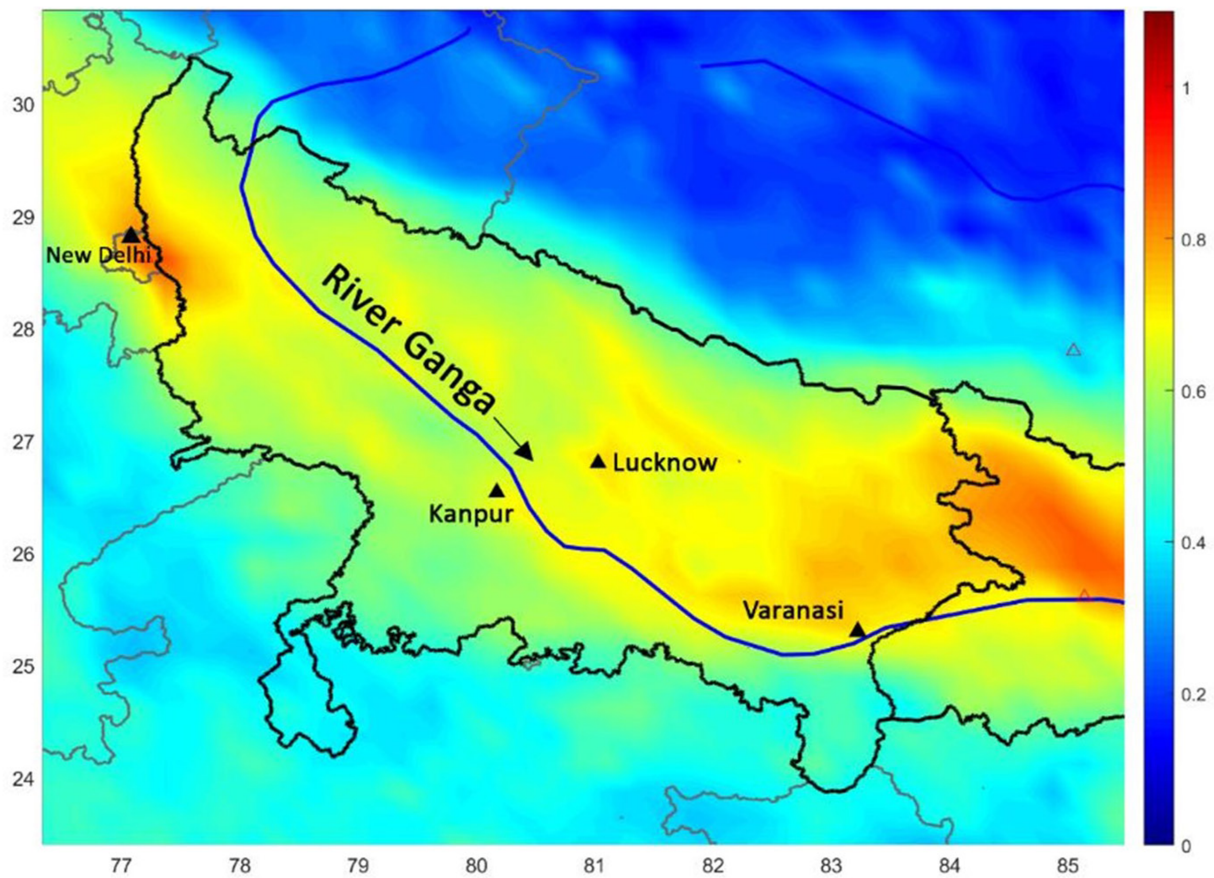
Satellite-based aerosol measurements and derived surface PM2.5 concentrations

Optical measurements by satellites pointed towards the earth surface provide a measure of the 'aerosol optical depth' of the atmosphere (AOD). Such measurements can be converted to indicate surface concentrations of aerosol particles, specifically PM2.5. When satellites pass over a territory these measurements scan the surface areas and enable to produce a map of the aerosol/PM2.5 levels across the area via developed algorithms for the AOD to PM2.5 conversion. AOD-derived surface PM2.5 for Uttar Pradesh was obtained from the satellite-based V5.GL.03 dataset produced by van Donkelaar et al. (2021)[17].While uncertainties exist (see discussion in the next section), satellite data can provide a more complete picture of the PM situation across the state compared to what the available CAAMS stations can give.

High AOD values, indicating high PM concentrations, are observed towards the eastern Uttar Pradesh, and even higher concentrations are seen around the regions near New Delhi. Slightly lower but still high AOD values can be observed along the Ganga River. Figure 16 shows the long-term average (2017-2020) of AOD measurements over the state of Uttar Pradesh. The maps show average AOD data for grid cells of about 10 km x10 km size. Thus, the maps indicate polluted regions both in urban and rural areas but are not suitable for showing very local hot-spots.

Monthly AOD concentrations for August 2017 – October 2020 (Figure 18) show a seasonal variation of PM pollution that coincides with what was shown in the previous section based upon PM measurements at CAAMS stations:

FIGURE 16: AVERAGE AOD MEASURED OVER UTTAR PRADESH, 2017-2020



[17] Van Donkelaar, A., Hammer, M. S., Bindle, L., Brauer, M., Brook, J. R., Garay, M. J., & Martin, R. V. (2021). Monthly global estimates of fine particulate matter and their uncertainty. Environmental Science & Technology, 55(22), 15287-15300.

During January, high concentrations of AOD occur towards the north-eastern part of Uttar Pradesh.

- The months of October, November, and December generally show the highest concentrations of AOD throughout the state.

For 2010-2020, AOD-derived PM2.5 concentrations are highest (annual average levels of 100+ µg/m³) in a wide area along the Ganges valley covering most of the central area of the state. Concentrations gradually decline towards below 60 µg/m³ in the southern and northern parts of the state (Figure 19). State-wide annual average AOD-derived PM2.5concentrations averaged over 2010-2020 is 89 µg/m³. Over these years the annual average has varied between 84 and 95 µg/m³ without a clear trend. The map for 2020 is shown in Figure 20, with an average concentration of 88.1µg/m³.

FIGURE 17: MONTHLY AOD MAPS OVER UTTAR PRADESH, AUGUST 2017 – OCTOBER 2020

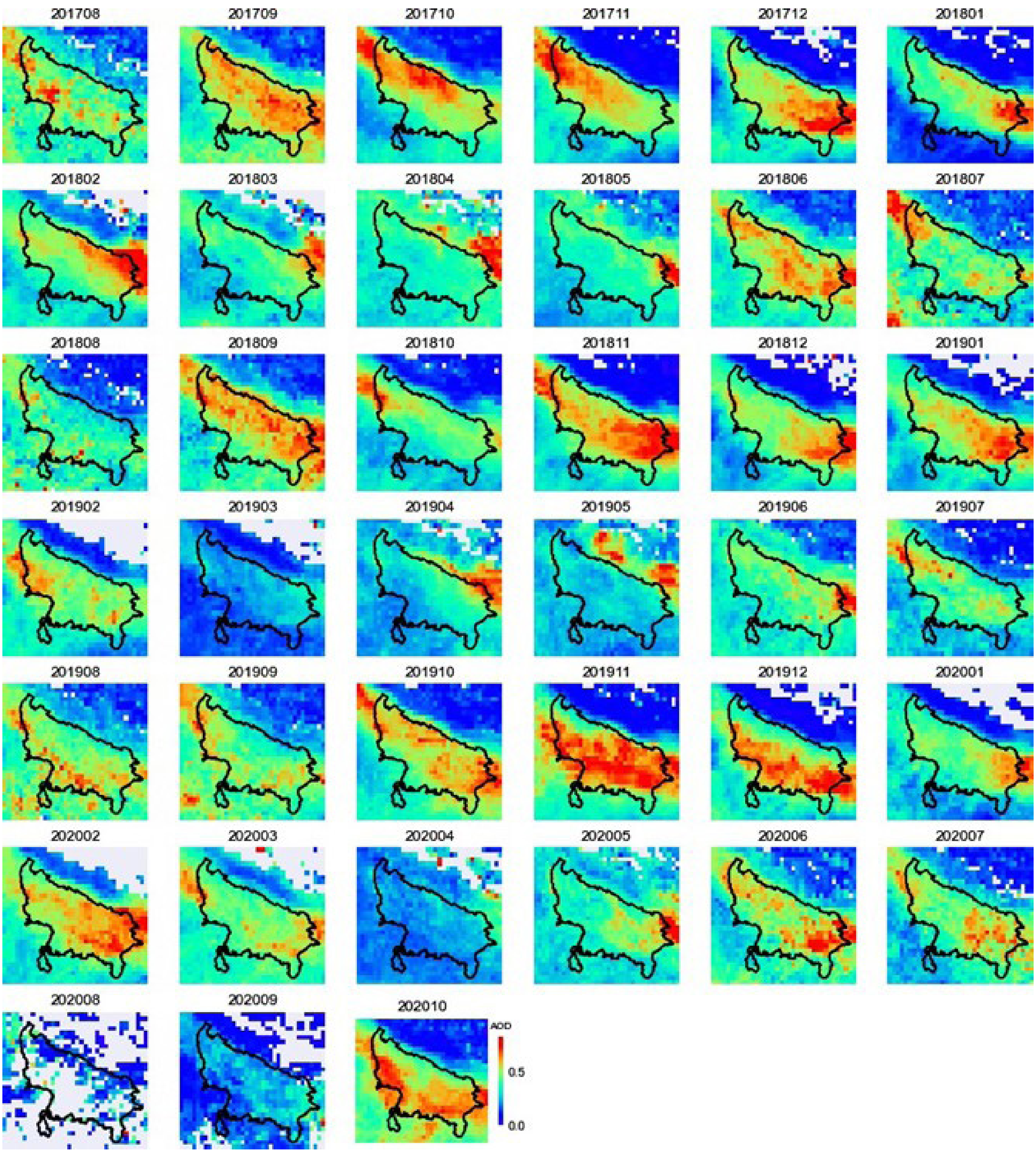


FIGURE 18: AOD-DERIVED SURFACE PM2.5CONCENTRATIONS ACROSS UTTAR PRADESH, μG/MS. AVERAGE OVER 2010-2020

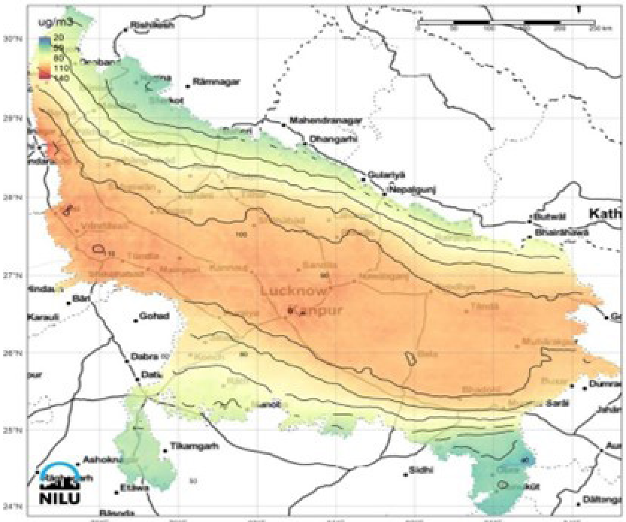
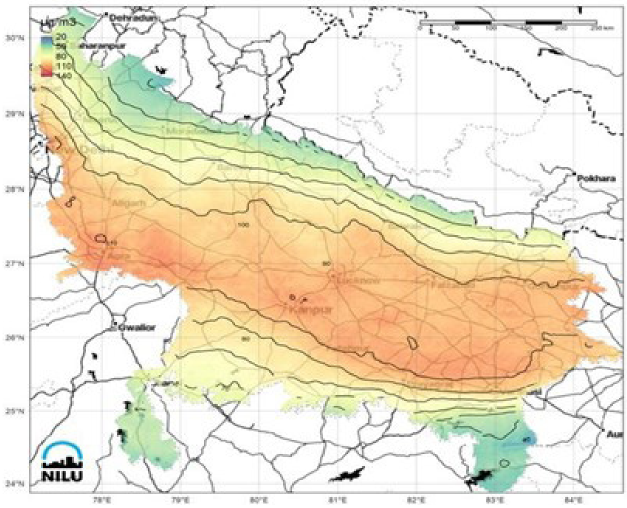
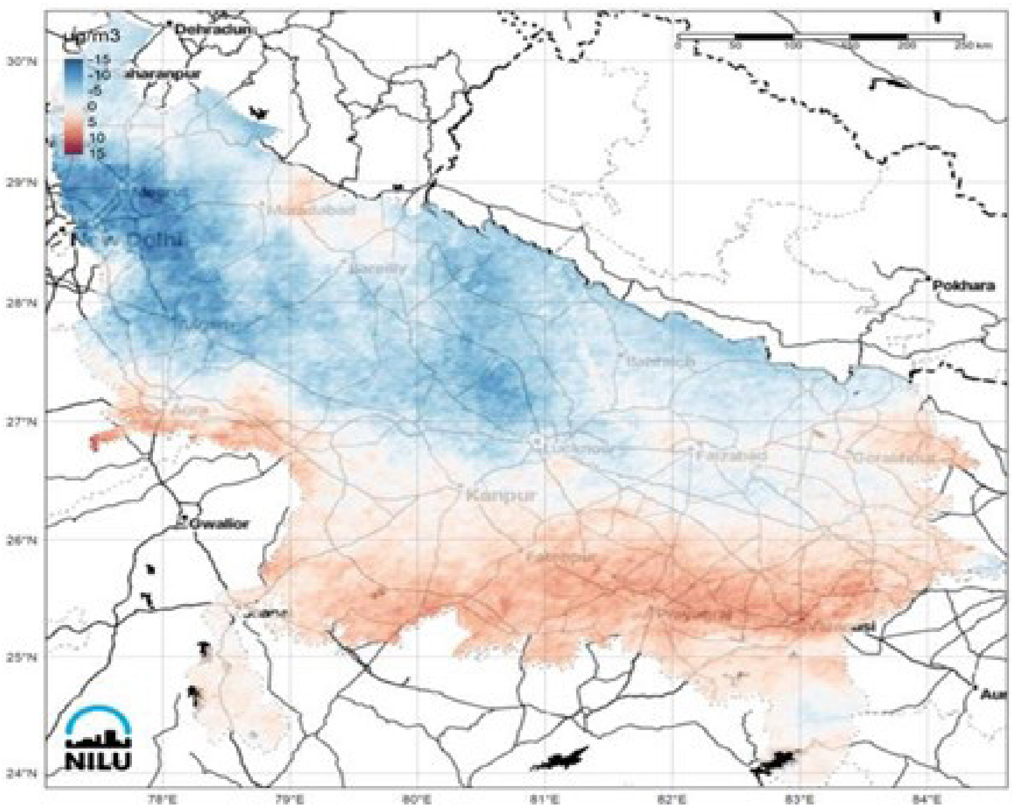


FIGURE 19: AOD-DERIVED SURFACE PM2.5 CONCENTRATIONS ACROSS UTTAR PRADESH IN 2020, μG/MS



In 2020, AOD-derived PM2.5 concentrations were significantly above the 2010-2020 average in the southern parts of the state, and lower in the northern parts (Figure 21) Explanations for the large differences might include, *inter alia*, changes in sectoral emissions (e.g., related to agriculture and/or residential practices/regulations, or other sectorial changes) and changes in meteorological/climate parameters (e.g., dryness).

FIGURE 20: DIFFERENCE BETWEEN AOD-DERIVED SURFACE PM2.5 CONCENTRATIONS FOR 2020 AND THE LONG-TERM AVERAGE 2010-2020 (MG/MS)

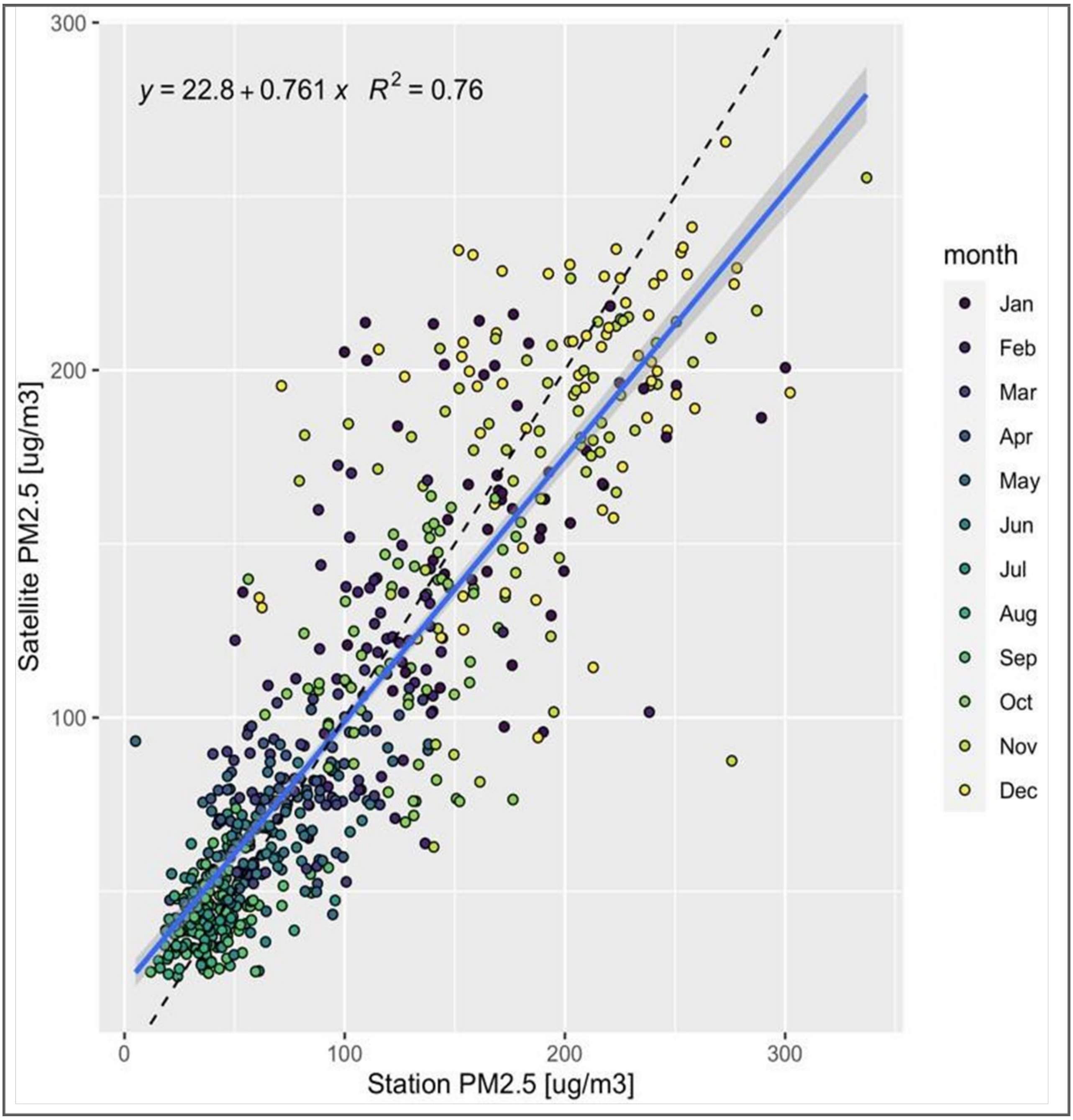


Comparison of AOD-derived surface PM2.5 concentrations with PM2.5 measurements at CAAMS stations

AOD-derived PM2.5 estimates could enable a robust extrapolation of urban CAAMS measurements to the wider area of Uttar Pradesh. Such a comparison must consider that AOD-based estimates represent average conditions over 10 km x10 km grids, while CAAMS data refer to measurements at specific point locations in urban areas. Figure 22 shows a scatter plot of station data where the blue line indicates a linear regression fit to the data and the dashed black line represents the 1:1 reference line.

Based on the correlation between monthly average PM2.5 concentrations derived from AOD data and ground-level measurements at CAAMS

FIGURE 21: SCATTER PLOT OF MONTHLY MEANS OF ALL STATIONS IN UTTAR PRADESH AGAINST THE CORRESPONDING MONTHLY AVERAGED SATELLITE-BASED SURFACE PM2.5 DATA (2017-2020)



of 0.76 (R^2) for the grids where the monitoring stations are located, the following observations are made:

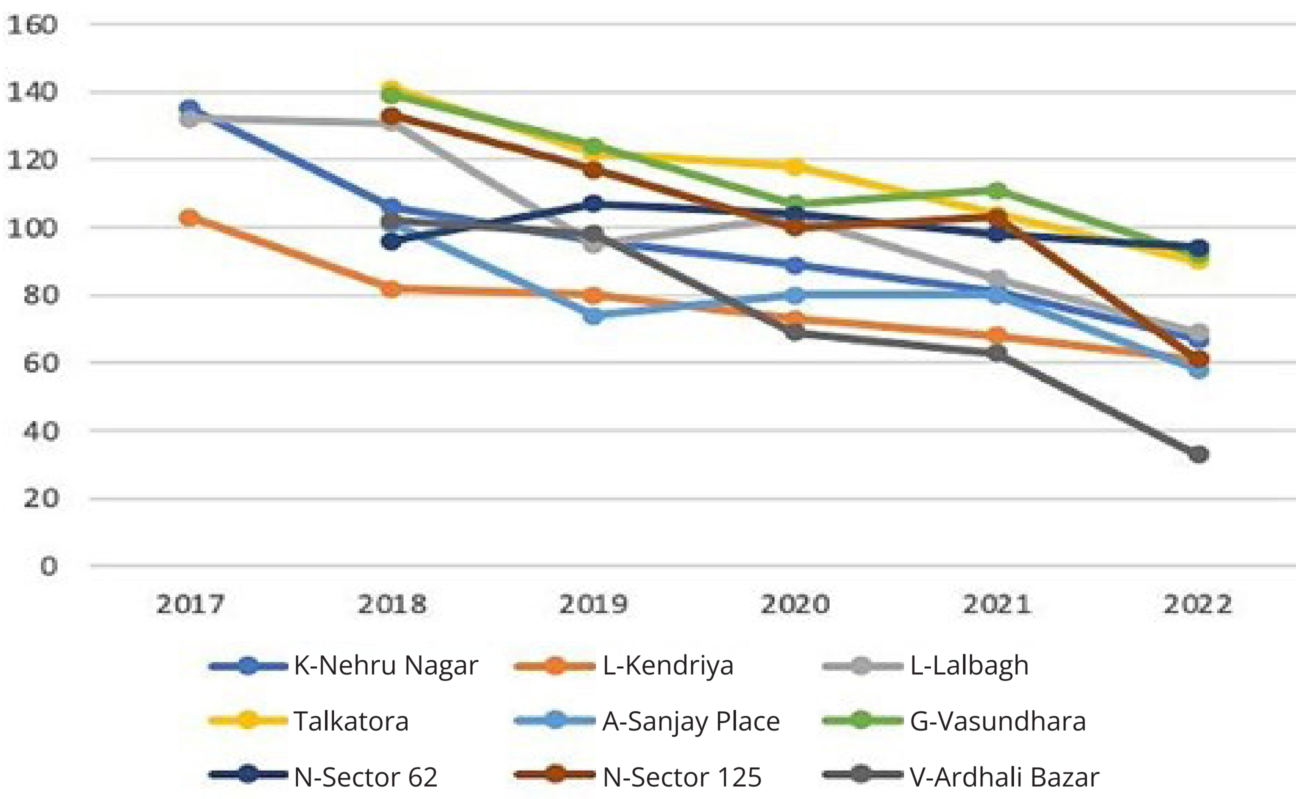
- The CAAMS data for Uttar Pradesh for 2020 deliver an overall annual average PM2.5 concentration of **86 µg/m³** for urban areas (25 stations in 13 cities) (full details of this can be found in Annex 4).
- Compared to that, the spatially averaged AOD derived PM2.5 for 2020 is **88.1 ug/m³**, average in 10 km x10 km grids over all areas in the State, mostly rural-village mixed areas (see section above and Figure 20). Although the state average estimates are very close to each other, a translation of the AOD data for urban grid cells to the monitoring points render an AOD-derived PM2.5 concentration for urban points of at least 102 µg/m³, as compared to the average CAAMS measurements of 86 µg/m³ for 25 stations in 13 cities. Details of such an exercise is described in Annex 4. Despite all methodological uncertainties, the exercise indicates that the AOD-derived PM2.5 levels represented by the AOD-derived PM2.5 map are higher than what CAAMS station measurements would give. However, AOD data provide valuable insight into the spatial variation of PM2.5 concentrations across the state. Beyond any doubt, a very large part of the Uttar Pradesh urban/small towns/village/rural areas experiences very high PM2.5 concentrations. The AOD data reveal that the entire population of Uttar Pradesh is more or less exposed to high PM2.5 concentrations.

Recent trends in PM concentrations in Uttar Pradesh

Trends at urban CAAMS stations

To assess the development in the air pollution situation with reasonable certainty, a data series covering a minimum of five years is required. From the CAAMS monitoring network in Uttar Pradesh cities, the following number of long-time series are available (see Annex 4 for details):

FIGURE 22: TIME TREND OF PM2.5 CONCENTRATIONS (2017-2022). DUE TO DATA AVAILABILITY, THE 'YEAR' RUNS FROM OCTOBER TO SEPTEMBER, EXCEPT FOR K-NEHRU NAGAR, L-KENDRIYA AND L-LALBAGH WHERE IT IS THE CALENDAR YEAR



- **For PM2.5:** 6-year time series from three stations, and 5-year series from another six stations, a total from six cities.
- **For PM10:** 6-year time series from 17 cities

In Figure 23 below, the time series for PM2.5 are plotted.

For PM2.5 in UP cities, there is a consistent decline in concentrations from 2017 towards 2022. Average concentration across these nine stations in six cities went down from 115 µg/m^3 in 2018 to 69 µg/m^3 in 2022, a 40 percent decline over the 5-year period. For the three stations with data also for 2017, the decline in concentrations started even in 2017.

The Covid anomaly 2020-22 (from late winter 2020 through to late winter 2022) must be considered when evaluating the trend development. It is the winter levels that dominate and drive the trend. The first full covid winter (represented by the 2021 data points) does not affect the PM2.5 level much compared to 2019 and 2020, while the second covid winter (2022) does. The downward trend in the following figure is affected by the covid shutdowns.

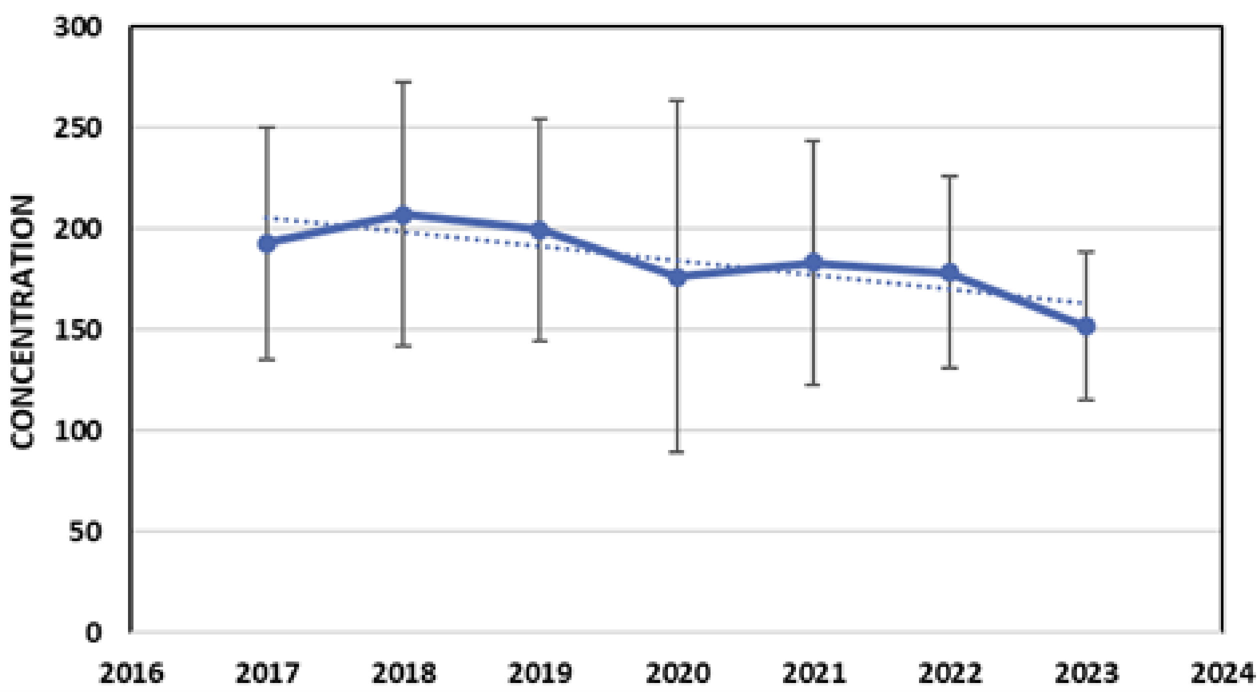
Trends shown by the AOD data

The trends shown in the AOD data were shown in Figure 18 above and further analyzed and summarized in Annex 4. The AOD data show a rather unchanged PM level across UP on the average since about 2015, while AOD data extracted for the largest urban areas show a reduction of 11 percent from 2017 to 2022, as an average for the entire urban areas. If extracted for urban hot spot locations, the decline could be expected to be larger, if local traffic measures have been carried out in the densest traffic areas.

NCAP Progress and Current Status

Ministry of Environment, Forest and Climate Change (MoEFCC) launched the NCAP in January 2019 to improve air quality in 131 cities (non-attainment cities and Million Plus Cities) in 24 States/UTs by engaging all stakeholders. The programme envisages to achieve reductions up to 40 percent (from the base year 2017-18) or achievement of National Ambient Air Quality Standards for PM10 concentrations by 2025-26.

FIGURE 23: TIME TREND OF PM10 CONCENTRATIONS (2017-2023) FROM 17 NON-ATTAINMENT CITIES



Based on data for the period 2014 – 2018, non-attainment cities with respect to PM10, with a consistent increasing trend of PM10 were identified. Seventeen cities in the state of Uttar Pradesh have been designated as non-attainment under NCAP: Agra, Anpara, Bareilly, Firozabad, Gajraula, Ghaziabad, Gorakhpur, Lucknow, Jhansi, Meerut, Moradabad, Noida, Raebareli, Prayagraj, Kanpur, Khurja, and Varanasi. All non-attainment cities have drawn an action plan for control of PM10 and are implementing the actions. The time series of PM10 data from the average of all nonattainment cities is shown in Figure below.

It is seen that the levels of PM10 are dropping and a reduction of about 19 percent has been achieved over six years. PM10 concentrations declined to a lesser extent than for PM2.5, mainly due to the persistence of the coarse PM fraction (PM10 - PM2.5) This shows that measures affecting PM2.5 do not necessarily reduce the coarse PM fraction of PM10 to the same extent.

Apart from the influence of the COVID-19 epidemic 2020-22, a combination of various factors related to ongoing air pollution control efforts may contribute to the reduction in PM2.5 concentrations observed in cities throughout UP 2017 to 2022. PM2.5 declines occurred in the *National Capital Region* (NCR) part of UP (Ghaziabad – K-Nehru Nagar and G- Vasundhara and in Noida – N-Sector 62 and N-Sector 115), in *South Western UP* (Agra – A- Sanjay Palace), in *Central UP* (Lucknow – Talkatora, L-Kendriya and L-Lalbagh) and in *Eastern UP* (Varanasi – V-Ardhali Bazar).

The PM reductions may be due to:

- Implementation of the graded response action plan (GRAP) addressing pollution from several sources from controlling municipal waste burning, transport (scrapping policies, introducing e-vehicles and CNG policies particularly for busses), agriculture (CRB both in UP and neighboring states), industry (stricter enforcement of emission policies in MSMEs).
- Installation of de-dusters, desulfurization and de-NOx devices and scrubbers in particularly high-stack sources (power plants and larger industries) throughout IGP.

Summary of Air Quality monitoring data

- PM2.5 at urban hot spot CAAMS stations show a reduction of 40 percent in 6 cities (9 stations) 2018-2022. This large reduction is to some extent driven by the noticeable decline in the in 2022.
- AOD data indicate declines in PM2.5 of 11 percent during 2017-2022 as an average across the largest urban areas[18]
- PM10 at urban NAMS stations show about a 19 percent reduction on average in 17 nonattainment cities over 2017-2023.

Moving towards meeting the NCAP goals for PM10

The data presented in the sections above gives a certain basis for assessing the movement towards meeting the NCAP PM10reduction goal. As it is still three years until 2026, a continued reduction in line with what has been seen since 2017 will bring the PM10 reduction closer to the goal. For alignments of PM2.5 projections to NCAP targets to projections refer to Chapter 5.

[18] See figure 57 in annex 4.

Sources of Air Pollution in the State

The preceding chapter identified particulate matter (PM10 and PM2.5) as the main contributor to poor air quality in UP. With a primary focus for air quality management on public health, the further analysis in this report centers on PM2.5 due to its overwhelming dominance over the health impacts from other pollutants. It presents estimates of the precursor emissions of PM2.5 and examines the contributions that originate from the direct (primary) emissions of PM2.5 as well as from the chemical processes that generate (secondary) PM2.5 in the atmosphere, especially from the gaseous precursor emissions sulfur dioxide (SO2), nitrogen oxides (NOx), and ammonia (NH3). For each of these pollutants, the analysis identifies the sectoral origin as well as the locations where they are emitted. Emissions of volatile organic compounds (VOC) are considered in the source apportionment, although their sources are not addressed here in detail.

Emissions of PM2.5 precursors

A good understanding of all emission sources is an indispensable prerequisite for any effective air quality management approach. The analysis presented in this chapter developed an initial estimate of the emissions of all relevant sources that contribute to primary and secondary PM2.5 pollution in the state of UP, considering direct emissions of primary PM2.5 as well as SO2, NOx and NH3.

Considering the exceptional circumstances of the Covid lockdowns in 2020, the analysis is centered on the two-year period of 2019/2020 as the chosen base period. While capturing the most recent data would be optimal for establishing the base year situation, as of the current writing, many underlying statistics are only accessible up to 2020.[19]

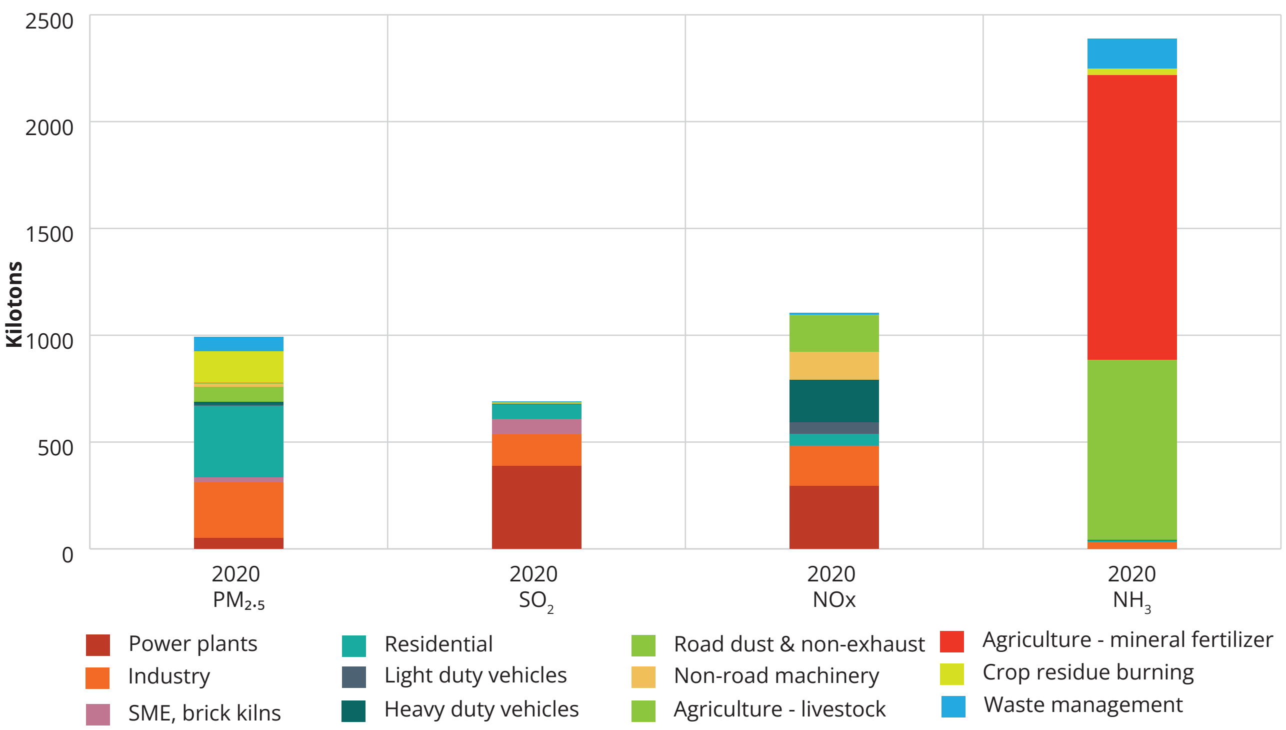
An in-depth technical review of the statistical input data to the GAINS-IGP (Indo-Gangetic Plain) model for the UP state as undertaken by the UPCAMP Working Group, The Energy and Resources Institute (TERI), and the World Bank team in early 2023. Based on this extensive quality review, some updates were made in the input data for UP of the GAINS-IGP model. The inventory of PM2.5 precursor emissions in Uttar Pradesh estimated for the 2019-2020 period based to the maximum possible extent on local statistics, measurements, and emission factors were found to be representative for South Asia, India, and Uttar Pradesh. Data sources are described in Annexes 2 and 3. Main results are presented in Figure 25. Notably, the sector contributions to the four precursor emissions (i.e., primary PM2.5, SO2, NOx, NH3) differ greatly owing to the different economic sectors that cause these emissions (Figure 26).

In 2019/2020, about one third of all primary PM2.5 emissions in UP originated from the residential sector, mainly from solid fuel use in cook stoves. Industrial sources were responsible for about 28 percent, and the open burning of crop residue for 15 percent. Mobile sources contributed about 9 percent to primary PM2.5 emissions, with most of it generated in the form of road dust. It is noteworthy that the available data suggest lower emission shares of sources that received high public attention in the past, such as road exhaust and brick kilns, even if rather pessimistic assumptions on emission factors are employed. Obviously, compared to total emissions in UP, road traffic contributes a larger share to PM2.5 emissions and concentrations in ambient air near busy roads in cities and similarly with brick kilns being established in clusters where poor air quality is prominently perceived by the public.

The picture looks fundamentally different for the precursor emissions of secondary PM2.5. Power generation, Industry and brick kilns are responsible for almost 90 percent of total SO2 in

[19] In some exceptional cases, data from 2018 has been recorded. Please refer to Annex 2.

FIGURE 24: EMISSIONS OF PM2.5 AND PRECURSORS IN UTTAR PRADESH, 2020



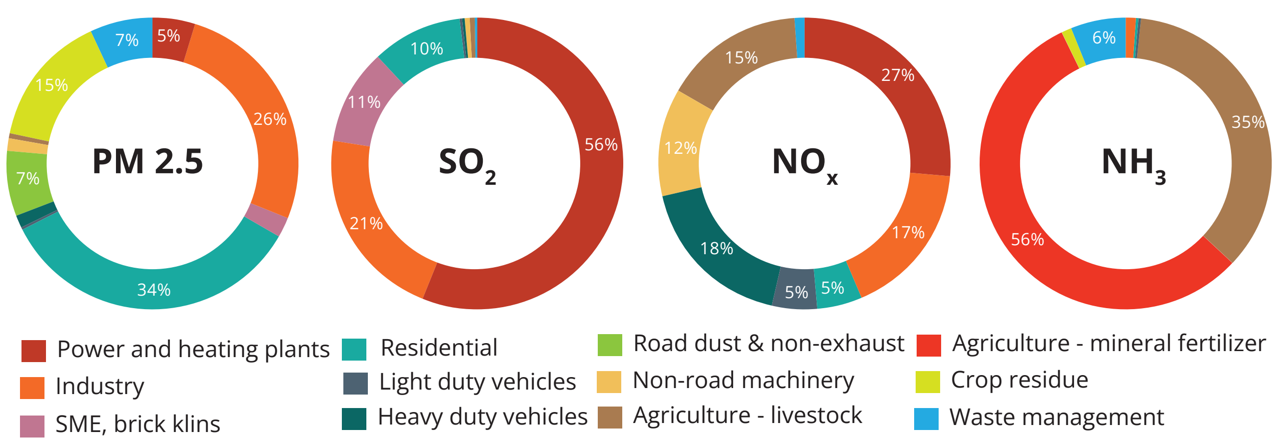
Source: Authors' original figure for this report as computed by the GAINS-IGP model

UP. Mobile sources (including non-road mobile machinery) account for only one third of all NOx emissions, while 44 percent are linked to power generation and industry. SO2, and to a lesser extent NOx, react in the atmosphere with NH3 to form ammonium sulphate and ammonium nitrate particles. It is estimated that in UP about 56 percent of total NH3 emissions are caused by the application of mineral (urea) fertilizer, and about 35 percent by livestock manure management.

PM2.5 concentrations in ambient air

The diversity in AOD and PM2.5 levels across UP that is revealed by satellite observations is mirrored by the spatial pattern of PM2.5 concentrations computed with the GAINS-IGP model for 2019/2020 based on the precursor emission presented above (Figure 27). Rather high PM2.5 levels above 35 μg/m³ prevail throughout UP, with hot spots in and

FIGURE 25: SECTOR SHARES TO THE PM2.5 PRECURSOR EMISSIONS IN UTTAR PRADESH, 2020



Source: Authors' original figure for this report as computed by the GAINS-IGP model around cities reaching concentrations of 80 µg/m³ and more. As discussed in Chapter 2, model results reproduce the available ground-level monitoring data rather well, considering the prevailing inadequacy of data and the necessary simplifications associated with any computer model.

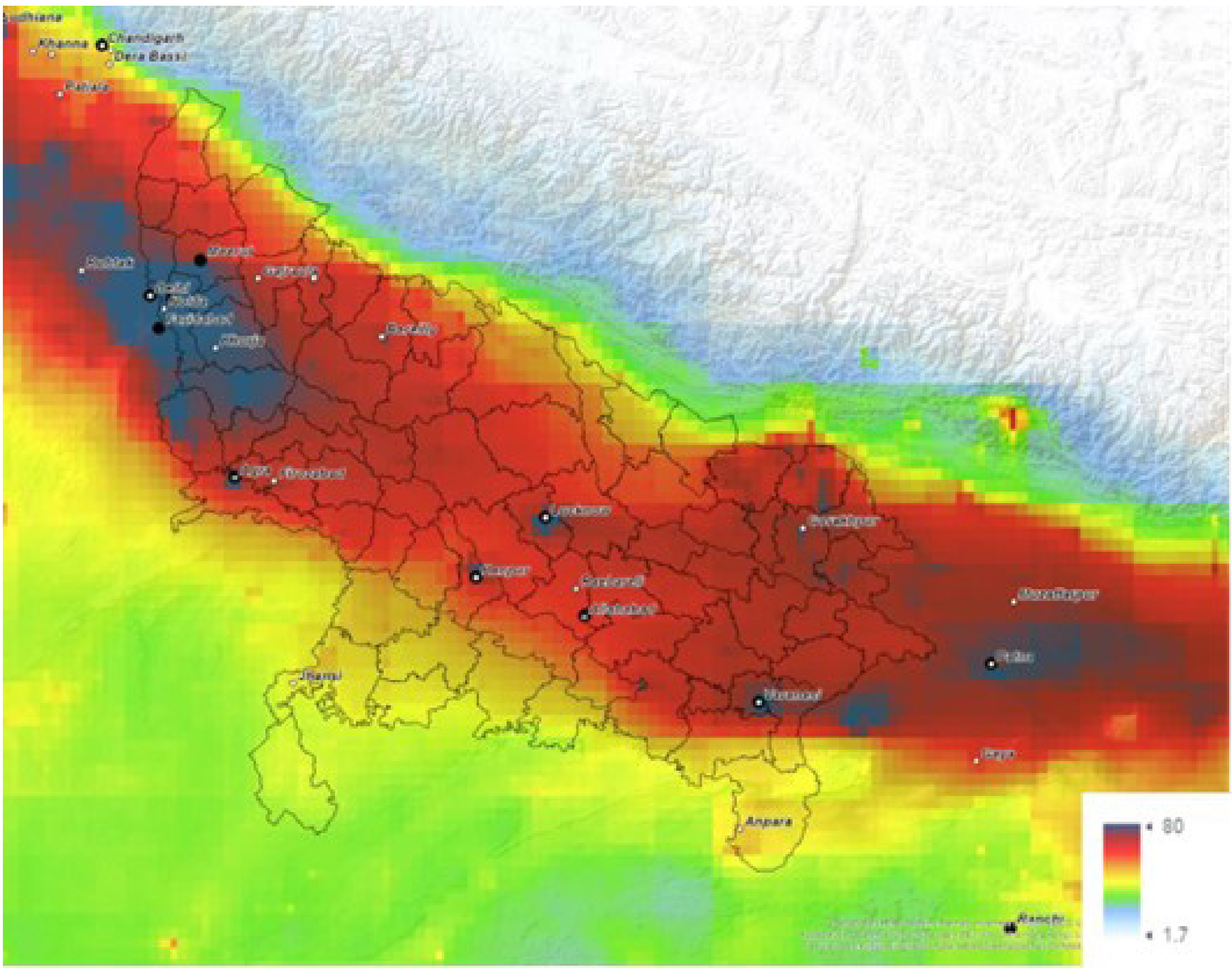
Long-range transport of PM2.5 in UP

The geo-physical approach of the atmospheric dispersion model employed by GAINS-IGP makes it possible to track the fate of emissions emerging from specific sources and thereby to quantify their contributions to total PM2.5 concentrations in ambient air in the defined area.

Uttar Pradesh, which is embedded in the IGP airshed, is characterized by a significant transport of pollution across the borders of the surrounding states and countries. This is a direct consequence of fundamental physics related to the small size of PM2.5 particles which cause a typical residence time of PM2.5 in the atmosphere of about a week. During this time, particles are transported with the wind over large distances, so that at any given location PM2.5 in ambient air originates from upwind emission sources extending over several hundreds of kilometers within the same airshed.

On average and accumulated over the entire year, in 2020 about 57 percent of the PM2.5 in ambient air in UP originated from UP emissions, while 43 percent were imported from outside regions. Thirteen percent came

FIGURE 26: SPATIAL DISTRIBUTION OF PM2.5 CONCENTRATIONS IN UTTAR PRADESH IN 2020



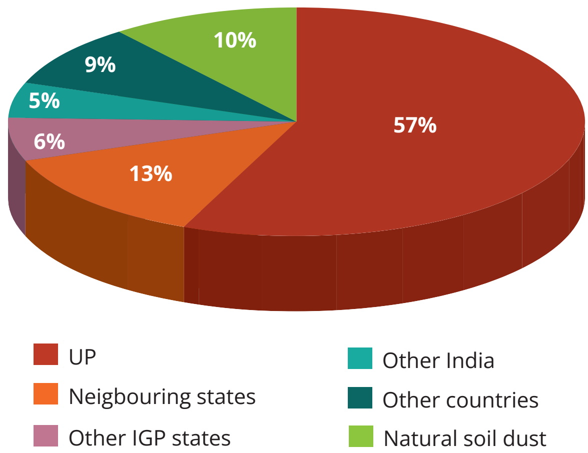
Source: Original figure for this report as computed by the GAINS-IGP model

from the neighboring states, six percent from other states in the IGP, five percent from other regions in India, and 9 percent from other countries. About 10 percent consisted of natural soil dust (Figure 28). The shares differ across sectors owing to their characteristic emission heights, their composition of PM2.5 precursor substances, and the temporal emission patterns of the various sources.

Transport sector

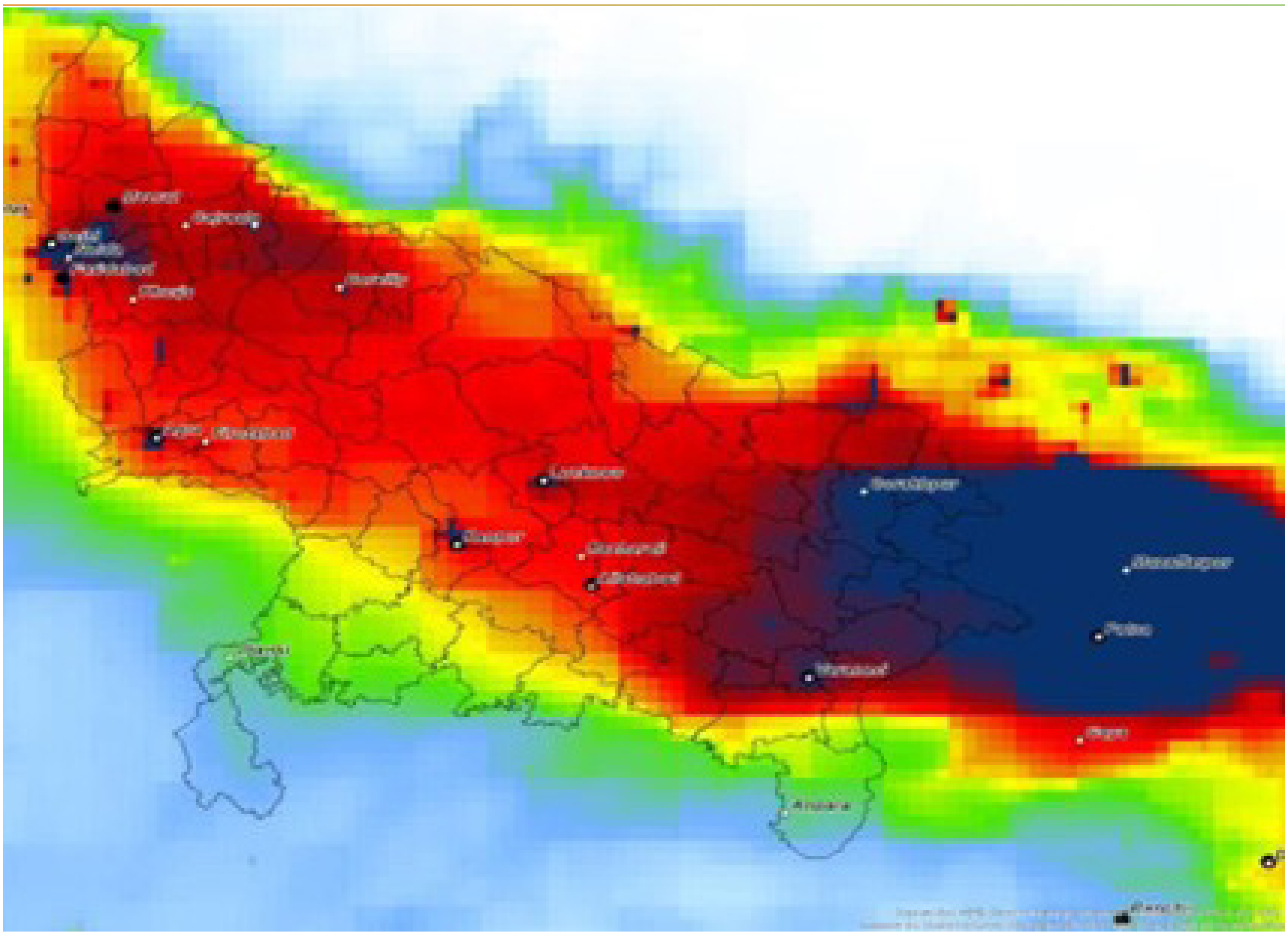
On average, in 2020 emissions from the transport sector contributed about 9.1 µg/m³ (~14 percent) to PM2.5concentrations in UP. Forty-two percent originated in upwind IGP regions outside of UP, leading to significant background levels of PM2.5 throughout UP with a strong decreasing gradient towards the east. Emissions from UP cause hot spots in cities (Meerut, Ghaziabad, Moradabad, Bareilly, Agra, Firozabad, Noida, and Gajraula) (Figure 30).

FIGURE 27: ORIGIN OF POPULATION WEIGHTED PM2.5 EXPOSURE IN UP IN 2020



Source: Original figure for this report as computed by the GAINS-IGP model

FIGURE 28: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN THE AMBIENT AIR IN UP FROM EMISSIONS OF THE RESIDENTIAL SECTOR IN THE IGP AIRSHED 2020 (NOTE THAT THE MAXIMUM SCALE OF THIS FIGURE IS 25 MG/MS)



Source: Original figure for this report as computed by the GAINS-IGP model

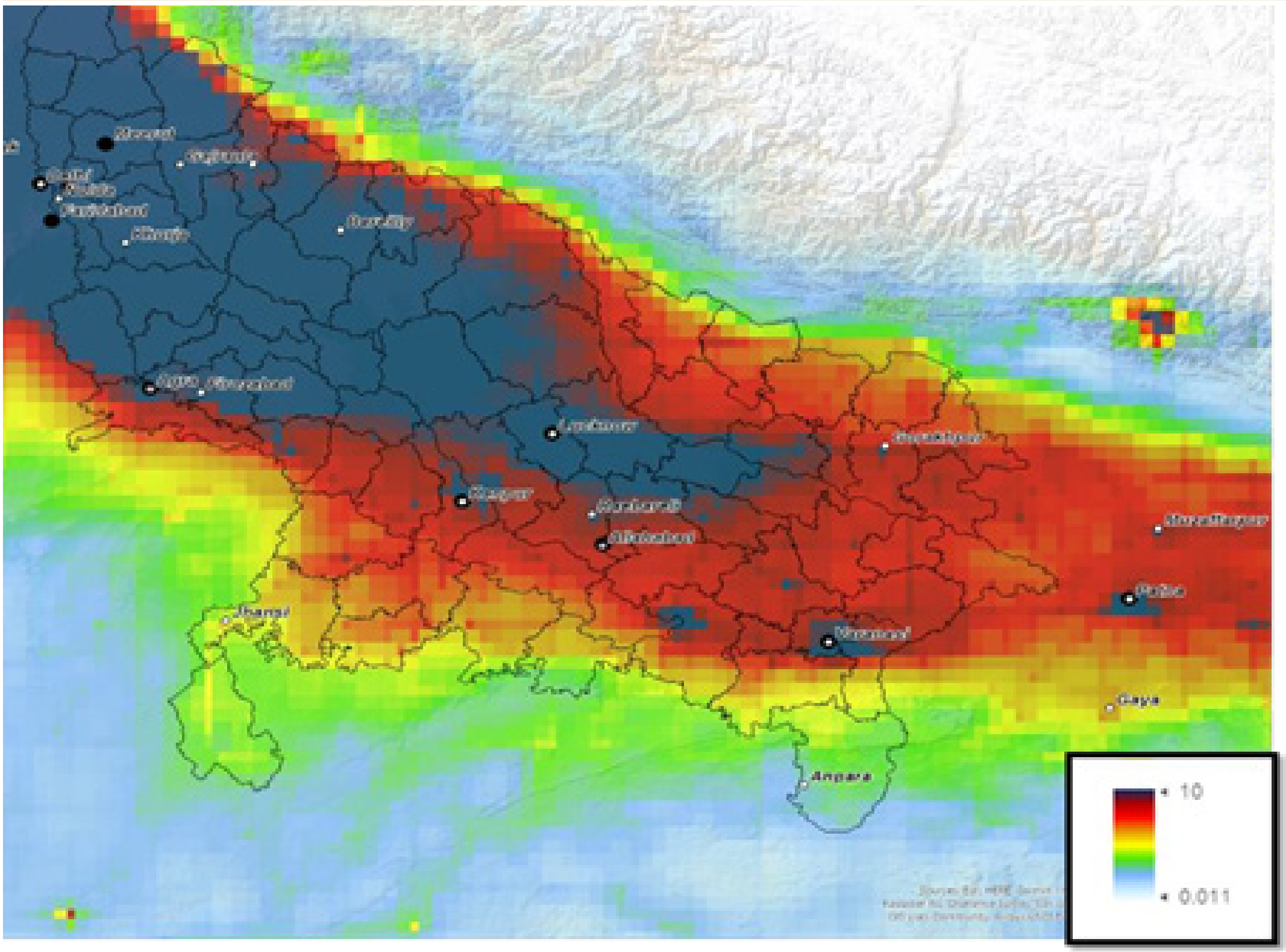
The largest share of PM2.5 from the transport sector (3.9 μg/m^3) originates from the resuspension of road dust. Tail-pipe emissions of primary PM2.5 emerge predominantly from diesel vehicles, with on average heavy-duty trucks (HDTs) and buses responsible for about 3.8 μg/m^3 in UP. Tailpipe PM2.5 emissions from gasoline vehicles are rather low, while 0.65 μg/m^3 can be attributed to two- and three-wheelers, and 0.8 μg/m^3 to non-road mobile machinery such as agricultural tractors and construction machinery (0.7μg/m^3). In addition, vehicles are a major source of NOx emissions, which can lead to the formation of secondary PM2.5 and ground-level ozone under suitable meteorological conditions. It is further noted that the state-wide contributions to PM2.5 from road dust and heavy-duty trucks are partly following the main highway network throughout UP while contributions from buses are more evenly distributed.

Municipal waste management

Current practices of municipal waste management in UP lead to significant amounts of solid waste that end up burned either in centralized waste dumps or spatially dispersed as uncollected waste. The latest emission estimates suggest an average contribution of 2.7 μg/m^3 across UP, significantly lower than in the surrounding states (Figure 32). Within UP, the highest levels occur around Noida city and a few cities such as Agra, Lucknow, Kanpur, and Bareilly. The low levels in UP are mainly caused by a comparably low contribution from sources within UP, accounting for only 1.1 μg/m^3 (40 percent) of the total sector contribution.

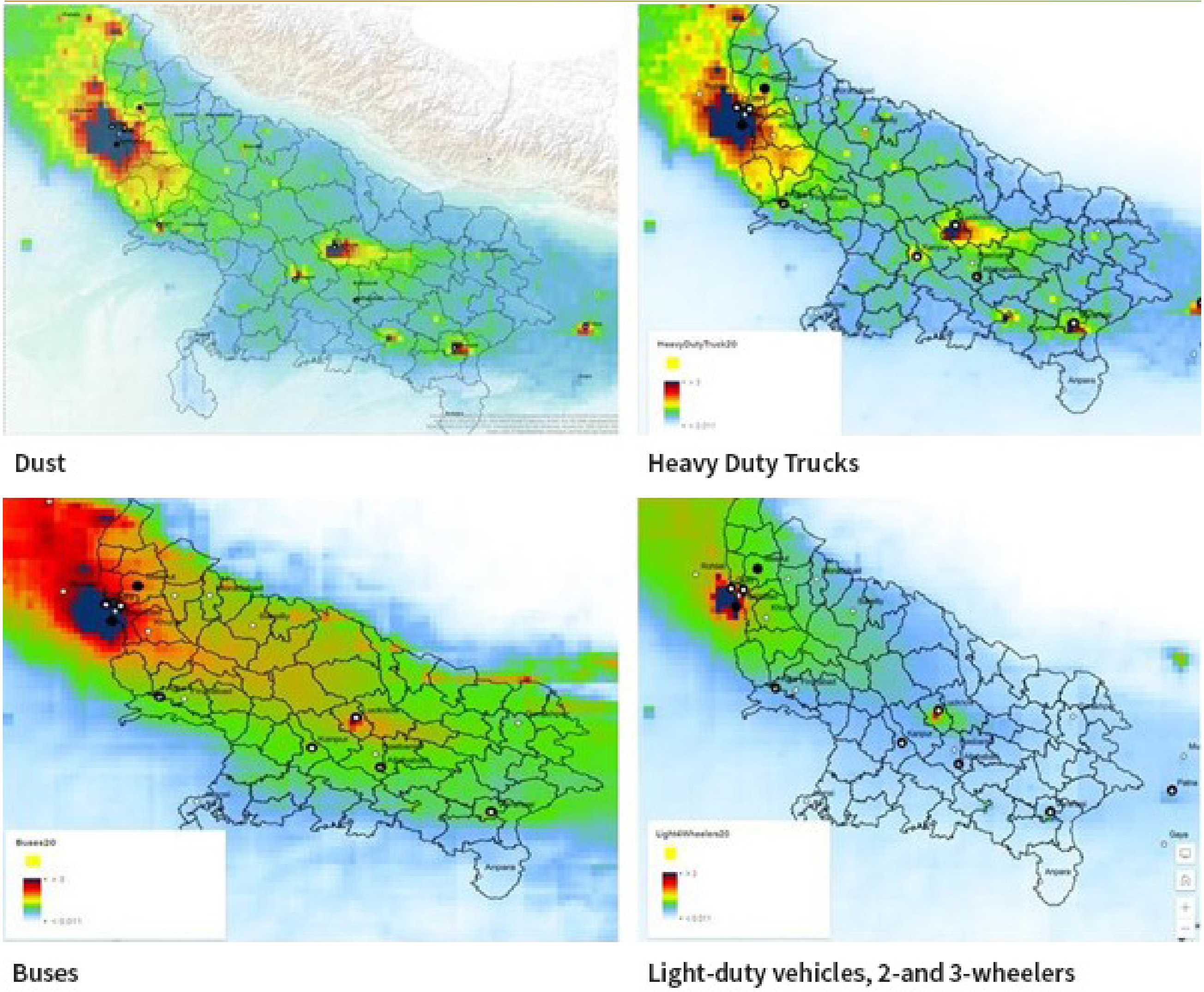
This estimate emerges from the emission estimates that have been compiled by the UCAMP experts in early 2023. However, gaps

FIGURE 29: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN THE AMBIENT AIR IN UP FROM EMISSIONS FROM THE TRANSPORT SECTOR IN THE IGP AIRSHED, 2020



Source: Original figure for this report as computed by the GAINS-IGP model

FIGURE 30: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS FROM DIFFERENT VEHICLE CATEGORIES IN IGP AIRSHED, 2020



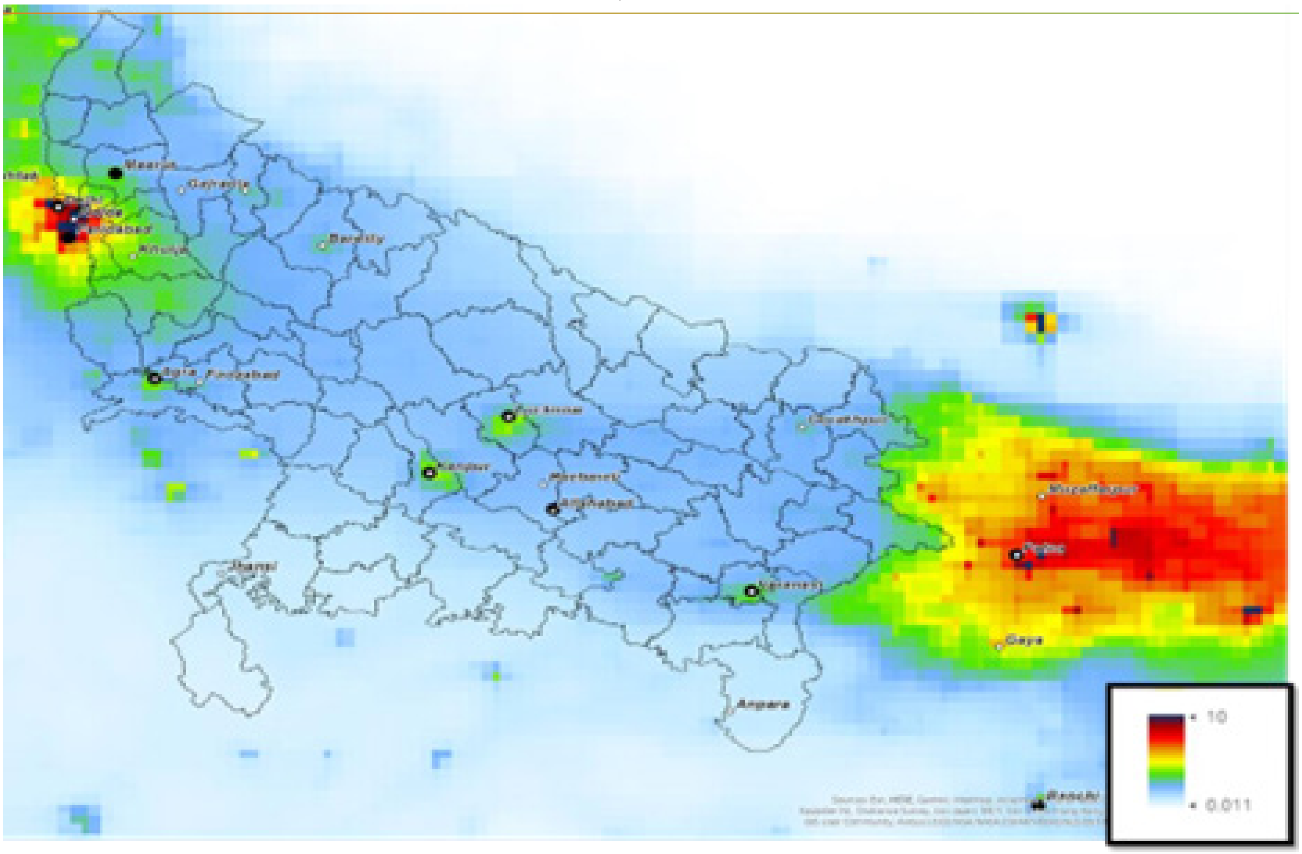
Note: maximum scale for road dust is 10 μg/m3 while it is 3 μg/m^3 for HDTs, buses and LDVs)
Source: Original figure for this report as computed by the GAINS-IGP model

in available statistics for this sector indicate several uncertainties and potential biases in the estimated reduction potentials. In particular, the published statistical information on municipal waste management is likely to have missed major parts of informal waste management, especially in rural areas. Thereby, emissions from waste management estimated in the 2023 inventory are about 80 percent lower than what has been estimated before by IIT Delhi and IIASA based on statistical correlations between generated waste volumes and per-capita income derived from comparable conditions in other states and areas in South Asia. A potential low bias of the emission estimated is supported by the fact that the PM2.5 concentrations calculated with the GAINS-IGP model for Uttar Pradesh are somewhat lower than AOD-derived estimates (see Chapter 3) while there is a good match in the surrounding States. Also, the original GAINS-IGP emission estimate resulted in a good fit of the source apportionment data for Kanpur with the PMF source apportionment that has been derived from speciated monitoring data (see Chapter 3).

Micro Small and Medium Enterprises (MSMEs) including brick kilns

On average, small and medium industries within IGP contributed about 7 μg/m^3 to PM2.5

FIGURE 31: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN THE AMBIENT AIR IN UP FROM EMISSIONS OF MUNICIPAL WASTE MANAGEMENT IN THE IGP AIRSHED, 2020



Source: Original figure for this report as computed by the GAINS-IGP model

concentrations in UP, and about one-third of MSME emissions came from sources outside UP. On an annual basis, about 1.5 µg/m³ is estimated to originate from brick kilns, although they make up a much larger contribution during their operating season. The highest levels occur in western districts/cities (Meerut, Bareilly, Agra, Firozabad, Noida, Gajraula), in eastern districts/ cities (Gorakhpur, Varanasi), and in some central parts in and around Lucknow.

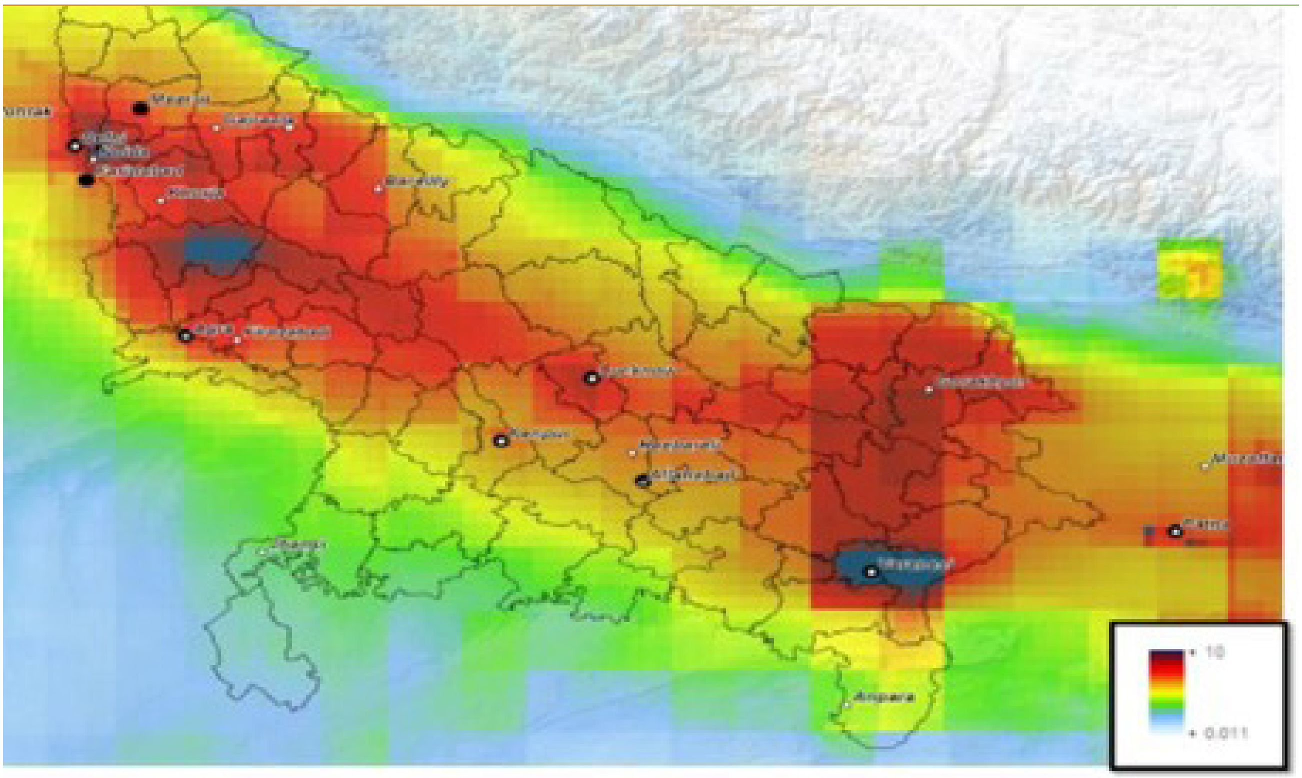
Power plants and large industries

On average, in 2020 power plants and large industrial installations contributed to PM2.5 levels in UP about 3.6 and 1.9 µg/m³, respectively (Figure 34). Due to a limited number of high stack industries and power plants in UP, about three-quarters were imported from mainly other regions in the IGP, to some extent from other parts of India and from other countries. Heavy contributions to PM2.5 concentrations from high stack sources are predominantly in mining and industrial areas in neighboring Jharkhand state in the Southeast.

Manure management and fertilizer application

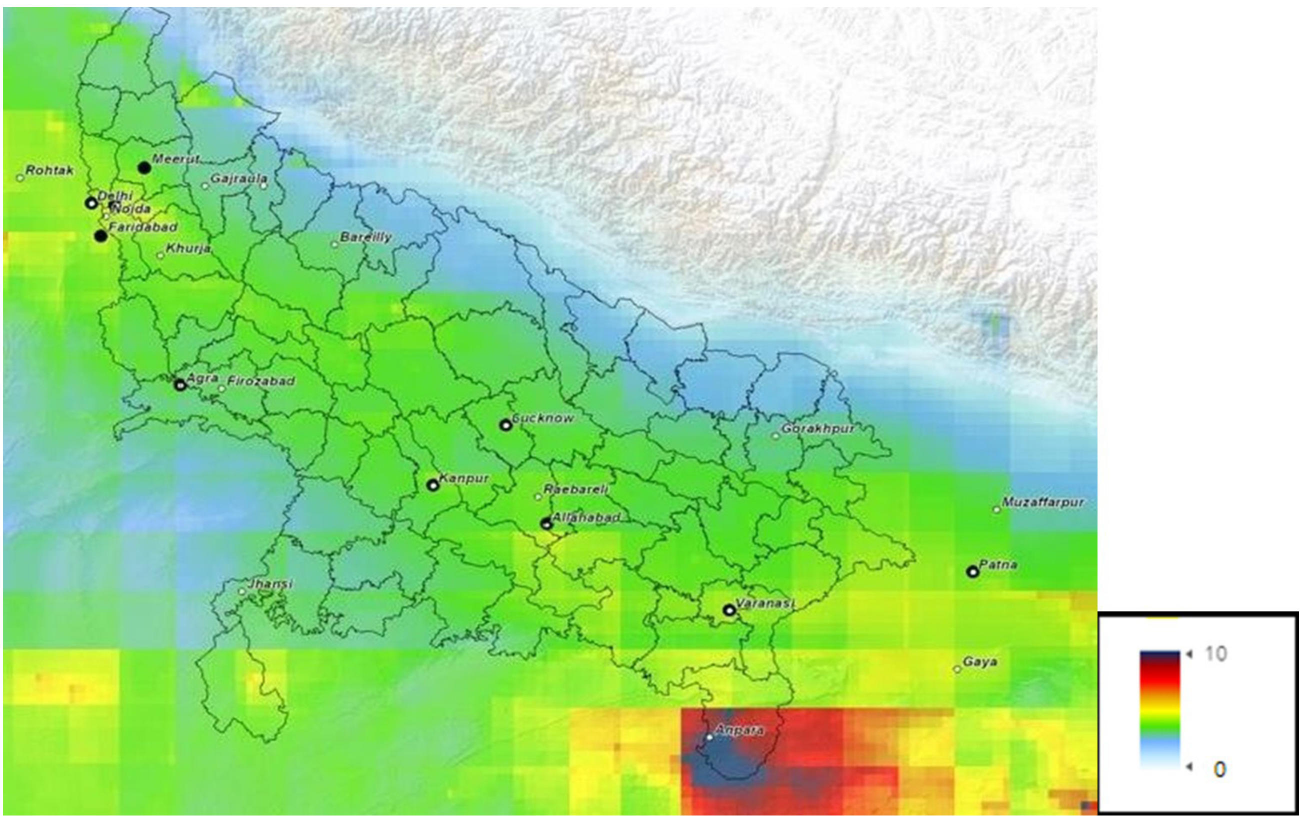
The evaporation of manure during storage and application to fields as well as the application of fertilizer (especially urea-based fertilizers) causes significant emissions of NH3 to the atmosphere, which act as a potent precursor in the formation of secondary PM2.5 (ammonium sulfates and ammonium nitrates) which is subsequently formed in the atmosphere and transported over significant distances. In 2020, these sources accounted for about 8.2 µg/m³ (11 percent) of PM2.5 concentrations in the ambient air in UP. Livestock manure (cattle, buffalo, cows, goats, horses, and pigs) accounts for 57 percent of this contribution, while the rest is related to fertilizer usage. High levels occur throughout the state, with peaks in the central, western, and

FIGURE 32: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN THE AMBIENT AIR IN UP FROM EMISSIONS FROM SMALL INDUSTRIES (INCLUDING BRICK KILNS) IN THE IGP AIRSHED, 2020



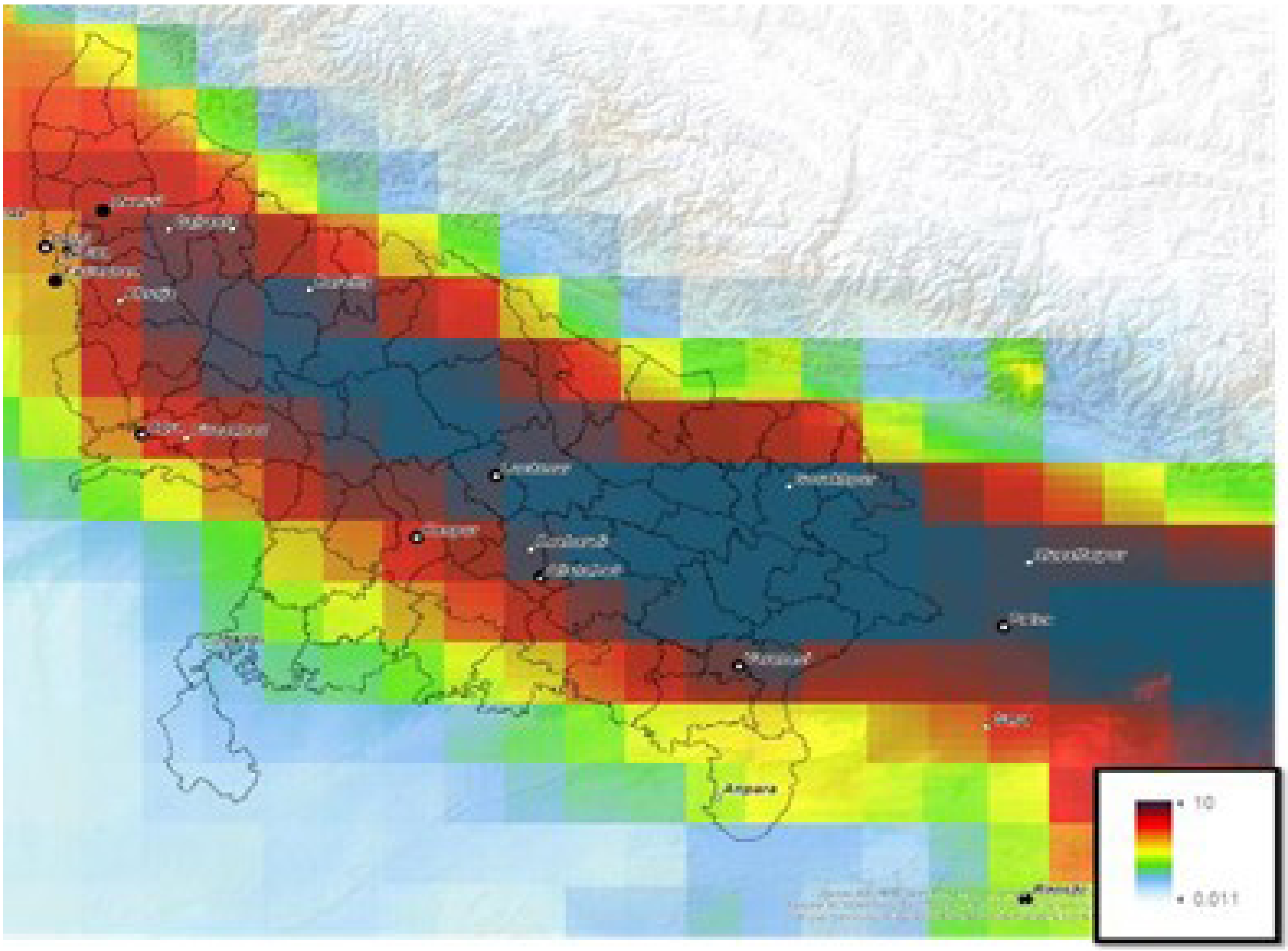
Source: Original figure for this report as computed by the GAINS-IGP model

FIGURE 33: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN THE AMBIENT AIR IN UP FROM EMISSIONS FROM HIGH STACK SOURCES - POWER PLANTS AND LARGE INDUSTRIES - IN THE IGP AIRSHED, 2020



Source: Original figure for this report as computed by the GAINS-IGP model

FIGURE 34: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN THE AMBIENT AIR IN UP FROM EMISSIONS FROM LIVESTOCK MANURE MANAGEMENT AND FERTILIZER APPLICATION IN THE IGP AIRSHED, 2020



Source: Original figure for this report as computed by the GAINS-IGP model

eastern parts of districts/cities Lucknow, Meerut, Raebareli, Bareilly, Agra, Firozabad, Noida, Gajraula, Gorakhpur, and Varanasi.

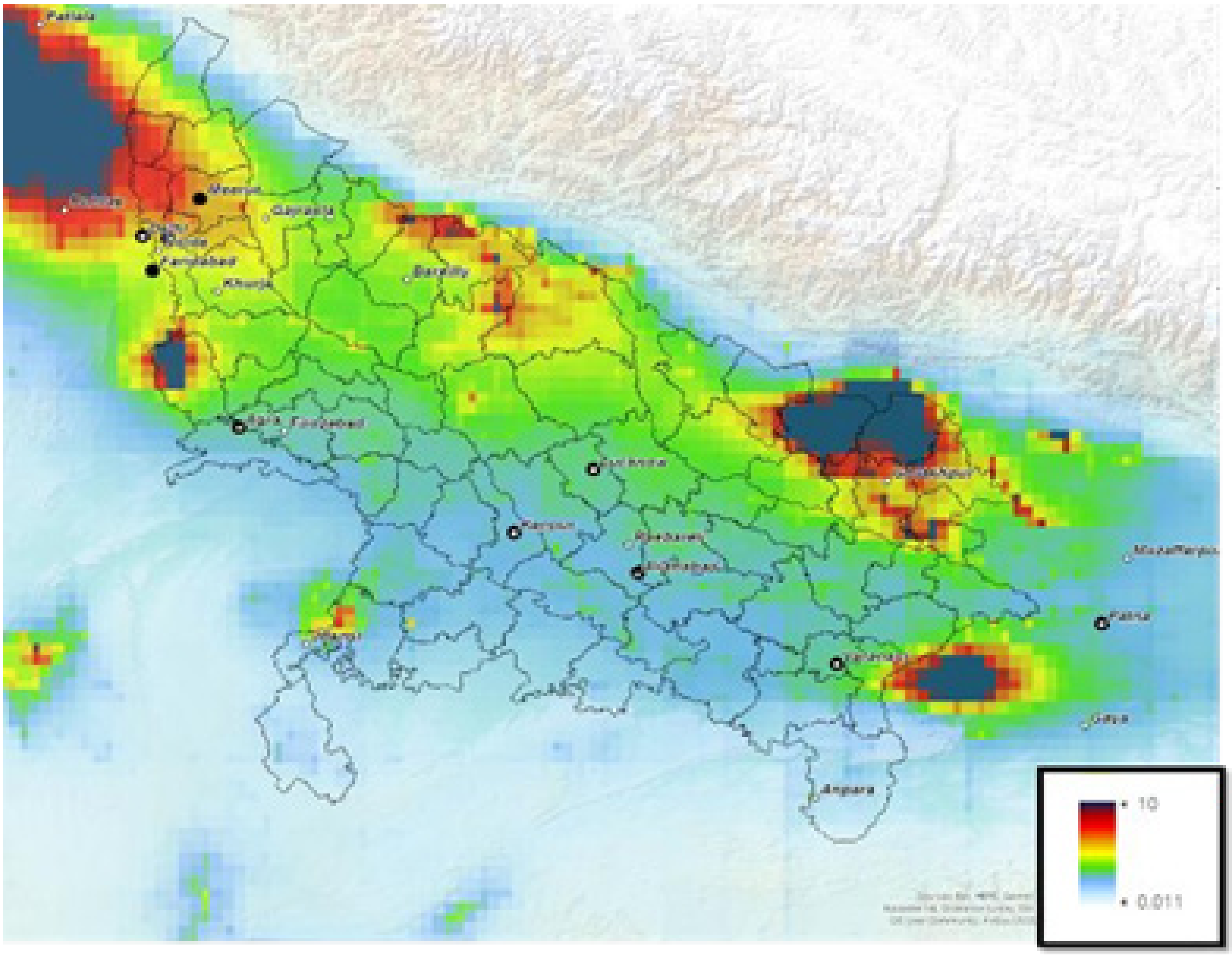
Open burning of agriculture residue

The open burning of agriculture residue is leading to episodes with high PM2.5 concentrations, with large visible impacts on air quality throughout the IGP during those events. However, as these burning periods do not extend over long times, the impact on annual mean concentrations is much lower. The GAINS-IGP model estimated that, averaged over the entire UP and the full year, this source contributes about 4.2 μg/m^3 (6 percent) to the total PM2.5 level in UP, with 40 percent imported from other areas in the IGP airshed outside of UP. The UP specific sources from residue burning are particularly highest in the eastern part of UP (districts north of Gorakhpur), the central part (north and east of Bareilly) and the western part (west of Agra) (Figure 36).

Summary

A wide range of economic activities cause significant deterioration of ambient air quality in UP. Average concentrations emerging from the various sectors and the concentration peaks are summarized in Table 5.

FIGURE 35: CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN THE AMBIENT AIR IN UP FROM EMISSIONS FROM THE OPEN BURNING OF AGRICULTURE RESIDUE IN THE IGP AIRSHED, 2020 (MAXIMUM SCALE: 10 MG/MS)



Source: Original figure for this report as computed by the GAINS-IGP model

TABLE 5: SUMMARY OF THE SECTOR CONTRIBUTIONS TO PM2.5 CONCENTRATIONS IN UTTAR PRADESH, 2020 (CONSIDERING ALL EMISSION SOURCES IN THE IGP AIRSHED)

Sector	Average PM2.5 concentrations in UP (not population- weighted)	Highest PM2.5 concentrations	
		µg/m³	Areas
Residential	18.5 µg/m³	~25 µg/m³	Several eastern districts, Delhi-near areas
Transport	9.1 µg/m³	~10 µg/m³	Western UP areas NW of Lucknow, as well as in several cities
Manure management and fertilizer application	8.2 µg/m³	~10 µg/m³	Widespread central belt from East towards Gajraula
Medium & small industry	6.5 µg/m³	~10 µg/m³	Bhadohi, Chandauli, Aligahr, various urban hot spots

Sector	Average PM2.5 concentrations in UP (not population- weighted)	Highest PM2.5 concentrations	
		μg/m³	Areas
Waste management	2.2 μg/m³	~10 μg/m³	Delhi-near areas, hot-spots in Agra, Lucknow, Kanpur, Varanasi (up to 4 ug/m3)
Power sector and large Industries	3.6 μg/m³	~10 μg/m³	Various hotspots
Agri residue burning	4.0 μg/m³	~10 μg/m³	Maharajganj, Siddarthnagar, Mathura
Natural soil dust	7.1 μg/m³		Southwest areas

Source apportionment of PM2.5 in UP

While the maps in Figure 25 to Figure 36 provide valuable insights into the spatial diversity of the sectoral contributions to PM2.5 concentrations throughout UP, aggregated metrics that summarize contributions in a larger region or at specific locations are more informative to address the burden of air pollution on public health and to maximize health benefits from pollution control interventions. The spatial and sectoral origins of population exposure (see discussion in Chapter 2) in a region or at a location can be illustrated by so-called source apportionment diagrams. The situation in UP in 2020 is depicted in Figure 38: indicating the contributions to PM2.5 exposure that originate from (i) natural emission sources, i.e., soil dust, (ii) from other countries, (iii) from other regions in India except for the neighboring states of Bihar, (v) from the neighboring states of UP, and (vi) from UP itself.

In 2019/2020, about 57 percent of the PM2.5 in ambient air in UP originated from UP emissions, while 43 percent were imported from outside

FIGURE 36: SOURCE APPORTIONMENT OF (POPULATION-WEIGHTED) PM2.5 EXPOSURE IN UTTAR PRADESH FOR 2020 –TOTAL CONTRIBUTIONS (PRIMARY AND SECONDARY PM2.5) BY SECTOR

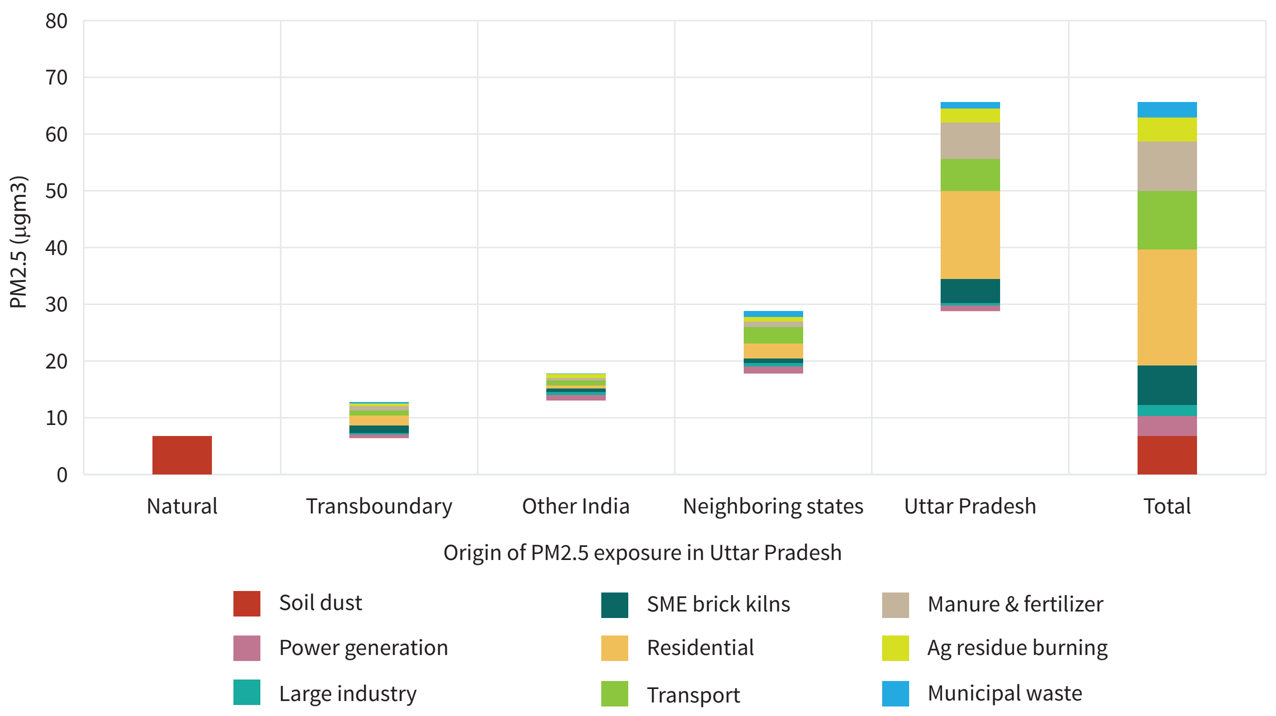
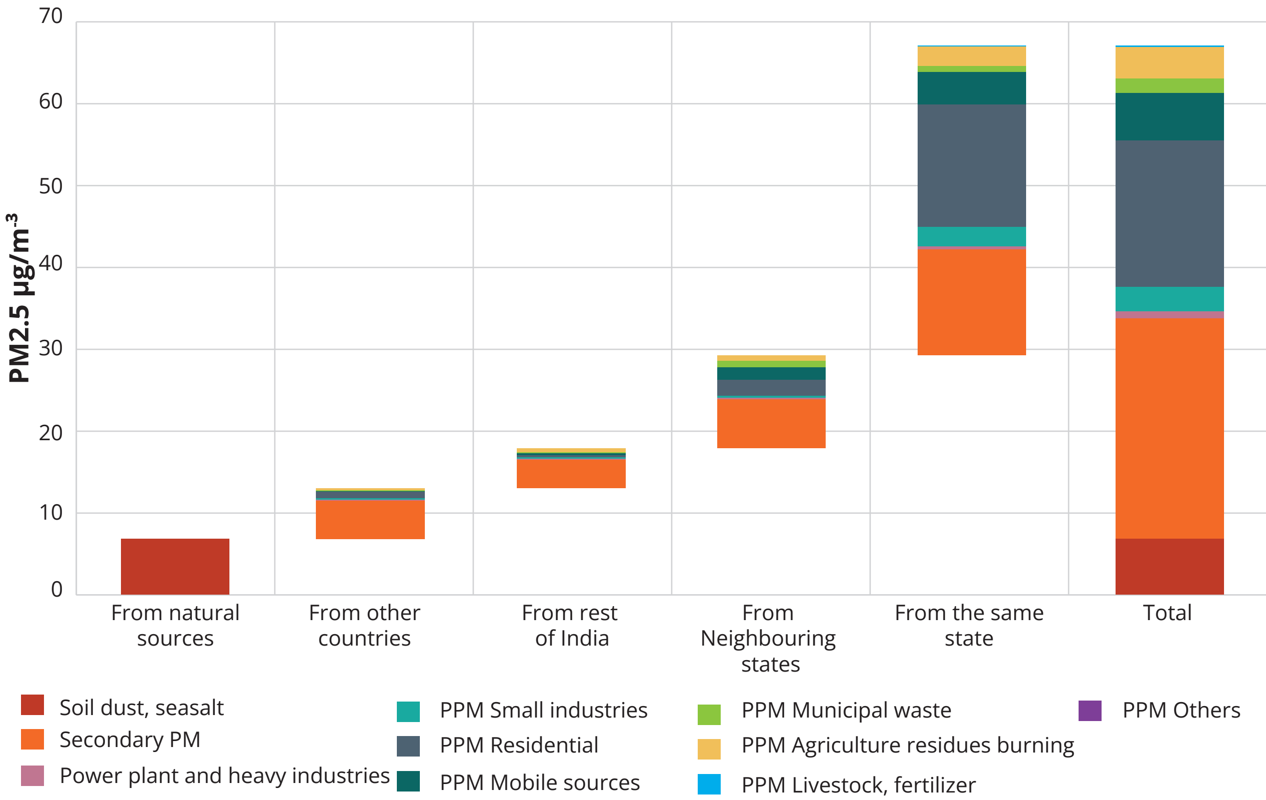


FIGURE 37: SOURCE APPORTIONMENT OF (POPULATION-WEIGHTED) PM2.5 EXPOSURE IN UTTAR PRADESH FOR 2020 –SECTORAL CONTRIBUTIONS OF PRIMARY PM AND TOTAL CONTRIBUTION OF SECONDARY PM



regions.13 percent came from the neighboring states, six percent from other states in the IGP, five percent from other regions in India, and nine percent from other countries. About 10 percent consisted of natural soil dust.

The largest local source of PM2.5 exposure in Uttar Pradesh relates to households, mainly solid fuel cookstoves. Sources in the power and industry sectors, transport, waste management and agricultural activities (agriculture residue burning, livestock manure, fertilizer application) make up for the rest at almost equal shares. The residential sectors are less relevant for the contributions from neighboring States, essentially because there is less solid fuel use in households in the upwind Delhi and northwest areas. Contributions from more distant sources are dominated by the sources of secondary PM2.5, especially coal combustion in power plants and industry.

Considering emissions throughout the IGP airshed, the largest contribution to PM2.5 exposure in UP emerges from the residential sector (31 percent), followed by transport (16 percent) and manure and fertilizer application (13 percent). Natural soil dust accounts for 10 percent, agriculture residue burning 6 percent, power generation 5 percent, and municipal waste management 4 percent.

However, the impact on air quality in UP from emission sources within UP that can be readily influenced by local policies is distinctively different. As mentioned, only 36.9 µg/m^3 (57 percent) out of the total exposure of 65.6 µg/m^3 originate from UP sources. 42 percent are related to the residential sector in UP, 17 percent to manure management and fertilizer use, 15 percent to transport sources, and 11 percent to small and medium enterprises including brick kilns. The open burning of agriculture residue in UP contributes about seven percent, power generation and large industry about four percent, and municipal waste management about three percent (Table 6).

TABLE 6: ORIGIN OF PM2.5 EXPOSURE IN UP 2020

	Spatial origin of PM2.5 exposure in UP (µg/m^3)						Share of	
	Natural	Other countries	Other India	Neighbor states	UP	Total	local UP contribution	total IGP exposure
Soil dust	6.71					6.71	0%	10%
Power generation		0.55	0.92	1.17	0.96	3.61	3%	5%
Large industry		0.29	0.51	0.63	0.47	1.90	1%	3%
SME, brick kilns		1.36	0.57	0.86	4.20	6.99	11%	11%
Residential		1.71	0.58	2.59	15.50	20.37	42%	31%
Transport		0.92	0.87	2.92	5.67	10.38	15%	16%
Manure & fertilizer		0.83	0.48	1.00	6.41	8.72	17%	13%
Agriculture residue burning		0.36	0.64	0.72	2.53	4.24	7%	6%
Municipal waste		0.35	0.17	1.09	1.11	2.73	3%	4%
Total	**6.71**	**6.38**	**4.73**	**10.G8**	**36.86**	**65.65**	**100 %**	**100 %**

Source: Original calculation for this report

The importance of secondary PM2.5, which is formed in the atmosphere from precursor emissions of SO2, NOx, NH3 and VOC, is depicted in Figure 38:, revealing that (i) about 40 percent of total PM2.5exposure in UP consists of secondary PM2.5, and (ii) about 60 percent of secondary PM2.5 originates from sources outside the state.

Given this variety in contributing sources, effective solutions need balanced combinations of measures across sectors and other regions in the IGP airshed and to prioritize those measures that achieve air quality improvements at relatively low cost. Particularly secondary PM2.5 sources must be managed at the regional scale.

APPLICATION OF AIRSHED MODELING TO PRIORITIZE ACTIONS

Airshed modeling

Context and approach

Given the high PM2.5 level in Uttar Pradesh that is likely to prevail in the future, this chapter explores the potential and priority areas for bringing down PM2.5 levels to national and international air quality standards. For this purpose, it examines the scope of PM2.5 exposure reductions from the full implementation of existing policies and additional measures that could be taken within Uttar Pradesh beyond those which are already in place, and their interplay with possible action in other areas within the IGP airshed.

The analysis is carried out with the GAINS-IGP model that has been tailored to the Indo-Gangetic Plain (the GAINS model is described in Chapter 2). Based on the latest available statistics, GAINS-IGP estimates for 2020 the PM2.5 precursor emissions from all relevant sources and computes the impact of each emission source on PM2.5 exposure in Uttar Pradesh in 2020. It extrapolates the source contributions to 2035 considering the likely impacts of economic and social development on the levels of emission-generating activities as well as full implementation of already existing pollution control policies and regulations. As outlined in chapter 2, GAINS-IGP considers about 1,100 possible emission control options that could be applied in Uttar Pradesh beyond what is required by current regulations, quantifies the effect of each option on the various PM2.5 precursor emissions and how this would affect PM2.5 exposure in 2035. Subsequently, the analysis develops a likely scenario of the available emission control options along their potential reduction of PM2.5 exposure in Uttar Pradesh, considering control options that could be taken within UP as well as benefits from coordinated action within the IGP.

Given the latest available statistics, the analysis adopts 2020 as the base year. With a 10 years' time frame for the implementation of additional measures starting in 2025, the future analysis addresses exposure in 2035. This year is about halfway towards 2047, for which India strives to reach the status of a high-income country. Importantly, such a status should not only be reflected by the economic output of the economy, but equally by the wealth and the quality of life of Indian people, with good air quality as an important dimension.

Reaching the high-income status requires fundamental transitional changes throughout the economy. These will affect all the sectors that are currently major sources of air pollution. On the one hand, rapidly growing production levels, urbanization, mobility demand, and energy needs will enhance the pressure on pollution. Structural and technological restructuring of industries and transition to more sustainable cities and agriculture will reduce the importance of the most polluting activities. Actions to build resilient and green infrastructure to provide universal access to services, to increase the efficiency and productivity of the India economy, and a shift to higher-productivity lower-pollution technologies offer an opportunity to improve air quality while accelerating India's journey toward high-income status.

Reference projections for 2035

Social development and economic growth will change the relative importance of the various economic sectors for the population exposure that has been identified in the preceding chapter for 2020, and policies and measures that have been recently decided will unfold their full impact only in the following years depending upon their status and efficacy of implementation. To this end, this report develops two reference projections for the year 2035 that outline the likely development of emissions and air quality and distil the importance of the full implementation of already adopted air quality policies and regulations.

A hypothetical business-as-usual (BAU) projection for 2035 illustrates the consequences of economic growth in the absence of any air quality policy interventions. The analysis in this UCAP report assumes an annual population increase of 0.8 percent up to 2035. GDP will grow by seven percent annually between 2020 and 2035 so that total economic output will be about 2.7 times higher than in 2020 (Table 7). This projection applies the assumed growth rates of population and GDP to the 2020 volumes of the various emission-generating activities (industrial activities, transport demand, and waste generation are assumed to follow the GDP trend, while the demand for final energy for cooking is aligned with population growth). Furthermore, no energy policy interventions that would change the shares of the various fuels are assumed, although the energy efficiency improvements from autonomous technological progress (e.g., new coal power plants) are considered. However, this hypothetical projection does not assume any emission control measures (e.g., flue gas desulfurization of coal powerplants etc).

TABLE 7: MACRO-ECONOMIC ASSUMPTIONS FOR 2035

	Unit	2020	2035
Population	Million people	226	254
GDP	trillion US-$/ year*)	231	577
GDP per capita	US per person per year	1,026	2,274

* constant 2020 US-$
Source: Original table for this report

The benefits of full implementation of the current air quality policies are illustrated in the baseline scenario (2035). This baseline scenario assesses the impacts of full implementation of a wide range of currently adopted policies that will have an impact on air quality in Uttar Pradesh on the hypothetical business-as-usual projection for 2035. It considers a wide range of sectoral policies for energy, power generation, industry, transportation, agriculture, municipal waste management, as well as residential and commercial sources that have been adopted in the last decade.

As a result of full implementation of these policies and regulations, it is assumed that in 2035 all- new thermal powerplants will use low-NOx burners, and plants built before 2018 will be gradually retrofitted. Coal-fired power plants will be equipped with flue gas desulfurization and electrostatic precipitators with more than 99.8 percent removal efficiency. Diesel generator (DG) sets will switch to oil with 0.001 percent sulfur content. Similar measures apply to industrial boilers and furnaces, with specific requirements for the ceramic industry, foundries, glass production, lime kilns and reheating furnaces. All new brick kilns will employ zigzag or vertical methods of brick production and comply with the new standards as stipulated in the notification (MoEFCC, 2018b). Emission controls for road transport consider the phase-in of the Bharat VI standards, substituting the earlier requirements for new light- and heavy-duty vehicles (e.g., Bharat IV). Electric vehicles will enter the market, and public transport systems will be enhanced. For households, the Ujjwala scheme and other programs like India's Lifestyle for the Environment (LIFE) Campaign will further enhance access to clean cooking fuels such as LPG and electric (induction) stoves but will not eliminate the use of biomass in 2035. In Uttar Pradesh, about one- third of households will still burn fuel wood, dung or crop residues, although partly using improved cookstoves. Furthermore, the Indian waste management rules will prohibit the open burning of waste in cities and require segregation, processing and recycling of waste (MoEFCC, 2016). The burning of agricultural stubble after harvest is assumed to be restricted but not completely stopped. Similar regulations are assumed for other states in the IGP. The measures that are considered in the baseline are listed in Table 8 (the full list of regulations is provided in Annex 3).

The full implementation of the existing policies and regulations, however, requires adequate finances, institutional capacities, appropriate technologies, implementation framework and most importantly a robust monitoring and evaluation framework. Most of the Air Quality Management (AQM) interventions including their finances are to be implemented by the Urban Local Bodies. The competing commitments of ULBs mostly limit the financing for AQM and it takes time for building the institutional capacities involving hiring of resources, their training and capacity building etc. The involvement of multiple departments and agencies for AQM also poses challenges related to coordination, synergizing the targets, and monitoring the implementation of AQM measures. The implementation of regulations and ensuring the compliances remains a great challenge, therefore, there is a strong need for developing virtual monitoring mechanisms and technology driven audit systems that have minimal human interface along with a state of the science Decision Support System (DSS) backed up by strong monitoring infrastructure.

The State of Uttar Pradesh is taking up various leading measures including financing that are facilitating effective implementation of the existing policies and regulations. Such measures are required to be further strengthened so that full implementation of existing policies and regulations along with the associated projected benefits in respect of improved air quality in the State is achieved as hypothesized in baseline scenario.

TABLE 8: SUMMARY OF AIR QUALITY MANAGEMENT MEASURES ASSUMED TO BE FULLY IMPLEMENTED IN THE BASELINE FOR 2035[20]

Mobile sources:
Heavy-duty trucks and buses, diesel: 91 percent of vehicles complying with Bharat VI controls, older vehicles with Bharat III and Bharat IV emission standards
Light-duty vehicles (cars and vans), gasoline: 81 percent of vehicles complying with Stage VI controls
Light-duty vehicles (cars and vans), diesel: 56 percent of vehicles complying with Stage VI and 15 percent of vehicles with Stage IV controls Similar controls for CNG-powered vehicles
Mopeds: 100 percent complying with Stage 3 controls
Agricultural machinery: 100 percent complying with emission standards equivalent to EU Stage 3B
Construction machinery: 95 percent complying with emission standards equivalent to EU Stage 3A
Power generation:
Moderate PM controls for large power stations (e.g., electrostatic precipitators with about 95 percent efficiency)
Effective desulfurization of flue gases at [all] large coal power stations
Diesel generators: 95 percent complying with Stage 1 controls
Households:
79 percent of households cooking with electricity or LPG (54 percent in 2020)
Improved cookstoves at 10 percent of the remaining biomass cookstoves
Partial collection and disposal of municipal waste
Industry:
Basic PM controls (cyclones/ESP1) in most industrial sectors (90 percent of fuel consumption)
Moderate PM controls (ESP2) at a few industrial sectors (cement, fertilizer)

Source: Original table for this report

[20] Assumptions for the application rate for each measure in 2030 were agreed upon in meetings discussing control options to be applied in the UP module of GAINS-IGP between IIASA, the UP-CAMP working group and TERI in April 2023 after the database for the UP module had been updated (ref. pp 43-44) and extrapolated to 2035.

PM2.5 precursor emissions in 2035

The adopted pollution control regulations, if fully implemented, will lead to a clear decoupling between emissions and economic growth trends in 2035. Despite the assumed growth in GDP by a factor of 2.7, SO2 emissions in the baseline projection (which takes account of current emission control regulations) shrink by 50 percent and primary PM2.5 by eight percent (Table 9). In contrast, NOx emissions grow by 37 percent and NH3 emissions by 15 percent (Table 10), all well below the growth of GDP. The importance of the adopted emission regulations is clearly visible from the difference to the business-as-usual scenario, in which SO2, NOx, PM2.5 emissions increase by 172 percent, 135 percent and 78 percent respectively.

TABLE 9: PM2.5 AND SO2 EMISSIONS IN UP, 2020 AND 2035 (KILOTONS)

	PM2.5			SO2		
	2020	Business-as-usual[1)] 2035	Baseline[2)] 2035	2020	Business-as-usual[1)] 2035	Baseline[2)] 2035
Power generation	48	89	10	387	1008	39
Industrial combustion	157	348	186	125	510	76
Industrial processes	33	112	44	23	70	49
Brick kilns	24	129	41	73	195	88
Residential cooking	317	400	215	17	23	13
Other residential	72	55	55	52	49	49
HDT vehicles	12	34	30	2	10	10
Other road vehicles	5	10	8	1	3	3
Road dust	72	205	83	0	0	0
Non-road machinery	13	57	20	3	8	7
Livestock	6	5	5	0	0	0
Fertilizer use	0	0	0	0	0	0
Crop burning	148	170	136	5	6	5
Municipal waste	15	104	22	0	3	1
Total	**G21**	**171G**	**856**	**68G**	**1885**	**33G**

[1)]Without air quality policies and regulations
[2)]With full implementation of current air quality policies and regulations
Source: Original table for this report

TABLE 10: NOX AND NH3 EMISSIONS IN UP, 2020 AND 2035 (KILOTONS).

	NOx			NH3		
	2020	**Business-as-usual[1] 2035**	**Baseline[2] 2035**	**2020**	**Business-as-usual[1] 2035**	**Baseline[2] 2035**
Power generation	294	500	317	0	0	0
Industrial combustion	167	538	257	5	8	6
Industrial processes	21	77	36	27	37	37
Brick kilns	0	1	1	0	0	0
Residential cooking	36	49	27	6	8	5
Other residential	19	10	26	1	0	0
HDT vehicles	198	606	312	0	0	0
Other road vehicles	55	81	64	1	2	2
Road dust	0	0	0	0	0	0
Non-road machinery	132	479	232	0	0	0
Livestock	28	18	18	843	663	663
Fertilizer use	140	203	203	1304	1806	1805
Crop burning	5	6	5	30	35	28
Municipal waste	10	68	15	141	160	160
Total	**1105**	**2636**	**1514**	**235G**	**2718**	**2706**

[1] Without air quality policies and regulations
[2] With full implementation of current air quality policies and regulations

A wide range of policies and regulations in different sectors are responsible for the avoided emissions as per the baseline scenario. For primary emissions of PM2.5, about 40 percent of the total avoided emissions are linked to measures in the industrial sector including brick kilns (Table 11). Efforts in the residential and commercial sector (*inter alia*, the *Ujjwala* scheme to replace biomass used for cooking with Liquified Petroleum Gas (LPG) and/or electric (induction) cook stoves) expected to account about one quarter of the total avoided PM2.5 emissions. Measures for road and construction dust deliver about 16 percent, and the rules for municipal waste management about 10 percent. About two thirds of the avoided SO2 emissions come from power generation, and the rest from industrial sources. About 30 percent of the expected NOx reductions are a consequence of the Bharat emission standards, while regulations for industry, power generation and non-road mobile machinery contribute similar shares of the remainder.

TABLE 11: BUSINESS-AS-USUAL EMISSIONS IN 2035 (WITHOUT POLLUTION CONTROL POLICIES AND REGULATIONS) AND EMISSIONS AVOIDED BY THE CURRENT POLICIES AND REGULATIONS IN 2035 (KILOTONS) IF FULLY IMPLEMENTED

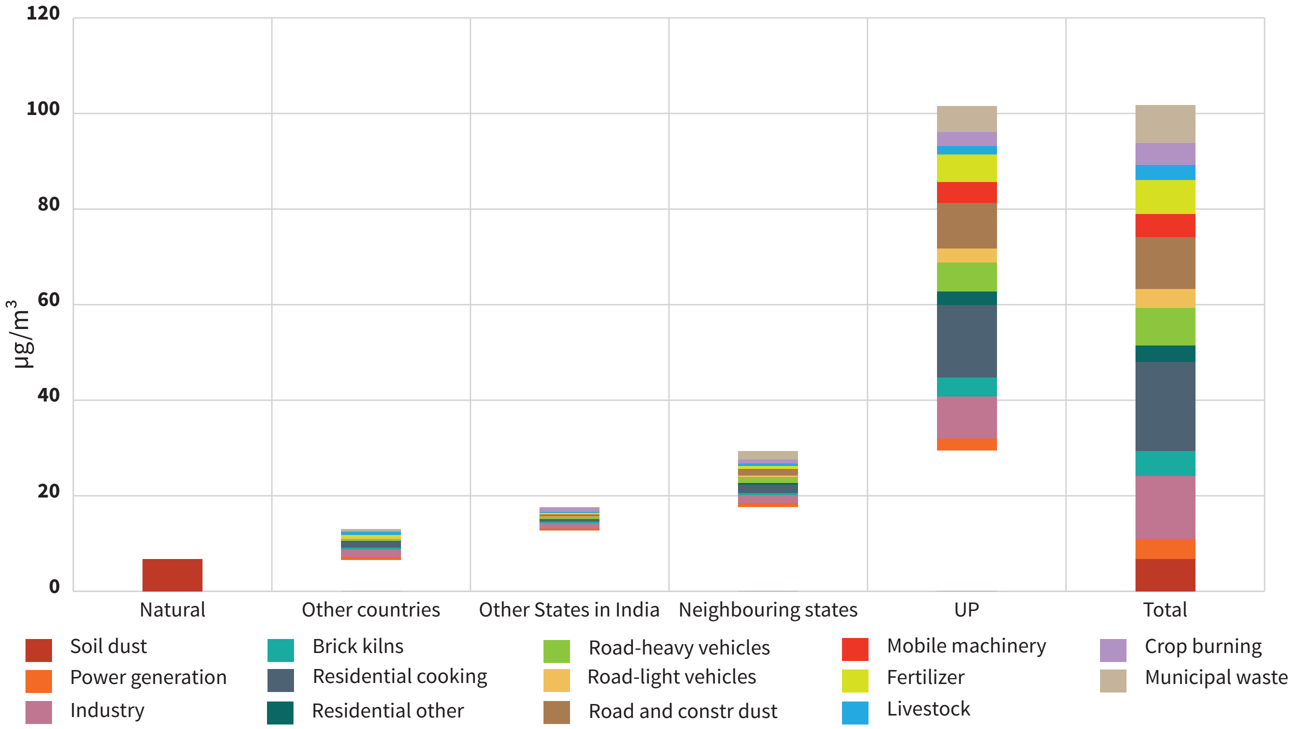
	PM2.5		SO_2		NO_x	
	Business-as- usual 2035	Emissions[1] avoided by policies and regulations	Business-as- usual 2035	Reduction from policies and regulations	Business-as- usual 2035	Reduction from policies and regulations
Power generation	89	-79	1008	-969	500	-182
Industrial combustion	348	-161	510	-435	538	-281
Industrial processes	112	-69	70	-22	77	-41
Brick kilns	129	-87	195	-107	1	0
Residential cooking	400	-185	23	-10	49	-22
Other residential	55	0	49	0	10	16
HDT vehicles	34	-5	10	0	606	-294
Other road vehicles	10	-2	3	0	81	-17
Road dust	205	-122	0	0	0	0
Non-road machinery	57	-37	8	-1	479	-246
Livestock	5	0	0	0	18	0
Fertilizer use	0	0	0	0	203	0
Crop burning	170	-34	6	-1	6	-1
Municipal waste	104	-82	3	-2	68	-53
Total	**1615**	**-782**	**1882**	**-1544**	**2568**	**-1068**

[1] With full implementation of current air quality policies and regulations
Source: Original table for this report

Baseline PM2.5 exposure in 2035

Without effective countermeasures, economic growth would lead to significant increases in PM2.5 exposure from industrial activities, road and construction dust, non-road mobile machinery, and waste management etc. so that total exposure in UP would surge to 102 μg/m^3 (Figure 39).

FIGURE 38: SOURCE APPORTIONMENT OF POPULATION EXPOSURE TO PM2.5 IN UP FOR THE BUSINESS-AS- USUAL PROJECTION (WITHOUT AIR QUALITY POLICIES AND REGULATIONS) IN 2035



Note: Long-range India includes all other States in India except UP and its neighboring States[21]
Source: Original figure for this report

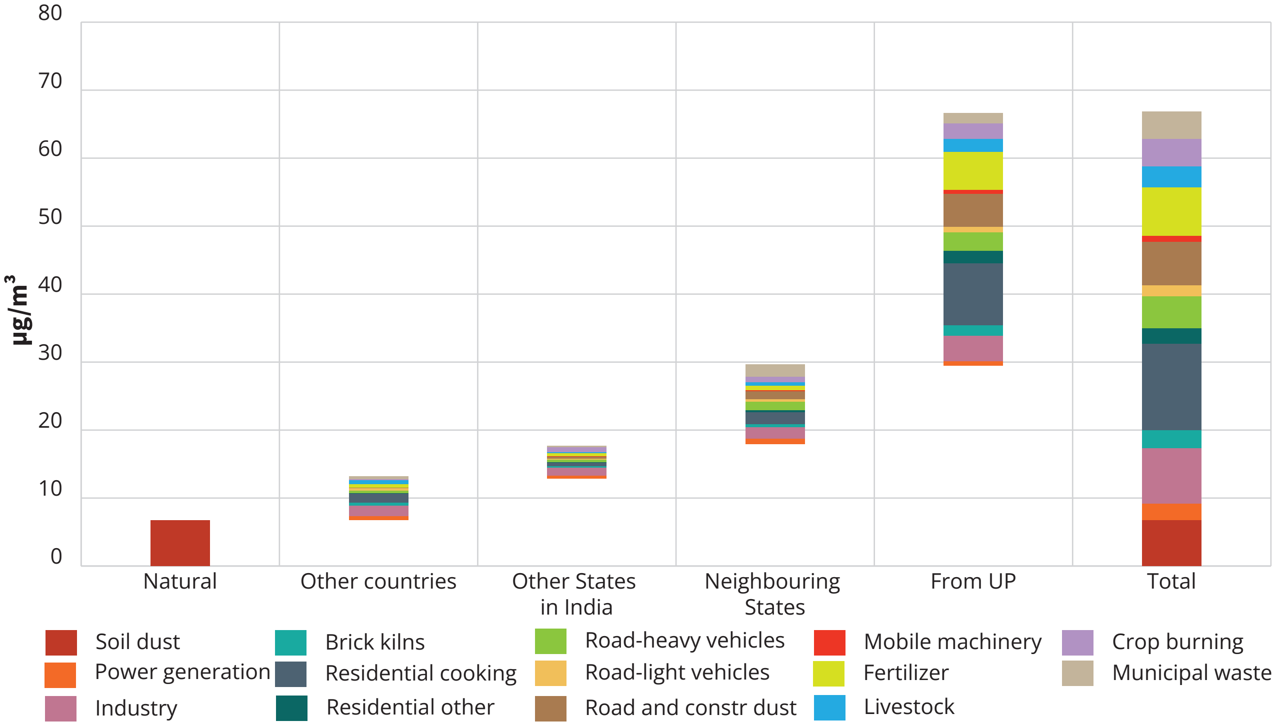
Full implementation of the already adopted air quality policies and regulations in UP and other IGP areas will counteract the 2.7-fold increase in GDP on population exposure to PM2.5 in UP in 2035 (Figure 40). PM2.5 exposure of the baseline scenario will nearly remain at the 2020 level despite the GDP growth because of the full implementation of the effective measures that the government has adopted in many economic sectors to counteract the pressure from increased economic activities (Figure 41), including measures to reduce the use of solid biomass for cooking. However, with 67 µg/m^3, exposure in the baseline 2035 scenario will remain well above national and international air quality standards despite the adopted measures.

The current policies and measures will unfold their full impact only with progressing implementation with full efficacy over time. For instance, for 2020-2025 it is estimated that without these policies and measures PM2.5 exposure in UP would have increased to 75- 80 µg/m^3, compared to about 65 µg/m^3 that occur in reality.

Similar dynamics are expected for other regions in the Indo-Gangetic airshed, so that the inflow of pollution into UP will hardly change. About 40 percent of the total exposure will still emerge from emission sources outside UP and from natural soil dust. The residential sector (in- and outside of UP) will contribute more than one quarter of the total exposure, while it will be responsible for one third percent of the local contribution from UP itself. Other sectors, such as (i) MSME, (ii) fertilizer application and livestock manure management, and (iii) transportation contribute about 13-16 percent each.

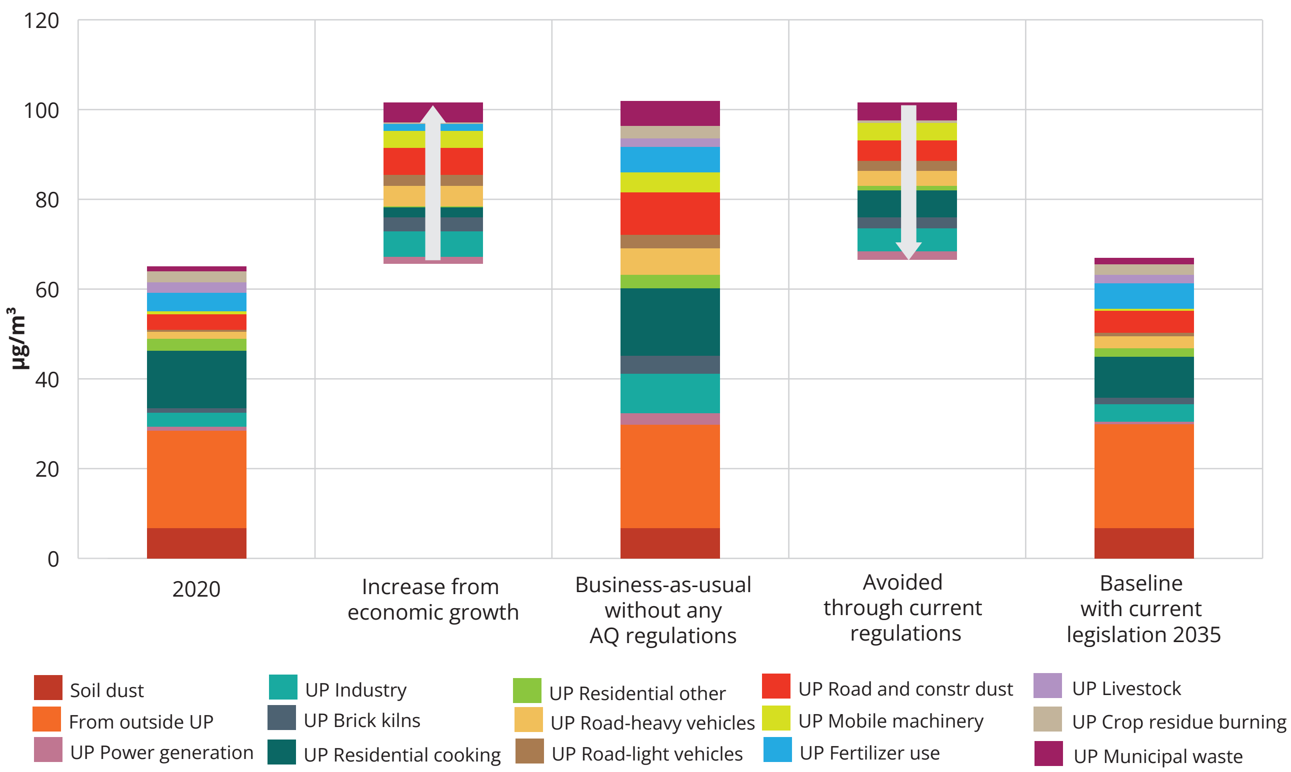
[21] Haryana, Delhi, Rajasthan, Madhya Pradesh, Chhattisgarh, Jharkhand, Bihar, Uttarakhand, and Himachal Pradesh.

FIGURE 39: SOURCE APPORTIONMENT OF POPULATION EXPOSURE TO PM2.5 IN UP FOR THE BASELINE PROJECTION (INCLUDING FULL IMPLEMENTATION OF POLICIES AND REGULATIONS) IN 2035.



Source: Original figure for this report

FIGURE 40: SOURCE APPORTIONMENT OF POPULATION EXPOSURE TO PM2.5 IN UP 2020-2035, WITH AND WITHOUT IMPLEMENTATION OF CURRENT POLICIES.



Source: Original figure for this report

Pathways to further reductions of PM2.5 exposure in Uttar Pradesh

The potential for further emission controls within UP in 2035

There remains an important potential for further air quality improvements from proven measures that are widely applied throughout the world that could possibly yield substantial air quality benefits in UP. The GAINS-IGP analysis presented in this plan explores the additional potential PM2.5 exposure reductions by such measures, as a matter of planning interests to explore pathways to reach NAAQS targets within a 10-year time. This will require further work on determining their implement ability based upon further financial assessments, institutional capacities etc. As discussed above, full implementation of the current policies and regulations will reduce exposure in UP from business-as-usual level by 35 µg/m^3, i.e., from 102 µg/m^3 to 67 µg/m^3 (the blue bars in Figure 42). Beyond these, the analysis identified additional measures in UP that could deliver substantial further reductions in PM precursor emissions. It is, however, made clear that the implantability of these additional measures in 10-year time, i.e. by 2035 would require a detailed analysis of financial requirements, technologies, and institutional capacities etc.

For residential cooking, a range of regulations have been issued with the aim to reduce emissions from biomass cookstoves, including the Ujjwala and the Saubhagya schemes (see Annex 3D for details). A complete phase-out of biomass cookstoves and replacement with electric/induction stoves, natural gas, LPG, or solar cookers could deliver an additional PM2.5 exposure reduction of up to **7.7 µg/m^3** in 2035 on top of what the current legislation (e.g., the Ujwala scheme) will yield. Alternative measures such as improved cook stoves can substantially reduce emissions ad interim by the time LPG realizes its full potential.

Excessive **application of urea fertilizer,** often causing overfertilization of agricultural soils, constitutes a major source of NH3 emissions in UP, an important ingredient for the formation of secondary PM2.5 in ambient air. The government has established a scheme to boost the growth of wheat and paddy and curb the black market and hoarding of urea (MoAFW, 2021) which promotes the use of neem-coated urea fertilizer (see Annex 3F). A variety of further options exist to increase the efficiency of fertilizer use and to reduce nitrogen emissions to the atmosphere, e.g., through the substitution of urea fertilizers with ammonium nitrate, the use of urease inhibitors, and the replacement of mineral fertilizer by organic fertilizer in circular agricultural practices. Many of these options involve education of farmers and/or economic incentives to farmers to change their farming practices. In total, these could reduce exposure in UP by up to **3.3 µg/m^3.** Noteworthy, there are numerous other benefits from avoiding overfertilization for soil fertility, groundwater quality, and not least the income of farmers (saving of fertilizer costs).

Although **road and construction dust** consists mainly of coarse particles larger than PM2.5, they also make a certain contribution to PM2.5 concentrations in cities. Measures are available to reduce such dust and its resuspension, such as water spraying at construction sites, street paving, and regular street washing. Road paving has taken place in the past and compensated some of the pressure from increased traffic volumes. While the efficiency of some options for PM2.5has not been established in all circumstances (see Annex 2), this initial analysis estimates a potential exposure reduction of **3.0 µg/m^3** from such measures. Note that this option refers mainly to the resuspension of dust that is deposited on road surfaces, even if the dust originates from other sources (e.g., windblown soil dust from agricultural areas or dust storm events from remote arid regions). Also, this dust source is different from road abrasion as well as from tyre and break wear, which are accounted for separately in the analysis.

Fuel combustion in industry constitutes an important source of PM precursor emissions, including primary PM2.5, SO2, and NOx. Although basic PM controls with moderate removal efficiency (e.g., cyclones or filter bags) are already applied at many installations (see Annex 3C), the analysis indicates a potential (up to **2.3 μg/m³**) from more efficient PM filters, such as electrostatic precipitators (ESPs) with more than 95 percent efficiency for small installations and more than 99.8 percent efficiency for larges plants. Also, desulfurization of coal emerges as a relevant option for large plants.

Heavy-duty diesel vehicles (trucks and buses) without appropriate emission controls are a major source of PM2.5 and NOx emissions with a significant impact on population exposure to PM2.5. The baseline analysis considers the progressing conversion of the vehicle fleet to Bharat-VI emission standards (details are provided in Table 1 of Annex 3.I). However, experience shows that without enforced regular inspection and maintenance schemes associated with mandatory repair programs real-world emissions can be substantially higher than what is laid down in the nominal emission standards. It is estimated that an enforced Inspection and Maintenance (I&M) system for heavy-duty vehicles and their speedy off roading could eliminate excess emissions from high-emitting vehicles and bring down population exposure by up to **2.1 μg/m³.** In theory, similar reductions could be achieved by full electrification of the vehicle fleet, especially of urban buses.

While the **open burning of crop residue** constitutes a major source of smog episodes with extremely high PM2.5 concentrations, it also adds a non-negligible amount to annual mean exposure that were found most relevant for public health impacts (see Annex 3F1). The 2015 order of the National Green Tribunal prohibits agriculture residue burning. It is estimated that an enforced ban of the open burning, combined with collection and energetic recycling of the waste material (e.g., pelletizing, co-firing in larger boilers, etc.), could reduce annual mean exposure in UP by up to **2.0 μg/m³.**

Currently, emissions from **non-road mobile machinery**, such as agricultural tractors, water pumps, construction machinery, railway engines, and ships that are often powered with diesel, are regulated through the CEV/Trem standards (see Annex 3H). Given the comparably long lifetime of such equipment, low-sulfur diesel offers a practical option for reducing PM emissions even for existing engines. More advanced options include the use of diesel particulate filters with low-sulfur diesel, especially for construction machinery that has a significant impact on population exposure in cities and could reduce annual mean exposure to PM2.5 in UP by up to 1.6 μg/m³.

With growing wealth, **municipal solid waste management** has become another important source of PM2.5 in ambient air, caused by the often uncontrolled burning of solid waste. It is important that waste management considers waste generation, avoidance, collection, separation, recycling, treatment, disposal and re-use of by-products in an integrated way. Following this concept, the 2016 solid waste management rules require segregation, processing, composting, and recycling of waste and ban the open burning of waste as well as the “single-use-plastic” (see Annex 3E), for which however only partial implementation is assumed in the baseline. The analysis reveals that fully integrated waste management that includes separation of municipal waste, collection, composting of food waste, recycling of wood, plastic, paper and textile waste, managed landfill of the residual waste, and the collection and use of landfill gas could reduce PM2.5 exposure by up to **1.1 μg/m³.**

Other activities in the residential and commercial sectors, beyond the household use of solid biomass for cooking purposes, constitute additional sources of PM2.5 emissions. These include, inter alia, heating of warm water, heating and cooling for public buildings and commercial offices, restaurant kitchens, fireworks, and cremation (see Annex 3.I). It is estimated that stricter efficiency standards for new heating stoves and boilers switch to pellets, PM filters for automatic boilers, use of low-sulfur oil, low-NOx burners as well as filters for restaurant kitchens, ban of fireworks and electric cremation can avoid about **1.0 μg/m³** exposure in 2035.

Non-energy related **emissions from industrial processes** are already addressed by a host of policies and regulations that helped to avoid significant PM2.5 exposure in UP. Stringent regulations have been issued for brick production, which require replacement of conventional kilns with zigzag or better technologies (see Annex 3C). However, it is not expected that all brick kilns will be fully operated in low emissions mode. Enhanced compliance with current policies must be fully established to optimize the current measures' effect. Also, there is room for enhanced control of PM2.5 emissions at large factories, especially for cement and steel production. In total, it is estimated that in 2035 such measures can reduce PM2.5 exposure in UP by up to **0.6 µg/m³.**

Recent legislation will lead to a drastic decline in SO2 and NOx emissions from **power generation.** The analysis considers compliance with, *inter alia,* the emission standards S.O. 3305 PM2.5 of 2015 and their relaxation of 2020 (see Annex 3B). Extending the scope of such regulations to older and smaller plants (fluidized bed boilers, desulfurization, low-NOx burners, selective non-catalytic reduction of NOx emissions) as well as emission controls for diesel generators equivalent to Stage 3B of the EU can reduce exposure in UP by another **0.5 µg/m³.**

For **light-duty four-wheelers and electric two- and three-wheelers** ("other road vehicles") a similar potential (up to **0.5 µg/m³)** is estimated for enforced inspection and maintenance systems with mandatory repair programs (Annex 3A).

As discussed in Chapter 4, **livestock manure management** makes a substantial contribution to PM2.5 exposure, although there is only rather limited potential for reducing NH3 emissions from farms operating with solid manure systems, as most of the current farms in UP. However, experience shows that large farms and especially new industrial animal holdings tend to employ liquid manure systems, which cause significantly higher NH3 emissions from the storage of manure and its application to fields. At the same time, a variety of options exist that could effectively reduce these emissions at rather low costs. (Note that this is only relevant for large industrial farms holding several hundred cattle, but not for small subsistence farmers.) To the extent that in the future new-built large farms in Uttar Pradesh would employ such liquid manure systems, it is likely that manure management options (e.g., covered storage of manure, low-emission manure application) provide rather cost-effective options for reducing NH3 emissions, an important precursor to secondary PM2.5 in Uttar Pradesh. The potential additional emission reductions (beyond the baseline projection) from these measures in 2035 are summarized in Table 12.

TABLE 12: PM2.5 PRECURSOR EMISSIONS OF THE BASELINE SCENARIO IN 2035 (WITH FULL IMPLEMENTATION OF CURRENT POLICIES AND REGULATIONS) AND THE FURTHER EMISSION REDUCTION POTENTIALS (KILOTONS)

	PM2.5		SO2		NOx		NH3	
	Baseline 2035	Further reduction potential	Baseline 2035	Further reduction potential	Baseline 2035	Further reduction potential	Baseline 2035	Further reduction potential
Power generation	10	-4	39	-21	317	-238	0	5[1)]
Industrial combustion	186	-183	76	-28	257	-99	6	-1
Industrial processes	44	-29	49	-44	36	-33	37	-35

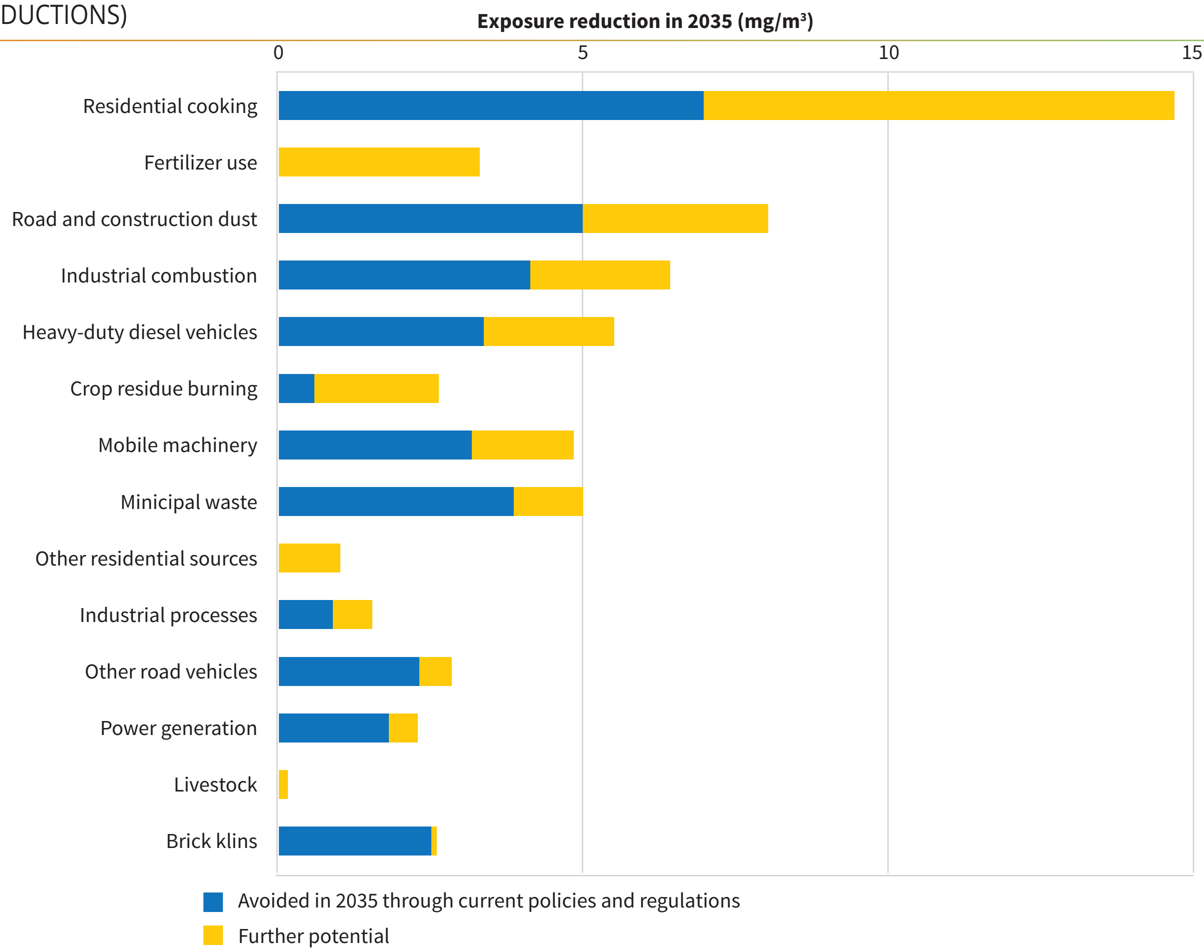
	PM2.5		SO2		NOx		NH3	
	Baseline 2035	**Further reduction potential**	**Baseline 2035**	**Further reduction potential**	**Baseline 2035**	**Further reduction potential**	**Baseline 2035**	**Further reduction potential**
Brick kilns	41	0	88	-1	1	1	0	0
Residential cooking	215	-207	13	-13	27	-25	5	-5
Other residential	55	-20	49	-27	26	-7	0	1
HDT vehicles	30	-23	10	-9	312	-124	0	0
Other road vehicles	8	-5	3	-2	64	-38	2	0
Road dust	83	-73	0	0	0	0	0	0
Non-road machinery	20	-13	7	-7	232	-193	0	0
Livestock	5	0	0	0	18	0	663	-55
Fertilizer use	0	0	0	0	203	0	1805	-1335
Crop burning	136	-119	5	-4	5	-4	28	-25
Municipal waste	22	-22	1	-1	15	-14	160	0
Total	**833**	**-678**	**338**	**-156**	**1500**	**-761**	**2546**	**-144G**

1) the increase occurs as a side-effect of the use of selective catalytic reduction (SCR) for NOx controls
Source: Original table for this report

In total, implementation of these additional measures in UP assuming their full implementation can possibly reduce PM2.5 exposure by 26 μg/m³ below the baseline projection in 2035 (Table 13 and the yellow bars in Figure 42). The impact on PM2.5 concentrations is discussed in the following section.

Eight broad categories of measures offer the largest additional potentials up to 2035: (i) clean cooking through replacement of wood, agricultural residue and dung by electricity, natural gas and LPG (7.7 μg/m³), (ii) efficient urea fertilizer use (3.3 μg/m³), (iii) reduction of construction and road dust (3.0 μg/m³), (iv) PM controls at industrial boilers including compliance checking mechanisms for brick kilns (2.3 μg/m³), (v) compliance with emission standards for heavy-duty diesel vehicles (2.1 μg/m³), (vi) ending of the open burning of agriculture residue (2.3 μg/m³), (vii) emission standards for non-road machinery (1.6 μg/m³), and (viii) low-emission management of municipal waste (1.1 μg/m³). In total, these eight groups of measures would deliver about 90 percent (23.3 μg/m³) of the total exposure reduction potential of the further additional measures over and above the current policies and regulations if fully

FIGURE 41: PM2.5 EXPOSURE REDUCTIONS IN UP IN 2035 EMERGING FROM THE POSSIBLE EMISSION CONTROLS IN THE VARIOUS ECONOMIC SECTORS WITHIN UP (RANKED BY DECREASING POTENTIALS FOR FURTHER EXPOSURE REDUCTIONS)



Source: Original figure for this report

implemented. More details are provided in Annex 5.

Achievable PM2.5 exposure in 2035

As mentioned above, unilateral implementation of the identified further measures within UP can reduce PM2.5 exposure in UP by 26 μg/m^3 below the baseline projection of 67 μg/m^3 , i.e., down to 41 μg/m^3 (Table 13).

Thereby, by 2035 Uttar Pradesh on its own - even with the implementation of the full portfolio of measures throughout the state- will not be able to bring down PM2.5 exposure in its territory below 41 μg/m^3. UP will fall short of reaching a potential target of 40 μg/m^3 in 2035. UP would also depart from a trajectory towards reaching in 2047 the PM2.5 air quality standard of 25 μg/m^3 that is currently adopted by many high-income countries.[22]

[22] E.g. in all EU countries (incl. both West European countries like France, Germany, Italy, Spain, the Nordics, and East European countries like Poland, Hungary, Bulgaria, the Baltic states etc), UK, Ukraine, the Russian Federation etc.

TABLE 13: PM2.5 EXPOSURE REDUCTIONS IN UP IN 2035 FROM THE FULL IMPLEMENTATION OF CURRENT POLICIES AND REGULATIONS AND THE POTENTIAL FOR FURTHER MEASURES IN 2035, RANKED BY THE ADDITIONAL POTENTIALS (MG/MS)

	Hypothetical Business-as-usual contributions to exposure in 2035 (without any air quality policies and regulations)	Exposure avoided in 2035 through full implementation of current policies and regulations	Further reduction potential from additional measures in UP in 2035	Remaining exposure in UP with unilateral measures in UP	Remaining exposure in UP if other States in the IGP airshed take additional measures[2)]
Inflow from outside	29.8[1)]			29.8[1)]	21.8[2)]
Total exposure in 2035	**101.8**			**67.0**	**59.0**
Residential cooking	15.1	7.0	7.7	59.3	51.3
Fertilizer use	5.7	0.0	3.3	56.0	48.0
Road and construction dust	8.4	5.0	3.0	53.0	45.0
Industrial combustion	7.2	4.2	2.3	50.7	42.7
Heavy-duty diesel vehicles	6.1	3.4	2.1	48.6	40.6
Crop residue burning	2.9	0.6	2.0	46.6	38.6
Mobile machinery	5.3	3.2	1.6	44.9	36.9
Municipal waste	5.3	3.8	1.1	43.8	35.8
Other residential sources	2.8	0.0	1.0	42.8	34.8
Industrial processes	1.7	0.9	0.6	42.2	34.2
Other road vehicles	3.0	2.3	0.5	41.7	33.7
Power generation	2.4	1.8	0.5	41.2	33.2
Livestock	1.8	0.0	0.1	41.1	33.1
Brick kilns	4.0	2.5	0.0	41.1	33.1
Total	**71.6**	**34.6**	**25.9**	**41.1**	**33.1**

1) With full implementation of current policies and regulations in all IGP States
2) With implementation of the common set of measures listed in Table 32 (Annex 5) in all IGP States.
3) Annual PM2.5 can reduce to 41 µg/mS with full implementation of additional measures by the State and 33µg/mSwith further measures similar actions by other IGP states (Table 14) compared to NAAQS level of 40 µg/mS and 35 µg/mS throughout the UP state.

Source: Original table for this report

After full implementation of the further measures in UP, about three-quarters of the residual exposure in UP will originate from emission sources outside UP. Without additional emission controls in other states, the inflow of PM2.5 from other regions and natural sources is estimated to reach roughly 30 µg/m^3 in 2035, while the UP contribution will be reduced to 11 µg/m^3.

However, further measures can be taken in other states and are likely to be taken, given that these states face very similar challenges in air quality management. Any additional measures within the same airshed will reduce background pollution in Uttar Pradesh. Vice versa, other regions in the IGP airshed will benefit from action taken in Uttar Pradesh.

Cooperation within the IGP airshed will not only make it possible for UP to reach adequate air quality targets (e.g., reaching 40 μg/m^3 by 2035 and with further help to reach potentially 35 μg/m^3), it will also avoid the need for taking the most expensive measures at home. As an illustrative example, this plan assesses how reduced pollution inflow from a common set of basic measures adopted in other regions would affect the need for additional measures in Uttar Pradesh. These measures (Table 14) form a subset of the full portfolio that is considered in the UP analysis above.

TABLE 14: THE COMMON SET OF MEASURES (IN ADDITION TO THE BASELINE MEASURES) ASSUMED IN THE COOPERATIVE SCENARIOS FOR THE OTHER IGP STATES. NOTE THAT THESE MEASURES FORM PART OF THE PRIORITY PORTFOLIO OF MEASURES IN UTTAR PRADESH (SEE ANNEX 5).

Mobile sources:
• Effective inspection and maintenance for heavy-duty and light-duty road vehicles
• Street paving and washing
Power generation:
• Stationary generators: Stage 3B controls
Households:
• Universal access to clean household fuels for cooking (LPG/electricity) to replace biomass fuels (fuelwood, dung)
• Diesel generators: Stage 3B controls • Filters for restaurant kitchens • Electric cremation • Ban of fireworks • PM controls of heating boilers • New/improved heating stoves burning solid fuels in households
Industry:
• Brick production: Zig-zag kilns (55 percent of production capacity) and vertical shaft brick kilns (VBSK) with basic dust control (40 percent of production capacity)
• Electrostatic precipitators (>99.8 percent efficiency) at large industrial sources • Basic NOx controls for industrial boilers • Electrostatic precipitators (>95 percent efficiency) at industrial furnaces • High-efficiency de-dusters (>99.8 percent efficiency) in aluminum production • Flue gas desulfurization of large industrial boilers and furnaces • Basic SO2 controls (-50 percent) at cement, aluminum, steel plants and refineries
Agriculture:
• Efficient urea fertilizer use
• Stop open burning of agricultural residue

Source: Original table for this report

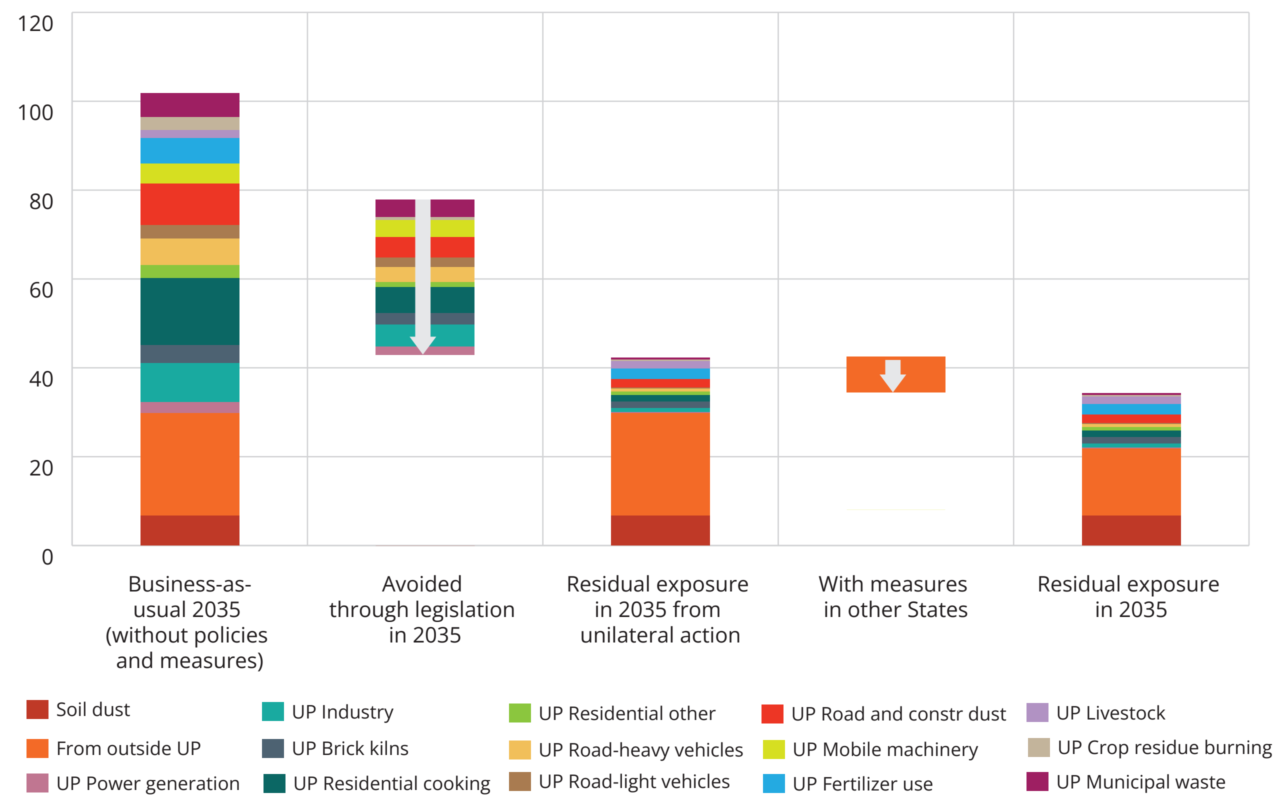
By 2035, implementation of the illustrative set of common measures in other IGP States will reduce the inflow of PM2.5 pollution into UP by 8 µg/m³and reduce exposure in Uttar Pradesh to 59 µg/m³ even without further measures in UP. In this case, the full portfolio of measures in UP would bring down exposure to about 33 µg/m³.

Airshed cooperation would make it possible for UP to achieve a potential of 35 µg/m³with a subset of the available measures (Figure 43) **which realizes about 90 percent of the full reduction potential.** More ambitious cooperative airshed arrangements than what is assumed in the illustrative set of common measures (Table 14) would further diminish the need for measures in UP through even larger reductions in background levels. This would avoid the most challenging measures within UP and could deliver substantial cost savings to UP.

It is feasible to achieve PM2.5 levels of below 35 µg/m³ in 2035 with additional measures in UP and similar measures in other IGP States

Successful examples of regional air quality management through regional cooperation have been developed in China, the US and Europe. The latter two particularly through the Convention for the Long-range Transboundary Air Pollution (LRTAP). While regional coordination within the IGP might appear challenging in the near term, this plan examines the potential magnitude of gains for Uttar Pradesh from such coordination and cooperation. Such collaboration is also initiated through the ongoing AQM collaboration process outlined in the Kathmandu Roadmap of December 2022 between the countries and jurisdictions within the IGP (India, Bangladesh, Nepal, Pakistan and Bhutan) and through the recent coordination workshops to enhance AQM cooperation between IGP states in May 2023 and March 2024.

FIGURE 42: PM2.5 EXPOSURE REDUCTIONS IN UP OFFERED BY FULL IMPLEMENTATION OF FURTHER MEASURES IN UP AND BY THE COMMON SET OF MEASURES IN OTHER IGP STATES



Source: Original figure for this report

Concentrations of PM2.5 in ambient air

Following world-wide practices of air quality management, the UCAP analysis focuses on population exposure to PM2.5, the most relevant metric for managing public health. As discussed in Chapter 2, there occur significant spatial variations of PM2.5 concentrations within areas due to local emission peaks, meteorology and topographic conditions. Public health impacts of air pollution within a given region are best represented by the average population exposure, i.e., population-weighted PM2.5 concentrations across the area. Given the paucity of available air quality monitoring stations, this metric cannot be directly measured. Thus, it needs to be computed with spatial population statistics and (calculated or interpolated) concentration fields throughout the entire region (here computed with a 10 km*10 km spatial resolution).

This population exposure metric is different from other frequently used air quality indicators, such as air quality standards expressed as the highest (annual mean or daily) concentration of PM2.5 occurring or measured at a monitoring site in a city (for example, next to an industrial complex or a busy street crossing). Although the latter metric is practical for administrative and legal compliance purposes, it is poorly related to overall population exposure and the pollution burden on public health.

Notably, the NCAP focuses on the highest PM concentrations that occur in the various domains (non-attainment areas) and not on population exposure. In addition, NCAP is mainly addressing PM10 concentrations in its target and baseline setting and not PM2.5. Although the NCAP has a main focus on PM10 in the non-attainment cities is clearly different from the UCAP analysis in this plan, the measures identified above will not only improve population exposure to PM2.5 but also reduce the PM10 concentrations.

As population is centered in higher polluted areas, population exposure (i.e., population-weighted average concentrations, 65 μg/m^3 in 2020) is higher than the spatial average of PM2.5 concentrations in UP (60 μg/m^3 in 2020, see Table 15).

Compared to 2020, the additional emission control measures identified in this plan lead to significantly lower PM2.5 concentrations throughout UP. However, at particular point locations concentration may be higher or lower due to local sources and meteorology and this may require further local actions (Figure 44).

By 2035 the additional UP measures would reduce average PM2.5 concentrations in UP by 35 percent to about 38 μg/m^3 (population exposure would fall to 41 μg/m^3). the additional UP measures would reduce average PM2.5 concentrations in UP by 35 percent to about 38 μg/m^3 (population exposure would fall to 41 μg/m^3).

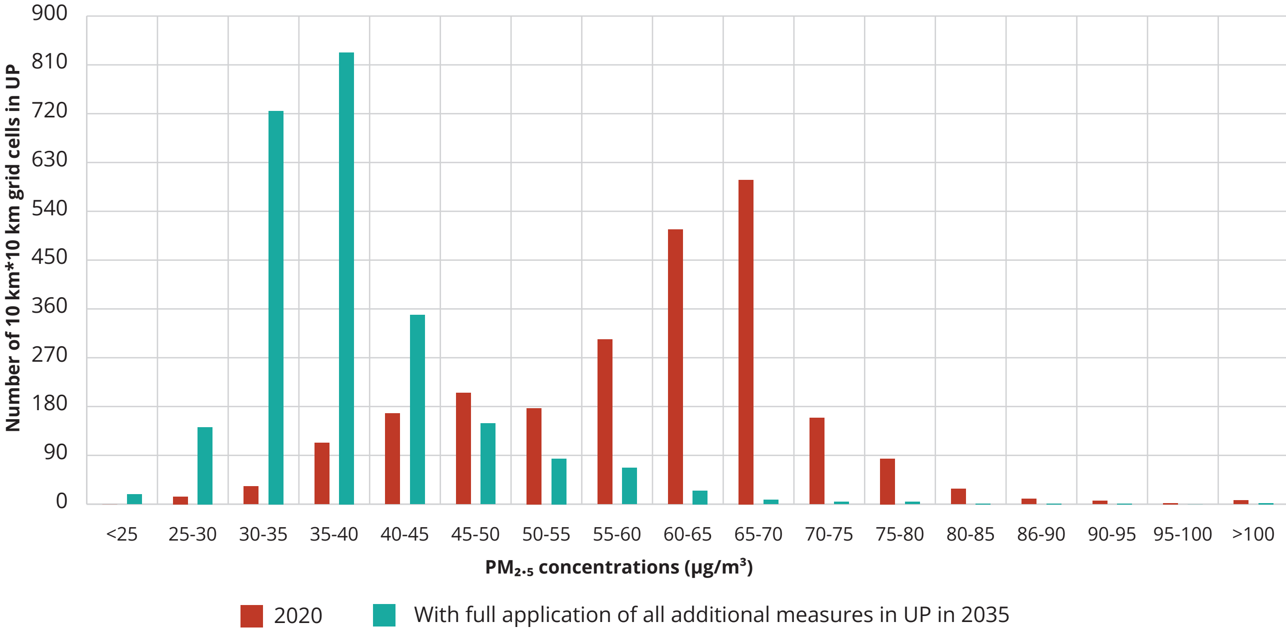
TABLE 15: DISTRIBUTION OF PM2.5 CONCENTRATIONS IN UP

	2020	With full application of all additional measures in UP in 2035
Population exposure (i.e., population-weighted concentrations)	67.3	41.1
Spatial average PM2.5 concentrations	59.7	38.2

Source: Original table for this report

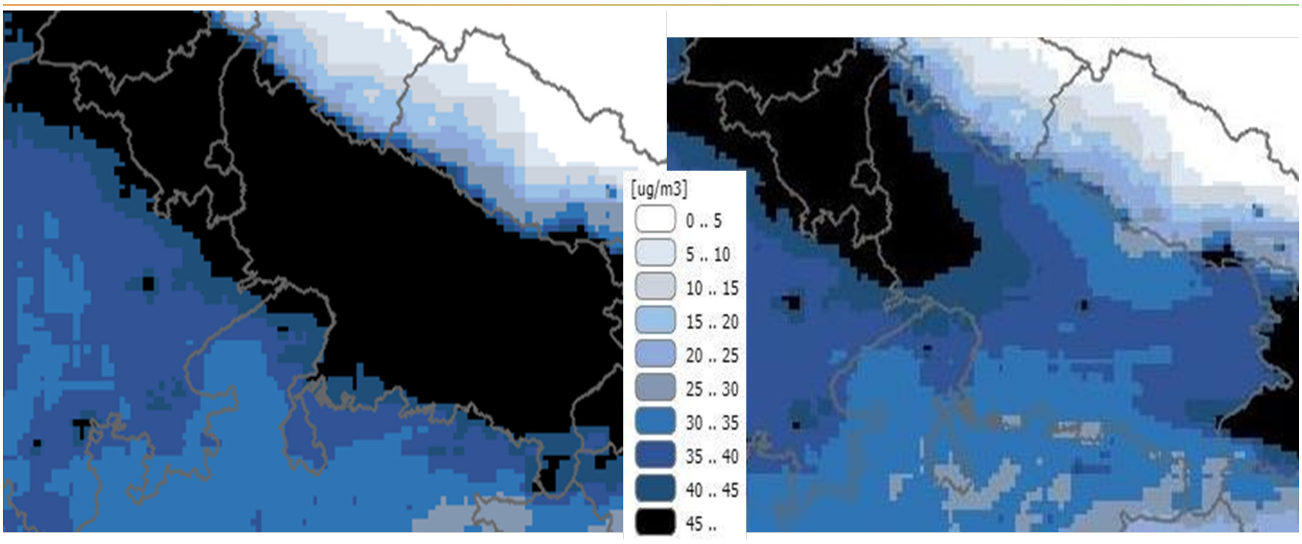
In 2020 PM2.5 concentration levels of more than 40 μg/m^3 prevailed throughout entire UP, in 2035 the measures would bring them below 30 μg/m^3 in large areas in the east of UP. However, in the absence of comparable measures in the neighboring IGP States in the west, PM2.5 concentrations in the western part of UP will remain above 40 μg/m^3 (Figure 45).

FIGURE 43: DISTRIBUTION OF PM2.5 CONCENTRATIONS IN UP IN 2020 AND FOR 2035 WITH FULL IMPLEMENTATION OF THE ADDITIONAL MEASURES



Source: Original graph for this report

FIGURE 44: PM2.5 CONCENTRATIONS IN 2020 AND THE CLEAN AIR SCENARIO IN 2035



Source: GAINS calculations for this report

Discussion

The analysis clearly reveals measures in five key sectors as indispensable for achieving substantial air quality improvements in UP in the coming decade: (i)Residential/commercial biomass burning, (ii) agriculture sector, (iii) transportation and dust, (v) medium and small industries and partly (v) municipal waste burning. From a technical perspective, measures for these sectors appear as low-hanging fruits for reducing PM2.5 exposure in UP. Measures in other sectors can make important contributions as well but cannot compensate for lack of progress in the key sectors due to their dominating impact.

Uncertainties

Gaps in available statistics cause several uncertainties and potential biases in the

estimated reduction potentials. The exposure reduction potentials presented here emerge from the emission inventory and its underlying input data that have been developed for the implementation of the GAINS-IGP model for UP and reviewed in 2023. However, there remain uncertainties, for example about the emissions from municipal waste management (see discussion in Chapter 2, incl. fig. 8). A higher emission estimate, especially from a more complete consideration of the informal waste sector, would directly translate into a more comprehensive and ultimately larger exposure reduction potential for this sector. The original GAINS-IGP estimate, employing data found to be representative of other areas in South Asia, was about 4-5 times higher, with an exposure reduction potential of up to 8 μg/m^3, which is like the potential from solid fuel use in household cookstoves, the largest source found in this analysis.

Furthermore, there is a lack of agricultural statistics on current manure management practices at large industrial cattle farms in UP, as well as robust projections up to 2035. Even with a conservative assumption that all farms in UP operate with solid manure systems, the source apportionment in Chapter 4 indicates a considerable contribution from manure management to PM2.5 exposure in UP. However, experience shows that large farms and especially new industrial animal holdings tend to employ liquid manure systems, which cause significantly higher NH3 emissions from the storage of manure and its application to fields. At the same time, a variety of options exist that could effectively reduce these emissions at rather low costs (Note that this is only relevant for large industrial farms holding several hundred cattle, but not for small subsistence farmers). To the extent that in the future new-built large farms in Uttar Pradesh would employ such liquid manure systems, it is likely that manure management options (e.g., covered storage of manure, low-emission manure application) provide rather cost-effective options for reducing NH3 emissions, an important precursor to secondary PM2.5 in Uttar Pradesh. Given these important data gaps and their critical relevance for the determination of priority action areas, further analyses of the actual situations for waste management and agricultural practices are recommended. These would therefore be two high priority topics for further refinement of the state emissions inventory and the establishment of new policies and programs in the next several years.

Implementation challenges

While visible success of current air quality policies and regulations in UP is masked by the sharp increase in economic activities, the analysis reveals a huge impact of these policies in terms of avoided emissions and exposure that would have otherwise occurred in absence of these policy interventions.

Nevertheless, the actual air quality benefits of measures in the key sectors critically depend on the speed and effectiveness of their implementation. Recent experience with similar policy initiatives in India clearly reveals practical challenges with the implementation of the identified key measures, related to distributional, social, governance, financing, capacity, and enforcement aspects. Also, the interplay with already existing strategies needs to be considered.

The government has implemented a strong legal and regulatory framework to address air pollution in the country. This includes, inter alia, the Air (Prevention and Control of Pollution) Act (the "Air Act") enacted in 1981 (amended in 1987), the Environment (Protection) Act (EPA) (1986), and the National Clean Air Program (NCAP), and a host of sectoral interventions. This has yielded improvements in the air quality. However, there is mixed experience with the effectiveness of the current regulations as witnessed, *inter alia,* by achieving the full potential ofair quality improvements at the large scale (see Chapter 3). To enhance the effectiveness of further policy interventions in UCAP, a primary analysis has been made which highlights the requirement for expansion of air quality monitoring network, real-time emission source monitoring, enhancing the institutional capacities for monitoring and implementation of AQM measures, green skill development to support the operation & maintenance of air pollution control systems and most importantly, a state of the science Evidence Based Decision Support System (DSS) fully backed up by the monitoring infrastructure. However, a detailed study would be required to design this strategy along with its potential to facilitate full implementation of existing policies and regulations.

Without preempting a more comprehensive assessment, important lessons are to be learned from the refill challenges in particularly low-income areas of the ambitious Ujjwala scheme aimed at transitioning from biomass-based cooking to LPG as the preferred solution. However, large-scale complete adoption of LPG is hampered by the limited affordability for the main target group. Therefore, the focus of the Ujjwala scheme on LPG as the single long-term solution - should also be supported by appropriate strategies relating to alternative solutions such as improved cookstoves, household level bio-digesters etc. even if they are less optimal in the long run. Consequently, except for a few pilots, there is rather little progress across the country on the transition to clean cooking fuels, with large implications on air quality.

Similar concerns apply, for instance, to waste management and dust control, where the Government has started taking actions and made funds available through XV-FC, NCAP and convergence. However, challenges related to knowledge, available capacity, coordination, and governance, developing viable business models will prevail, which could render investments in technical solutions as rather ineffective. Tailored approaches to facilitate these aspects need to be strengthened (e.g., developing shared knowledge bases, good statistical data and reliable air quality monitoring regimes, development and use of platforms and tools to address knowledge gaps).

The analysis also clearly reveals priority interventions at sectors that were not adequately addressed by air quality management up to now. These include, *inter alia,* fertilizer use, municipal waste management, construction, and road dust. As air quality concerns are not on the sectoral agendas, there is little awareness of the necessity of such interventions and experience with their implementation, which is likely to hamper enforcement of sectoral measures without proper awareness raising. International experience shows that regulations without proper enforcement mechanisms turn out to be costly and ineffective.

The examples above highlight the critical importance of a holistic design of policy interventions along with a robust implementation framework. It will be important that measures will not have unintended consequences, either on air quality itself (e.g., banning most polluting heavy-duty vehicles from certain zones without enforced scrapping will move them to other areas within the same airshed), or on other policy priorities (e.g., greenhouse gas emissions).

Some of the priority sectors emerging from this analysis require substantial resources, while they deliver benefits for multiple policy objectives. For instance, transition to clean mobility or zero/low emission mobility is very important in the long run not only for PM2.5 exposure in cities, but also for reducing greenhouse gas emissions. It will be important to clearly demonstrate the multiple benefits of successful pilots, to enhance their large-scale implementation in the long run.

While the analysis presented in this chapter ranks emission control options by their potential for PM2.5 exposure reduction in UP, this sequence does not necessarily constitute the economically most efficient way for improving air quality in UP. In many parts of the world, pollution control costs and the cost-effectiveness of the various measures, their impacts on the overall economy, and the distribution across sectors and groups in society were important aspects in the development of clean air portfolios. The cost-effectiveness of the options is attempted and presented in Annex 5 to this plan but is not considered in the selection of key measures. As a way forward the State may validate and adopt this methodology that suggests cost effectiveness to the society of AQM measures.

All these aspects highlight the importance of a careful design and proper piloting of present policy interventions that should ultimately lead to the full adoption of the envisaged emission controls. While such piloting might take time, it is indispensable for a successful transition to the clean air solutions at large scale. Thus, comprehensive clean air strategies should consider the need for a temporally staged transition pathway, with clear end- dates for the intermediate steps.

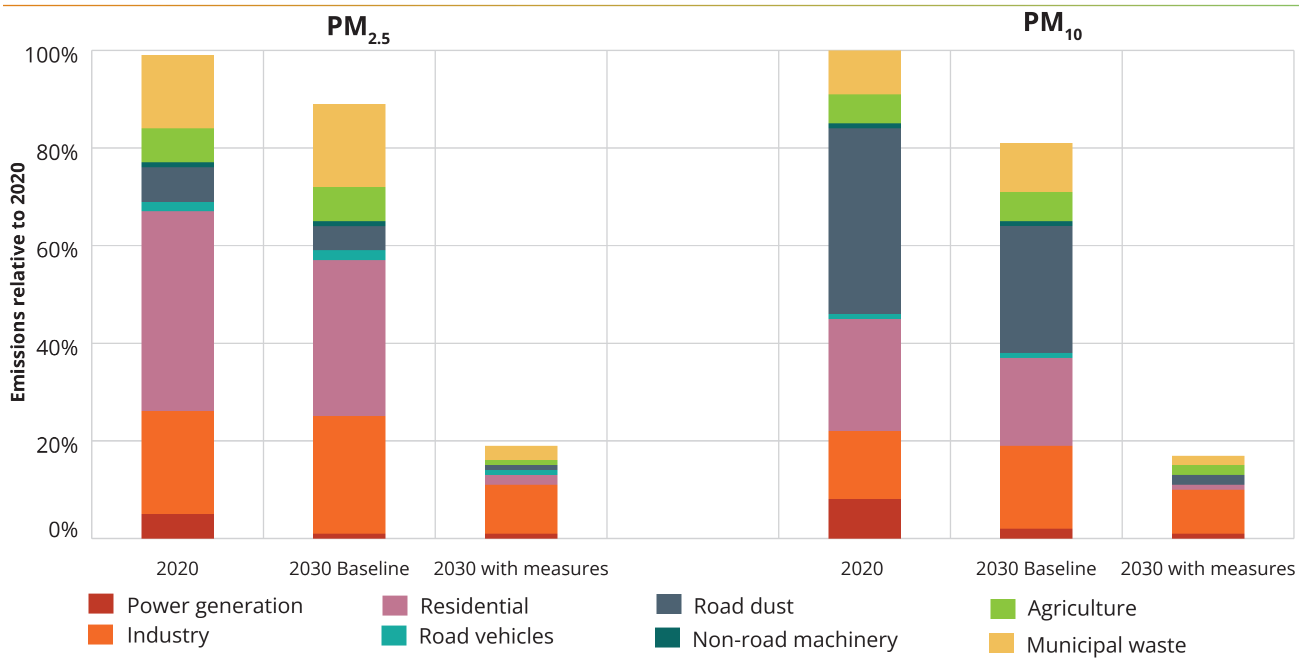
The current largely city-focus of air quality management in India has been clearly showing improvements and been able to retain an status quo in overall air quality in the country. To be more effective, a clean air plan for UP needs to consider that about 40 percent of the overall PM2.5 exposure in UP is caused by emission sources outside UP within the IGP airshed. This dominance of outside sources holds even more so for PM2.5 concentrations in individual cities.

Alignment with the NCAP Vision

A comprehensive clean air plan for UP needs to be aligned with national clean air visions and targets. In particular, the NCAP imposes for 2025-26 a 30-40 percent reduction target for PM10 concentrations in the NACs compared to 2017-18. Notably, the NCAP focus on PM10 in baseline and target setting for urban areas is clearly different from the UCAP analysis that addresses, based on robust worldwide evidence, population exposure to PM2.5 throughout UP as the most relevant target metric for public health. Thus, the priority measures identified in this plan have been derived with a focus on PM2.5 exposure. However, while priority measures for PM10 concentrations in urban areas will be different, the measured geared towards PM2.5 will deliver, as a positive side effect, benefits on PM10 emissions and thereby affect PM10 concentrations in cities.

To this end, the UCAP analysis determined the impacts of the identified PM2.5 priority measures on PM10 emissions in UP To align with the NCAP time scale, the analysis of PM10 impacts is focused on 2030. This calculation was conducted with source-specific emission factors for PM10 that reflect the specific impact of the considered emission control measures on PM10 emissions. Note that the removal efficiency for the PM10 size fraction is in many cases different from the efficiency for smaller particles such as PM2.5.

FIGURE 45: EMISSIONS OF PM2.5 AND PM10 IN UP IN 2020 AND IN 2030 ASSUMING IMPLEMENTATION OF THE (CURRENT POLICY) BASELINE AND THE IDENTIFIED PRIORITY MEASURES (RELATIVE TO 2020).

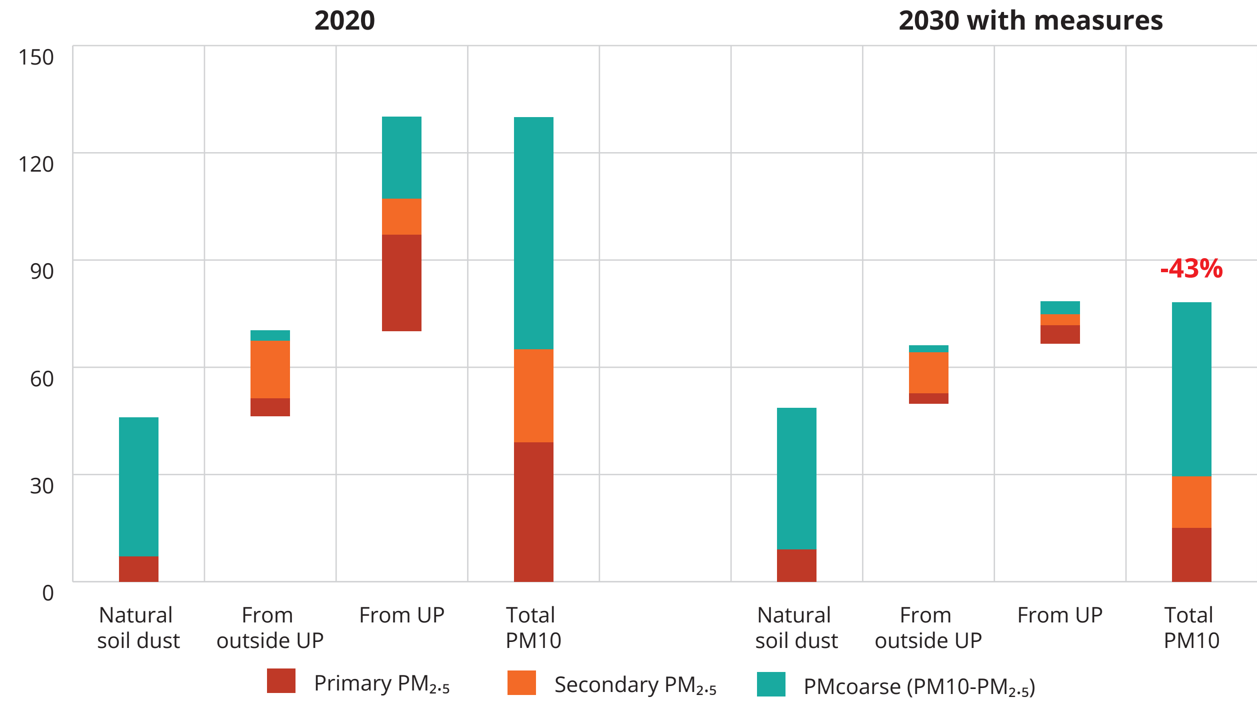


Source: GAINS calculations for this report

The contributions of the various source sectors to total emissions differ for PM2.5 and PM10 (Figure 46)**, owing to the different shares of coarse particles in PM10 (for instance, road dust consists mainly of particles which are larger than PM2.5, while most of the exhaust emissions from transport are within the PM2.5 size category).** The NCAP priority on PM10 is reflected by the larger PM10 reductions (-20 percent in 2030 compared to 2020) compared to the PM2.5 reduction (-11 percent). By 2030, implementation of the priority measures will reduce PM2.5 emissions in UP by 80 percent compared to 2020 and PM10 emissions by even 83 percent.

A provisional assessment of the likely implications of these emission changes indicates a 43 percent decrease of UP-wide (population-weighted) PM10 concentrations in 2030 (Figure 47)**.** However, a robust estimate of the impacts of these emission changes on PM10 concentrations at hot spots in UP cities was beyond the scope of the UCAP analysis at this stage as this would require extensive further analyses with different atmospheric dispersion models. This overall decline emerges from different changes of the various source categories: While natural soil dust is assumed to remain at the current level, the inflow of PM2.5 and PM10 from outside regions into UP should shrink by about 30 percent, assuming that other regions in India take comparable measures in order to achieve their NCAP target (see Table 32 in Annex 5). The contributions of primary PM10 and secondary PM2.5 emissions in UP will then decline proportionally to the changes in the precursor emission within UP, i.e., by about 80 percent. Due to the more localized impacts of PM10 emissions, PM10 in urban emission hot spots are likely to be larger than the UP-wide average of 43 percent. Thus, implementation of the full set of measures would exceed the NCAP target of a 30-34 percent reduction of PM10 concentrations in the non-attainment cities. However, as shown before, these cuts will not be sufficient to achieve neither a current 40 µg/m³ (NAAQS) or help reach a future 35 µg/m³ concentration target for PM2.5 at such hot spots.

FIGURE 46: (POPULATION-WEIGHTED) PM10 CONCENTRATIONS IN UP FOR 2020 AND 2030 ASSUMING IMPLEMENTATION OF THE FURTHER EMISSION CONTROLS IDENTIFIED IN THIS REPORT



Source: GAINS calculations for this report

Full implementation of the current air quality policies and regulations will keep PM2.5 concentrations in ambient air in UP in the coming decade at current levels despite the envisaged GDP increase by a factor of 2.7. Without effective countermeasures, economic growth would lead to significant increases in PM2.5 exposure from industrial activities, road and construction dust, non-road mobile machinery, and waste management so that in 2035 PM2.5 exposure in UP would grow by 50 percent surging to 102 µg/m^3.

1. **However, without additional measures, exposure in 2035 will remain with 67 µg/m^3 well above national and international air quality standards despite the full implementation of adopted measures.**

2. **Following current trends, in 2030 about one third of total PM2.5 exposure in UP will still originate from the residential sector, mainly from the use of solid fuels in households for cooking purposes.** Other sectors, such as transportation, MSMEs, fertilizer application and municipal waste management will contribute up to 15 percent each. The relative importance of the remaining contributions to exposure is clearly different from the priorities of the current air quality policies and regulations. This focuses mainly on-road vehicles and large power stations and puts less emphasis on sources that make the largest contributions to poor air quality throughout UP.

3. **Moving towards national and international air quality standards must extend the current portfolio of measures to the sectors that make the larger contribution to PM2.5 concentrations.** This should be based on a solid understanding of the benefits of action, as well as of the relative importance of the various sources, the potential emission and exposure reductions that are offered by different available measures, and the social and economic implications of such measures.

4. **This report analyzes the potential air quality improvements that could be achieved by 2035 by worldwide proven additional measures that could be taken in Uttar Pradesh.** In total, additional measures in UP has a potential to reduce PM2.5 exposure by another 26 µg/m^3 below the baseline projection in 2035. However, this will further require a detailed analysis about the implantability the basis of financial requirements, institutional capacities, appropriate technologies and the governance.

5. **The analysis clearly reveals measures in five key sectors as indispensable for achieving substantial further air quality improvements in UP:** (i) Residential/commercial biomass burning, (ii) agriculture sector, (iii) transportation and dust, (iv) medium and small industries and (v) municipal waste burning. From a technical perspective, measures for these sectors appear as low-hanging fruits for reducing PM2.5 exposure in UP. Measures in other sectors can make important contributions as well but cannot compensate for lack of progress in the key sectors due to their dominating impact.

6. **Without additional emission controls in other states, full implementation of these potentials can reduce PM2.5 exposure in UP to about 41 µg/m^3.** This level falls short of both 40 µg/m^3 (NAAQS) target and also ambitious 35 µg/m^3 level in 2035, and UP would depart from a trajectory towards reaching in 2047 the PM2.5 air quality standard of, for example, 25 µg/m^3 that is currently adopted by many high-income countries.[23]

7. The limited impact of the measures that can be taken within UP is explained by the inflow of PM2.5 from other regions and from natural sources, which is estimated to reach roughly 30 µg/m^3 in 2035.

[23] Refer to footnote 28.

8. **A cooperative airshed approach in which all IGP States would adopt a common set of basic measures would make it possible for UP to bring average PM2.5 exposure in the State even below 35 μg/m^3.** Such cooperation would avoid the need to take the most expensive measures within UP, which will enable substantial reductions in pollution control costs in UP.

9. **Rapid implementation of the identified additional measures will also decrease PM10 concentrations in UP (in 2030 by -43 percent on a population-weighted basis).** This will accelerate the achievement of the NCAP target of a 30-40 percent reduction of PM10 concentrations in the NACs compared to 2017-18. In essence, by continuously focusing on the implementation of the PM2.5 measures outlined in this plan, the reduction in PM10 as outlined in the NCAP will be well achieved in full alignment with NCAP. It is noted that additional measure (iv) (including spray washing) is effective in reducing course PM10 concentrations.

Overall, all actions and suggested control measures outlined in this plan are expected to have positive effects on the GDP of UP State. Shifts to cleaner energy use in particularly rural households will increase employment in manufacturing and delivery of clean cooking devices, better management of fertilizer use will improve the economy of farmers, road pavement and dust control throughout the states will increase jobs and improve the health of the population. Application of a state-wide ambient air quality and emission monitoring network will further increase employment (and in some cases maybe also local manufacturing within the IGP region). New jobs will also further be created through the application of a municipal waste management system and through full implementation of 100 percent abolishment of CRB.

TABLE 16: SUMMARIZED REDUCTION POTENTIALS OVER A 10-YEAR PERIOD

Measures to be applied	Potential PM2.5 exposure reduction in UP over a 10-year period	PM2.5 exposure in UP
Base year 2020 with already implemented emission control measures		65 μg/m^3
Baseline projection for 2035 assuming an increase of GDP by a factor of 2.7 and full implementation of current policies and regulations		67 μg/m^3
Application of measures with largest reduction potentials • Clean cookstoves and improved heating • Efficient urea fertilizer use • Control of construction and road dust • Ban of open burning of crop residues • Enforced inspection and maintenance programs for heavy-duty vehicles • PM control at industrial sources (mostly MSME) • Improved solid waste management • Enhanced emission standards for mobile machinery (e.g., construction machinery)	~24 μg/m^3	
Common measures applied in other IGP states	~8 μg/m^3	
Key measures in UP combined with common measures applied in other IGP states	~32 μg/m^3	35 μg/m^3

Uttar Pradesh Clean Air Management Plan - Activities/ Measures Matrix

Key lessons from the technical analysis

The above analysis delivers several key lessons that provide useful guidance to the formulation of priority activities in the UCAP:

- The analysis clearly reveals measures in five key sectors as indispensable for achieving substantial air quality improvements in UP in the coming decade: (i) Clean Energy in the Residential/commercial sector,(ii) Agriculture sector (particularly fertilizer use but also crop residue burning and gradually livestock manure management if it can be made effective at larger scale), (iii) Transportation (particularly HD trucks) and dust (road and construction), (iv) Medium and Small industries including brick kilns and industrial combustion, and (v) Municipal Waste Burning. From a technical perspective, measures in these sectors appear as low-hanging fruits for reducing PM2.5 exposure in UP.

- With adequate monitoring network, financing, developing institutional capacities, enhancement in the implementation framework, appropriate technologies that facilitate evidence-based decision support system - that lead to effective governance and supporting implementation mechanisms, measures taken within UP could bring down PM2.5 exposure by about 26 μg/m^3 in 2035 from the current projected PM2.5 levels of 65 μg/m^3.

- In addition, cooperation with neighboring states could lower the inflow of pollution into UP and thereby reduce background concentrations in UP by about 8 μg/m^3. Thereby, UP could first bring PM2.5 exposure to 40 μg/m^3 in 2035 and further help reach w 35 μg/m^3 while avoiding the need for taking the most expensive or difficult measures within UP. Given that these air quality improvements seem attainable within an about 10-years period, the date of achieving the 40 μg/m^3 target and further help reaching 35 μg/m^3 will critically depend on the starting point of the proposed measures.

  International experience shows that regulations without proper enforcement mechanisms turn out to be costly and ineffective. Full adoption of the envisaged emission controls will be indispensable for the success of the action plan. This requires a careful design and proper piloting of policy interventions, possible with a staged transition pathway, with clear end- dates for the intermediate steps.

Recommended Actions

With reference to the strategic objectives of UCAP (ref. chapter 1), recommended actions are:

A. Outlining pathways for achieving NAAQSs:

By **effectively enforcing current policies** (as of 2020), Uttar Pradesh will be able to retain current PM2.5 concentrations at around **65 µg/m³** over the next 10 years (fig. 41 and table 13) despite (i) strong economic growth (almost tripled between 2020 and 2035) and a population increase of around 12 percent over the 15 years.

This will require that each of the current policies are being implemented fully and effectively by, for example:

(i) Expansion of air quality monitoring network, real-time emission source monitoring, enhancing the institutional capacities for monitoring and implementation of AQM measures, green skill development to support the operation & maintenance of air pollution control systems and most importantly, a state of the science Evidence- Based Decision Support System (DSS) fully backed up by the monitoring infrastructure.

(ii) Achieving Bharat standards to level VI (both HDVs and LDVs), control of CNG-powered vehicles.

(iii) Mopeds, agricultural and construction machinery all reach (EU) stage 3 controls.

(iv) Moderate PM control (ESPs) and effective desulfurization are achieved in large power plants.

(v) Almost 80 percent of households have applied electric or LPG cooking while basic PM control (cyclones/ESP1) are applied in most industries.

(vi) Moderate PM control (ESO2) are applied in large-scale and heavy pollution industries like cement and fertilizer.

(vii) Achieving enhanced compliance for non-energy related emissions from industrial processes including MSME and brick kiln.

However, to “bend the curve” and potentially reach current and new NAAQSs by around 2035 (table 13 and fig. 43), it is recommended that Uttar Pradesh analyze the feasibility of additional measures based on finances, technologies, institutional capacities, implementation framework, policies and regulations etc. that are required and start implementing them as early as possible. These includes applying measures like:

i. Full application of clean energy in all households that use traditional cookstoves today by applying a set of improved cookstoves, induction cookstoves where electricity supply exists, apply localized household-base biogas digesters and solar-powered energy sources.

ii. Promoting the use of neem-coated fertilizer and increase in the NUE in all major cropping areas in each agro-ecological zone in UP.

iii. Develop management models for reduced ammonia emissions from livestock manure, particularly in large cowsheds (Gaushalas).

iv. Paving roads and applying water spraying, street washing etc. to reduce road dust and apply water spraying and construction curtains to reduce dust generation at construction sites.

v. More efficient application of PM filters to reduce fuel combustion in industries and achieve almost 100 percent efficiency in larger industrial plants.

vi. Apply enforced inspection and maintenance systems for HDVs, particularly for HD trucks.;

vii. Enforce a ban on CRB and collection and energetic recycling of municipal waste material.

viii. Reduce emissions from non-road sources.

ix. Full integration of waste generation, avoidance, collection, separation, recycling, treatment and waste disposal.

By effectively applying these additional measures, Uttar Pradesh has the potential to reach an average yearly PM2.5 concentration of 41 $\mu g/m^3$ by around 2035.

To further improve the air quality and potentially reach India's expected new PM2.5 concentration standard of 40 $\mu g/m^3$ by around 2035 and further help to reach 35 $\mu g/m^3$, Uttar Pradesh must ensure positive spillovers from similar actions taken in other IGP states, mostly in neighboring states (table 13 and figure 43). This should be ensured through **systematic coordination of application of common AQM measure between the IGP states**. Moreover, substantive improvements in air quality in Uttar Pradesh will also have important impacts on the air quality in the other IGP states.

Through these three forms of actions Uttar Pradesh has the potential for reaching a PM2.5 level of 40 $\mu g/m^3$ by around 2035 and further help to reach 35 $\mu g/m^3$.

To strengthen and build capacities for effective and full implementation of existing policies and regulations.

This requires expansion air quality monitoring network, real-time emission source monitoring, enhancing the institutional capacities for monitoring and implementation of AQM measures, green skill development to support the operation & maintenance of air pollution control systems and most importantly, a state of the science Evidence-Based DSS fully backed up by the monitoring infrastructure.

B. To promote pilots and establish protocols for Standard Operating Procedures (SOPs) for all relevant sectors:

For additional policies, - that are not part of the current policies and plans - pilots or demonstrations could be carried out with the aim for SOPs to be developed to gradually ensure full implementation potential for application of new policies. These include demonstration of the relevant alternative clean energy technologies in households reflecting the large variety of user profiles throughout Uttar Pradesh, demonstrate increased NUE in selected districts in each of the nine different agro-ecological zones in Uttar Pradesh that can be further scaled up to all relevant districts throughout the zones (which also can serve as demonstrations for other IGP states), pilot new methods for road and construction dust, demonstrate the effects of inspection and maintenance systems for particularly heavy duty trucks. Demonstrations of larger-scale brick kiln technologies, like tunnel manufacturing, could be further carried out.

TABLE 17: ACTIVITIES AND TIMELINES FOR DEVELOPMENT OF SOPS FOR ADDITIONAL MEASURES IN UP AS PART OF UCAP IMPLEMENTATION:

Additional Measures	Activities	Timelines for SOPs	Agency responsible
1. Apply clean energy through advanced technologies (e.g. LPGs, improved cookstoves and other solutions) in rural households.	Map fuel use, cooking practices and advanced technologies to be applied in households throughout UP.	Develop SOP in 2025.	DoRD, DOEFCC, UPNEDA, UPSRLM
2. Use of neem-coated fertilizer and increase NUE.	Set baselines and start testing NUE improvements in 2 demonstration projects in each of the 9 agro- ecological zones.	Develop SOP in 2026 after upstart of NUE testing in selected demonstration sites.	DoA, UP-CAR
3. Develop and apply management practices to reduce ammonia emissions from cowsheds (gaushalas).	Demonstrate NH3 emission reductions in 1-2 cow shelters in e.g. Gorakhpur or neighboring districts (areas with combined high crop residue generation and large live stocks/gaushalas).	Develop SOP in 2026/27 after initial demonstrations in 1-2 large-scale cow shelters (gaushalas).	DoAH,
4. Paving roads, apply water spraying and street washing.	Study reduced road dust practices in selected dust cells in the UP part of NCR.	Develop SOPs in 2025 prior to further expansion of dust cells to other parts of UP.	PWD, ULBs, DoRD
5. Efficient application of PM filters in industries, achi-eve almost 100 percent efficiency in large industrial plants	Study PM filter application in industries in UP and other IGP states as well as international best practices.*	Develop SOPs in 2025-26.	UPPCB, MoPI
6. Enforced inspection and maintenance systems for HDVs, particularly HD Trucks.	Establishing first inspection and maintenance systems (I&M systems) in UP. Draw upon experience from first establishments	Develop SOPs in 2025-26 after first I&M system has been piloted.	DOT
7. Ban on CRB and recycling of municipal waste	Enforce ban on CRB and energetic recycling of waste material (pelletizing, co- firing in larger boilers etc)	Develop SPOs in 2025-26 after further pilots of recycling of waste material	DoULB, DoUD
8. Reduce emissions from non-road vehicular sources	Test out the combination of applying CEV/Trem standards and more advanced options (e.g. diesel filters).	Develop SPOs around 2026 (when e.g. conformity checks of BS V engines are required).	DoT

Additional Measures	Activities	Timelines for SOPs	Agency responsible
9. Full integration of municipal waste processing	Test fully integrated SWM from avoidance, collection, separation to recycling, treatment and disposal according to 2016 waste management rules	Develop SPOs around 2025-26 after gaining further experiences from implementation of the SBM and experiences from XVFC program on SWM.	DoUD, DoULB

· *For example, through study tour programs that involves UP delegates.*

C. To align state level interventions in AQM with the objectives of the NCAP:

The UCAP further shows that implementation of the suggested priority measures to effectively reduce PM2.5 concentrations throughout Uttar Pradesh will further have positive effects on reaching the objectives of the NCAP, which have set targets in PM10 concentrations by 2026. By continuously focusing on getting both the current and additional PM2.5 policies implemented, NCAP targets (40 percent reduction in 2026 over 2017/19 as baseline) will likely be reached by all NACs in Uttar Pradesh by 2026. It is recommended to continuously focus on the PM2.5 measurement implementation and the correspondent PM10 targets will be reached.

In the **first part** of the 10 years period, it is recommended to focus on (i) establishing needed implementation capacity and technical and managerial knowledge in the outlined state-wide priority sectors and (ii) carrying out demonstrations and pilot programs to gain needed experience and tailor technology and management practices to local economic conditions (e.g., in agriculture, transport and small-scale industry and household energy users). In parallel, a first phase of strong implementation (e.g., of existing city and SAPs) should be continuously carried out and accelerated of already established measures (e.g., clean energy use through advanced technology application in households, HD trucks, complete brick kiln industry conversion, complete CRB elimination etc.) to ensure tangible PM2.5 improvements in this period.

In the **second part** of the 10 years period, full-scale implementation of all the prioritized state- wide sectors in UCAP (both current and additional measures) should be enforced in full capacity after reviewing the emission data.

Detailed investments needs and specific finance options will be added to UCAP at a later stage.

Based on the lessons from the technical analysis and the recommended actions to meet the objectives of the UCAP, the following table presents priority activities and air quality measures to facilitate an efficient improvement of air quality in Uttar Pradesh. It groups activities and measures into **three result areas** where progress can be monitored, i.e., (1) Strengthening State Capabilities for Air Quality Management and Planning, (2) Advancing Sector Interventions, and (3) IGP Airshed Cooperation. For each of the activities, the matrix specifies its geographic focus, responsible agencies, policies and funding schemes, timing, and the eligibility for World Bank funding.

The plan combines (i) activities in UP's existing state clean air plan (SCAP - 2020) prepared by the UPPCB according to the Central Pollution Control Board (CPCB) according to the state air quality action template and (ii) additional actions recommended through the UCAP process to shift to a wider airshed approach (ref. previous parts of this chapter).

Sufficient time will be required for providing the required financial resources, developing strategic knowledge, building up technical, managerial and coordination capacities, and carrying out demonstration and pilot programs in sectors that need further experience before larger scale programs are applied. Therefore, it is suggested that implementation of UCAP intends to be carried out over an about 10-year period initially during which the required capacities, obtaining knowledge and state may consider gradual full-scale implementation of all prioritized measures that are required for the attainment of NAAQSs throughout Uttar Pradesh.

The plan identifies for each activity and measures the key implementation bodies, relevant policies and budget or funding schemes, and categories of actions (i) policies, (ii) implementation, and (iii) research, and (iv) capacity building.

Actions have been identified through the technical UCAP analysis that is presented above and were discussed in a series of stakeholder meetings held during the UCAP preparation process. These included discussions facilitated in larger meetings across sectors, and in-depth discussions with groups of stakeholders linked to more specific actions and measures.

Although the action matrix table below is comprehensive, it is not exhaustive of all the ongoing programs and schemes in UP contributing to cleaner air such as larger scale renewable energy schemes like rooftop solar and energy conservation programs and schemes. These ongoing programs are more exhaustively described in the UP-State Action Plan for Climate Change which has a stronger energy sector focus.

The action matrix presented below is intended to be monitored, refined, and updated over time. Introduction of "additional" measures will be required for most topics to continually reduce and manage PM2.5 emissions in step with economic development and growth. Air quality is dynamic given atmospheric chemistry, the mix of emissions shifts over time and the overarching phenomenon of climate change, so this requires establishing permanent systems and human resource capacity for ongoing management. Measures that focus on upgrading and greening technology, and shifting management practices will be most sustainable in the longer run with the goal to reduce ambient air pollution exposures and decouple air quality from economic growth.

Notes:

a) The 2nd column "Activities/Air Quality Management Measures" can be defined as the current UCAP program, while the last column "World Bank co-finance" defines which part in UCAP that is included in the World Bank-funded UP Clean Air Management Program (UP-CAMP).

b) "+UCAP" in second last column illustrates what is included in current UP-CAMP.

c) "++UCAP" illustrates future AQM policies that are neither included in current SCAP nor UP- CAMP.

d) The UP-CAMP outlined activities (+UCAP), are further presented in detail in separate Detailed Project Reports (DPRs) that are available for each of the result areas 1, 2 (incl. clean cooking, agriculture, MSMEs, transportation) and 3 in the matrix. Further introductions to the policy framework, challenges, key interventions and implementing agencies for (i) domestic and commercial, (ii) transport & dust, (iii) waste, (v) industry and (v) agriculture sectors are included in annex 4 together with actions for institutional strengthening and knowledge augmentation.

TABLE 18: UCAP ACTIVITY MATRIX

	Activities/Air Quality Management Measures	Geographic Focus	Responsible Agency(ies)	Policies/Funding Schemes	Category	2020, +UCAP	World Bank "P" co- finance
Result Area 1: Strengthening State Capabilities for Air Quality Management and Planning							
1	Establish an AQM unit at DOEFCC & UPPCB	State level	DoEFCC and UPPCB	Scheme for Assistance for Abatement for Pollution	Capacity Building	+UCAP	Y
2	Expand CAAQMs network- 193 new stations	Gaps per detailed state AQM infra plan	DOEFCC and UPPCB	CPCB Guidelines, National Air Quality Monitoring Programme	Implementation, Capacity Building	+UCAP	Y
3	Establish 3 Super Sites for air quality monitoring	Noida, Lucknow UPPCB, BHU, Varanasi	DoEFCC and UPPCB	DoEFCC	Implementation	+UCAP	Y
4	Establish 15 Regional Knowledge Centres and 1 Apex Institution for capacity building support, training the green workforce, local monitoring, citizen engagement, health impact assessments, innovation and incubation hubs; knowledge dissemination.	Agra, Alighar, Bareilly, Bijnor, Firozabad, Gorakhpur, Delhi, Kanpur, Rorkee, Jhansi, Lucknow, Ambedkar Nagar, Meerut, Prayag Raj, Varanasi	DoEFCC	Scheme for Assistance for Abatement for Pollution	Implementation, Capacity Building, Research	+UCAP	Y
	Min-supersites at 4 Regional Knowledge Centers	Gorakhpur, Alighar, Jhansi, Agra/Mathura	DoEFCC	Scheme for Assistance for Abatement for Pollution	Implementation, Research	+UCAP	Y
5	Develop a web portal and audit platform for an internal MIS/monitoring dashboard for AQM actions.	State level	DoEFCC	Scheme for Assistance for Abatement for Pollution	Implementation	+UCAP	Y
6	Dynamic State Emissions Inventory and for NACs	State level and 17 Cities (2x)	DoEFCC and UPPCB	Scheme for Assistance for Abatement for Pollution	Implementation	+UCAP	Y
7	Early Warning System and Air Quality Decision Support System	State level	DoEFCC	Scheme for Assistance for Abatement for Pollution	Implementation	+UCAP	Y

	Activities/Air Quality Management Measures	Geographic Focus	Responsible Agency(ies)	Policies/Funding Schemes	Category	2020, +UCAP	World Bank "P" co- finance
8	Establish an Integrated Air Information Cell within UPPCB	State level	UPPCB	Scheme for Assistance for Abatement for Pollution	Capacity Building	+UCAP	Y
10	QA/QC study to evaluate operational efficiency of 750 existing CEMS	State level	SPV/DoEFCC/ UP PCB	Guidelines for Continuous Emission Monitoring Systems (CPCB)	Implementation	+UCAP	Y
11	Establish a Special Purpose Vehicle (SPV), UP-CAMPA for implementing and overseeing UP's air quality programs	State level	DoEFCC	Scheme for Assistance for Abatement for Pollution	Capacity Building	+UCAP	Y
Results Area 2: Advancing Sector Interventions							
Multi-Sector Cross-Cutting Air Quality Management Existing Programs							
1	Effective Utilization of NCAP Grant Funds provided for 17 Non-Attainment Cities	17 Cities	Urban Development and UPPCB	NCAP	Implementation	-	N
2	Air Cells in Every Non-Attainment City	17 Cities	Urban Development	NCAP and XV Finance Commission	Implementation	-	N
3	Effective Utilization of XV FC Air Pollution Grants; and achievement of targets for outer years	7 cities	Urban Development	XV Finance Commission	Implementation	-	N
Domestic Cooking & Heating							
1	Schemes for use of LPG/ PNG for cooking fuels and heating	State level	Department of Petroleum and Natural Gas and Food and Civil Supplies	Pradhan Mantri Ujjwala Yojana PAHAL-District Benefit Transfer for LPG Consumer	Implementation	2020	N
2	Amendments to the building by-laws for "Indoor air quality management"	State level	Housing and Urban Planning Department	PM Awas Yojana Urban	Policy	2020	N
3	Clean cooking state program offering cooking solutions: Improved Cookstoves (tier 3); household biogas (tier 4); and	State level – Priority to eastern districts and areas near Delhi.	DoEFCC/ UPNEDA/ UPSRLM	UP Bio Energy Programme and Policy (2022); UP State Rural Livelihood Mission - startup village	Policy	+UCAP	Y

Activities/Air Quality Management Measures		Geographic Focus	Responsible Agency(ies)	Policies/Funding Schemes	Category	2020, +UCAP	World Bank "P" co- finance
	Hybrid solar and electric induction (tier 5) etc	Interventions in 46 of 75 Districts		entrepreneurship; National Biogas and Manure Management Program (NBMMP); GOBAR-Dhan Scheme; Pradhan Mantri Ji- VAN Yojana; EESL and IOC programs for large scale adoption of solar based cookers			
4	Empanel project implementation entities/ partners for four clean cooking business models	State level	DoEFCC/ UPNEDA/ UPSRLM	Scheme for Assistance for Abatement for Pollution	Implementation	+UCAP	Y
5	Design and deploy mass awareness/ behavior change communication program on clean cooking for delivery with Self Help Groups (SHGs) and social mobilizers	Aligned geographically with rollout/ phasing of state clean cooking program	UPSRLM, Rural Development, DoEFCC	UP State Rural Livelihood Mission - startup village entrepreneurship Programme, Mission LIFE	Implementation	+UCAP	Y
6	Set up a technical advisory committee to guide selection and empanelment of appropriate cooking solutions for the state.	State level	DoEFCC	Scheme for Assistance for Abatement for Pollution	Implementation	+UCAP	Y
7	Training and capacity building of financial institutions (including NBFCs and MFI) for developing financing interventions for households and enterprises for clean cooking solutions	Aligned geographically with rollout of state clean cooking Plan	Department of Rural Development UPSRLM NABARD	National Rural Livelihood Mission - startup village entrepreneurship program (State share)	Capacity Building	+UCAP	Y
8	Training and women SHGs + Entrepreneurs on clean cooking models; leverage existing finance and credit products to facilitate clean cooking businesses	Aligned geographically with rollout of state clean cooking Plan	UPSRLM Department of Rural Development, Prerna Ojas Ltd	National Rural Livelihood Mission - startup village entrepreneurship program (State share)	Capacity Building	+UCAP	Y

Activities/Air Quality Management Measures	Geographic Focus	Responsible Agency(ies)	Policies/Funding Schemes	Category	2020, +UCAP	World Bank "P" co- finance
9 Supply chain market facilitation among stakeholders for 4 business models by existing rural development programs	State level	UPSRLM Department of Rural Development	National Rural Livelihood Mission - startup village entrepreneurship program (State share)	Implementation	+UCAP	Y
10 Clean Cookstove Technology Advanced Testing Centre and QA framework charter for UP	State level, potentially IIT-Kanpur	DoEFCC	UPCAMP Budget line	Implementation	+UCAP	Y
11 Future: Improved heating, including high efficiency stoves, replacements of old stoves, switch to pellet fuels, filters installed on automatic boilers	State level	Housing and Urban Development	Urban and Rural new Housing Programs (names TBC)	Implementation	++UCAP	N

Detailed Implementation Plan and other "Associated Parts" of UCAP: A more detailed GAANT chart and financial mapping for UCAP will be completed over the first year of the UCAP SAP implementation and after the proposed Special Purpose Vehicle UPCAMPA is established. Detailed costs and implementation arrangements have been defined so far for the activities that will be supported by World Bank Program for Results finance as highlighted in blue in the first column of the table above and indicated by a "Y" in the last column. Annex 7 further describes the priority actions included for support through the UP Clean Air Management Program for Results (UPCAMP) World Bank funding along with the related government programs and policies. A Government of India Detailed Project Report (DPR) has been separately prepared and is being circulated along with UCAP.

In line with the CPCB Guidelines for the Formulation of State Action Plans, supplemental work in due time will further specify more detailed institutional arrangements, along with intermediate and longer-term targets and related monitoring and evaluation plans to assess achievement of expected impacts. It will include intermediate steps, working periods, and timelines as well as resource commitments. A large part of this is already described in the UPCAMP DPR described above, along with the related stakeholder consultations and implementation roles.

The UP Graded Response Action Plan (GRAP) and GRAPs in non-attainment cities of UP already under implementation for several years now are regularly updated based on most up to current emissions and scientific information. This is additionally considered as a "living" part of UCAP based on the CPCB Guidelines.

The CPCB Guidelines also call for States to articulate and discuss in their SAP a list of activities that need to be discussed and be implemented by neighboring States in the same airshed. UCAP as described above already provides the technical and scientific information needed for Uttar Pradesh to understand this well. In parallel, a process and institutional mechanism is being established by the MoEFCC in 2024 to help ensure the discussions across States occur. UP has been a leader in the advocacy and promotion of this process and co-hosted the most recent meeting of the IGP States to discuss establishing a mechanism in Lucknow in March 2024.

TABLE 19: COSTS, REDUCTION POTENTIALS, FUNDING SCHEMES AND MATRIX REFERENCE TO ENSURE DEVELOPMENT OF ADDITIONAL MEASURES 2025-2030/35.

Activity	Reduction potential	Current Funding Scheme[1)]	Matrix reference
1. Apply clean energy through advanced technologies (LPGs and other solutions) in rural households.	10.6 μg/m³ PM2.5.	SRLM, NRLM (state schemes). Largely covered through Carbon Funding.	Domestic Cooking Heating # 3-10
2. Use of neem-coated fertilizer and increase NUE.	3.1 μg/m³ PM2.5.	NFSM (state share), PRANAAM, NMAET (state share)	Agriculture # 1-3, 5,
3. Paving roads, apply water spraying and street washing.	3.01 μg/m³ PM2.5.	Road Asset Management System, UP Road Development Project, NCAP, CAQM, 15th FC	Construction and Road Dust # 7a-7e
4. Ban on CRB and recycling of municipal waste.	2.1 μg/m³ PM2.5.	SBM Urban	Indirectly Agriculture # 7-17 and Urban WM
5. Reduce emissions from non-road vehicular sources.	1.03 μg/m³ PM2.5.		Not included
6. Efficient application of PM filters in industries and achieve almost 100 percent efficiency in large industrial plants	0.92 μg/m³ PM2.5.	Ministry of Power and Industry	Industry # 22.
7. Enforced inspection and maintenance systems for vehicles, particularly HD Trucks.	0.84 μg/m³ PM2.5.	Urban transport fund. National and State Vehicle Scrapping Programs	Indirectly Transport # 13–16.
8. Full integration of municipal waste processing.	0.79 μg/m³ PM2.5.	UP MSW and Sanitation Rules/2019. SBM Urban	Urban WM # 1 -3, 5-6.
9. Develop and apply management practices to reduce NH3 emissions from livestock manure in cowsheds (gaushalas).	0.14 μg/m³ PM2.5[2)]	NMAET (State share), SATAT scheme	Agriculture # 4, 18.

Notes

[1)] Additional funding comes from World Bank (UPCAMP) while other potential development partners (e.g., KfW, ADB, AFD, EU, SDC, FCDO etc) are joining the IGP AQM program with additional funding potentials.

[2)] Further research to be made to determine larger reduction potentials, particularly from liquid livestock manure. Ref. also table 12 and text above the table.

Literature List

References to main text

1. Bhaskar, V.S.,Sharma, M. 2008. Assessment of fugitive road dust emissions in Kanpur, India: A note. *Transportation Research Part D: Transport and Environment* 13 (6): 400–403. https://doi.org/10.1016/j.trd.2008.06.003.

2. Guttikunda, S.K., Nishadh, K.A., Jawahar, P.2019. Air Pollution Knowledge Assessments (APnA) for 20 Indian Cities. *Urban Climate* 27: 124–41. https://doi.org/10.1016/j.uclim.2018.11.005.

3. Khan, A., Rahman, N., Khan, H.U., Haq, B.S., Rahman, S. 2015. Particulate Matter and Its Source Apportionment in Peshawar, Northern Pakistan. *Aerosol and Air Quality Research* 15 (2): 634–47. https://doi.org/10.4209/aaqr.2014.10.0250.

4. Mansha, M., Ghauri, B., Rahman, S., Amman, A. 2012. Characterization and Source Apportionment of Ambient Air Particulate Matter (PM2.5) in Karachi. *Science of The Total Environment* 425 (Mai): 176–83. https://doi.org/10.1016/j.scitotenv.2011.10.056.

5. Meijer, J.R., Huijbregts, M.A.J., Schotten, K.C.G.J., Schipper, A.M. 2018. Global Patterns of Current and Future Road Infrastructure. *Environmental Research Letters* 13 (6): 064006. https://doi.org/10.1088/1748-9326/aabd42.

6. Nagar, P.K., Singh, D., Sharma, M., Kumar, A., Aneja, V.P., George, M.P., Agarwal, N., Shukla, S.P. 2017. Characterization of PM2.5 in Delhi: Role and Impact of Secondary Aerosol, Burning of Biomass, and Municipal Solid Waste and Crustal Matter. *Environmental Science and Pollution Research* 24 (32): 25179–89. https://doi.org/10.1007/s11356-017-0171-3.

7. Rubel, F., Kottek, M. 2010. Observed and Projected Climate Shifts 1901-2100 Depicted by World Maps of the Köppen-Geiger Climate Classification. *Meteorologische Zeitschrift* 19 (2): 135–41. https://doi.org/10.1127/0941-2948/2010/0430.

8. Sharma, S.K., Mandal, T.K., Srivastava, M.K., Chatterjee, A., Jain, S. et al. 2016. Spatio-Temporal Variation in Chemical Characteristics of PM10 over Indo Gangetic Plain of India. *Environmental Science and Pollution Research* 23 (18): 18809–22. https://doi.org/10.1007/s11356-016-7025-2.

9. US EPA. 2011. *Emission Factor Documentation for AP-42, Section 13.2.1: Paved Roads*. Washington D.C., U.S.A.: Office of Air Quality Planning and Standards, US Environmental Protection Agency.

10. ARAI. 2011. Indian Emissions Regulations. Automotive Research Association of India (ARAI), Pune.

11. Bittman, S.; Dedina, M.; Howard, C.M.; Oenema, O.; Sutton, M.A., eds. 2014 Options for ammonia mitigation: guidance from the UNECE Task Force on Reactive Nitrogen. Edinburgh, NERC/Centre for Ecology & Hydrology, 83pp. (CEH Project no. C04910) https://nora.nerc.ac.uk/id/eprint/510206/1/N510206CR.pdf

12. BSPCB. 2020. Charter for Wastewater Treatment and Other Pollution Control Measures in Hotels, Restaurants and Banquet Halls. Bihar State Pollution Control Board (BSPCB), Patna.

13. GoI. 2002. The Gazette of India Part II, Section 3, Sub-section (I) No. 318. Government of India (GoI), New Delhi, Thursday, July 11, 2002 (see: http://envfor.nic.in/legis/eia/epr_amd_489.html.)

14. Jena, M.S., Mishra, S.K., Moharana, H.S. 2020. Air Pollution from Cement Plants: Case Study on Particulate Matter in Bihar, India. Environmental Claims Journal, 32:3, pp. 221-232

15. MoEF. 2003. Notification G.S.R. 520(E). Ministry of Environment and Forests (MoEF), New Delhi (See: https://parivesh.nic.in/writereaddata/ENV/envstandard/envstandard45.pdf)

16. Roy, A.G. 2021. Stubble burning: Bihar plans to 'name and shame' violators. Hindustan Times, November 12, 2021.

17. UNFCCC. 2022. India's Updated First Nationally Determined Contribution Under Paris Agreement (2021-2030). United Nations Framework Convention on Climate Change (UNFCCC), Bonn.

18. Cofala, J., Syri, S. 1998a. Sulfur Emissions, Abatement Technologies, and Related Costs for Europe in the RAINS Model Database. IIASA Interim Report No. IR-98-035, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

19. Cofala, J., Syri, S. 1998b. Nitrogen Oxides Emissions, Abatement Technologies and Related Costs for Europe in the RAINS Model Database. IIASA Interim Report No. IR-98-088, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

20. Jeuland, M.A., Pattanayak, S.K. 2012. Benefits and Costs of Improved Cookstoves: Assessing the Implications of Variability in Health, Forest and Climate Impacts. PLoS ONE, 7 (2), pp. 1-15 (See: doi:10.1371/journal.pone.0030338).

21. Jain, A., Tripathi, S., Mani, S., Patnaik, S., Shahidi, T., Ganesan, K. 2018. Access to Clean Cooking Energy and Electricity: Survey of States 2018. Council on Energy, Environment and Water (CEEW), New Delhi.

22. Klimont, Z., Cofala, J., Bertok, I., Amann, M., Heyes, C., Gyarfas, F. 2002. Modeling Particulate Emissions in Europe. A Framework to Estimate Reduction Potential and Control Costs. IIASA Interim Report No. IR-02-076, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

23. Klimont, Z. &Winiwarter, W. (2011). Integrated Ammonia Abatement - Modelling of Emission Control Potentials and Costs in GAINS. IIASA Interim Report. IIASA, Laxenburg, Austria: IR-11-027

24. Kumar, S., Rana, S., Maithel, S. 2018. Learnings from Bihar's Experience of Implementing Cleaner Brick Kiln Directive: A Case Study. Greentech Knowledge Solutions Pvt. Ltd., New Delhi.

25. Kupiainen, K. &Klimont, Z. (2004). Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control. IIASA Interim Report. IIASA, Laxenburg, Austria: IR-04- 079

26. MoAFW. 2021. Neem Coated Urea. Ministry of Agriculture and Farmers Welfare (MoAFW), Government of India, New Delhi

27. MoEFCC, 2015. Environment (Protection) Amendment Rules, 2015. Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

28. MoEFCC, 2016. The Gazette of India: Extraordinary - S.O. 1357(E). Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

29. MoEFCC, 2018a. The Gazette of India: Extraordinary - G.S.R. 263(E). Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

30. MoEFCC, 2018b. The Gazette of India: Extraordinary – G.S.R. 233(E). Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

31. RDSO. 2017. Exhaust Emission Benchmarks for Diesel Locomotives on Indian Railways. Interim Report TR/ED/2017/244, Engine Development Directorate, Research Designs and Standards Organisation, Manak Nagar, Lucknow, March 2017 ihar completes 100 percent electrification two months before the deadline. The Economic Times, 25 October 2018.

32. UNECE (2014) Guidance document on preventing and abating ammonia emissions from agricultural sources. https://unece.org/DAM/env/documents/2012/EB/ECE_EB.AIR_120_ENG.pdf

33. UNECE (2015) Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions. https://unece.org/environment-policy/publications/framework-code-good-agricultural-practice-reducing-ammonia

34. Venkataraman, C., Sagar, A.D., Habib, G., Lam, N., Smith, K.R. 2010. The Indian National Initiative for Advanced Biomass Cookstoves: The benefits of clean combustion. Energy for Sustainable Development, 14 (2), pp. 63-72.

References to Annex 2

1. Bhaskar, V.S.,Sharma, M. 2008. Assessment of fugitive road dust emissions in Kanpur, India: A note. *Transportation Research Part D: Transport and Environment* 13 (6): 400–403. https://doi.org/10.1016/j.trd.2008.06.003.

2. Guttikunda, S.K., Nishadh, K.A., Jawahar, P.2019. Air Pollution Knowledge Assessments (APnA) for 20 Indian Cities. *Urban Climate* 27: 124–41. https://doi.org/10.1016/j.uclim.2018.11.005.

3. Khan, A., Rahman, N., Khan, H.U., Haq, B.S., Rahman, S. 2015. Particulate Matter and Its Source Apportionment in Peshawar, Northern Pakistan. *Aerosol and Air Quality Research* 15 (2): 634–47. https://doi.org/10.4209/aaqr.2014.10.0250.

4. Mansha, M., Ghauri, B., Rahman, S., Amman, A. 2012. Characterization and Source Apportionment of Ambient Air Particulate Matter (PM2.5) in Karachi. *Science of The Total Environment* 425 (Mai): 176–83. https://doi.org/10.1016/j.scitotenv.2011.10.056.

5. Meijer, J.R., Huijbregts, M.A.J., Schotten, K.C.G.J., Schipper, A.M. 2018. Global Patterns of Current and Future Road Infrastructure. *Environmental Research Letters* 13 (6): 064006. https://doi.org/10.1088/1748-9326/aabd42.

6. Nagar, P.K., Singh, D., Sharma, M., Kumar, A., Aneja, V.P., George, M.P., Agarwal, N., Shukla, S.P. 2017. Characterization of PM2.5 in Delhi: Role and Impact of Secondary Aerosol, Burning of Biomass, and Municipal Solid Waste and Crustal Matter. *Environmental Science and Pollution Research* 24 (32): 25179–89. https://doi.org/10.1007/s11356-017-0171-3.

7. Rubel, F., Kottek, M. 2010. Observed and Projected Climate Shifts 1901-2100 Depicted by World Maps of the Köppen-Geiger Climate Classification. *Meteorologische Zeitschrift* 19 (2): 135–41. https://doi.org/10.1127/0941-2948/2010/0430.

8. Sharma, S.K., Mandal, T.K., Srivastava, M.K., Chatterjee, A., Jain, S. et al. 2016. Spatio-Temporal Variation in Chemical Characteristics of PM10 over Indo Gangetic Plain of India. *Environmental Science and Pollution Research* 23 (18): 18809–22. https://doi.org/10.1007/s11356-016-7025-2.

9. US EPA. 2011. *Emission Factor Documentation for AP-42, Section 13.2.1: Paved Roads*. Washington D.C., U.S.A.: Office of Air Quality Planning and Standards, US Environmental Protection Agency.

References to Annex 3

1. ARAI. 2011. *Indian Emissions Regulations*. Automotive Research Association of India (ARAI), Pune.
2. Bittman, S.; Dedina, M.; Howard, C.M.; Oenema, O.; Sutton, M.A., eds. 2014 Options for ammonia mitigation: guidance from the UNECE Task Force on Reactive Nitrogen. Edinburgh, NERC/Centre for Ecology & Hydrology, 83pp. (CEH Project no. C04910) https://nora.nerc.ac.uk/id/eprint/510206/1/N510206CR.pdf
3. BSPCB. 2020. *Charter for Wastewater Treatment and Other Pollution Control Measures in Hotels, Restaurants and Banquet Halls*. Bihar State Pollution Control Board (BSPCB), Patna.
4. GoI. 2002. *The Gazette of India Part II, Section 3, Sub-section (I) No. 318*. Government of India (GoI), New Delhi, Thursday, July 11, 2002 (see: http://envfor.nic.in/legis/eia/epr_amd_489.html.)
5. Jena, M.S., Mishra, S.K., Moharana, H.S. 2020. Air Pollution from Cement Plants: Case Study on Particulate Matter in Bihar, India. *Environmental Claims Journal*, 32:3, pp. 221-232
6. MoEF. 2003. *Notification G.S.R. 520(E)*. Ministry of Environment and Forests (MoEF), New Delhi (See: https://parivesh.nic.in/writereaddata/ENV/envstandard/envstandard45.pdf)
7. Roy, A.G. 2021. Stubble burning: Bihar plans to 'name and shame' violators. *Hindustan Times*, November 12, 2021.
8. UNFCCC. 2022. *India's Updated First Nationally Determined Contribution Under Paris Agreement (2021-2030)*. United Nations Framework Convention on Climate Change (UNFCCC), Bonn.
9. Cofala, J., Syri, S. 1998a. *Sulfur Emissions, Abatement Technologies, and Related Costs for Europe in the RAINS Model Database*. IIASA Interim Report No. IR-98-035, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.
10. Cofala, J., Syri, S. 1998b. *Nitrogen Oxides Emissions, Abatement Technologies and Related Costs for Europe in the RAINS Model Database*. IIASA Interim Report No. IR-98-088, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.
11. Jeuland, M.A., Pattanayak, S.K. 2012. Benefits and Costs of Improved Cookstoves: Assessing the Implications of Variability in Health, Forest and Climate Impacts. *PLoS ONE*, 7 (2), pp. 1-15 (See: doi:10.1371/journal.pone.0030338).
12. Jain, A., Tripathi, S., Mani, S., Patnaik, S., Shahidi, T., Ganesan, K. 2018. *Access to Clean Cooking Energy and Electricity: Survey of States 2018*. Council on Energy, Environment and Water (CEEW), New Delhi.
13. Klimont, Z., Cofala, J., Bertok, I., Amann, M., Heyes, C., Gyarfas, F. 2002. *Modeling Particulate Emissions in Europe. A Framework to Estimate Reduction Potential and Control Costs*. IIASA Interim Report No. IR-02-076, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.
14. Klimont, Z. &Winiwarter, W. (2011). Integrated Ammonia Abatement - Modelling of Emission Control Potentials and Costs in GAINS. IIASA Interim Report. IIASA, Laxenburg, Austria: IR-11-027
15. Kumar, S., Rana, S., Maithel, S. 2018. *Learnings from Bihar's Experience of Implementing Cleaner Brick Kiln Directive: A Case Study.* Greentech Knowledge Solutions Pvt. Ltd., New Delhi.
16. Kupiainen, K. &Klimont, Z. (2004). Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control. IIASA Interim Report. IIASA, Laxenburg, Austria: IR-04- 079

17. MoAFW. 2021. *Neem Coated Urea*. Ministry of Agriculture and Farmers Welfare (MoAFW), Government of India, New Delhi

18. MoEFCC, 2015. *Environment (Protection) Amendment Rules, 2015.* Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

19. MoEFCC, 2016. *The Gazette of India: Extraordinary - S.O. 1357(E).* Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

20. MoEFCC, 2018a. *The Gazette of India: Extraordinary - G.S.R. 263(E).* Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

21. MoEFCC, 2018b. *The Gazette of India: Extraordinary – G.S.R. 233(E)*. Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

22. RDSO. 2017. *Exhaust Emission Benchmarks for Diesel Locomotives on Indian Railways*. Interim Report TR/ED/2017/244, Engine Development Directorate, Research Designs and Standards Organisation, Manak Nagar,Lucknow,March2017.

23. Sharma, A. 2018. Bihar completes 100 percent electrification two months before the deadline. *The Economic Times*, 25 October 2018.

24. UNECE (2014) Guidance document on preventing and abating ammonia emissions from agricultural sources. https://unece.org/DAM/env/documents/2012/EB/ECE_EB.AIR_120_ENG.pdf

25. UNECE (2015) Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions. https://unece.org/environment-policy/publications/framework-code-good-agricultural-practice-reducing-ammonia

26. Venkataraman, C., Sagar, A.D., Habib, G., Lam, N., Smith, K.R. 2010. The Indian National Initiative for Advanced Biomass Cookstoves: The benefits of clean combustion. *Energy for Sustainable Development*, 14 (2), pp. 63-72.