Pre-release Workshop: A new comprehensive Analysis and Report of Indian Air Pollution Levels, Sources and Health Effects, 11 Jan 2018, India Habitat Centre, New Delhi

Source influence on emission pathways and ambient PM-2.5 pollution in India (2015-2050)

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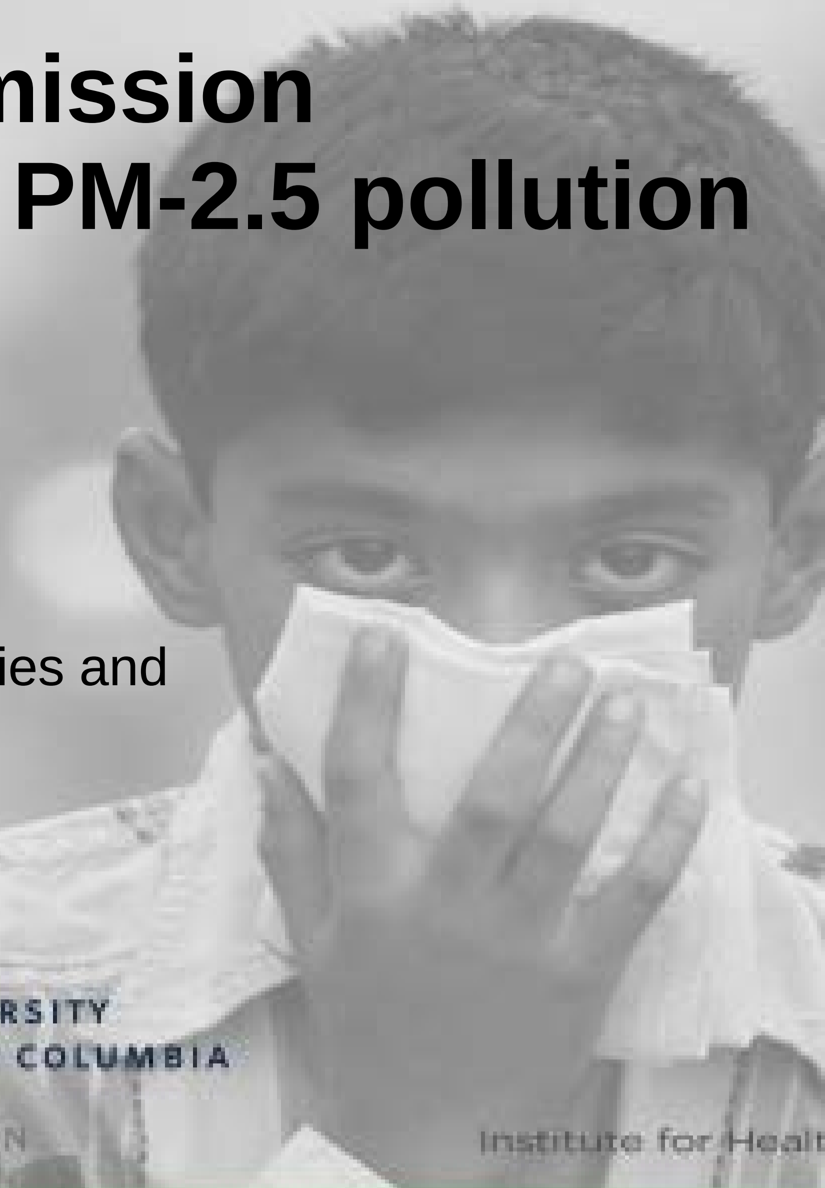
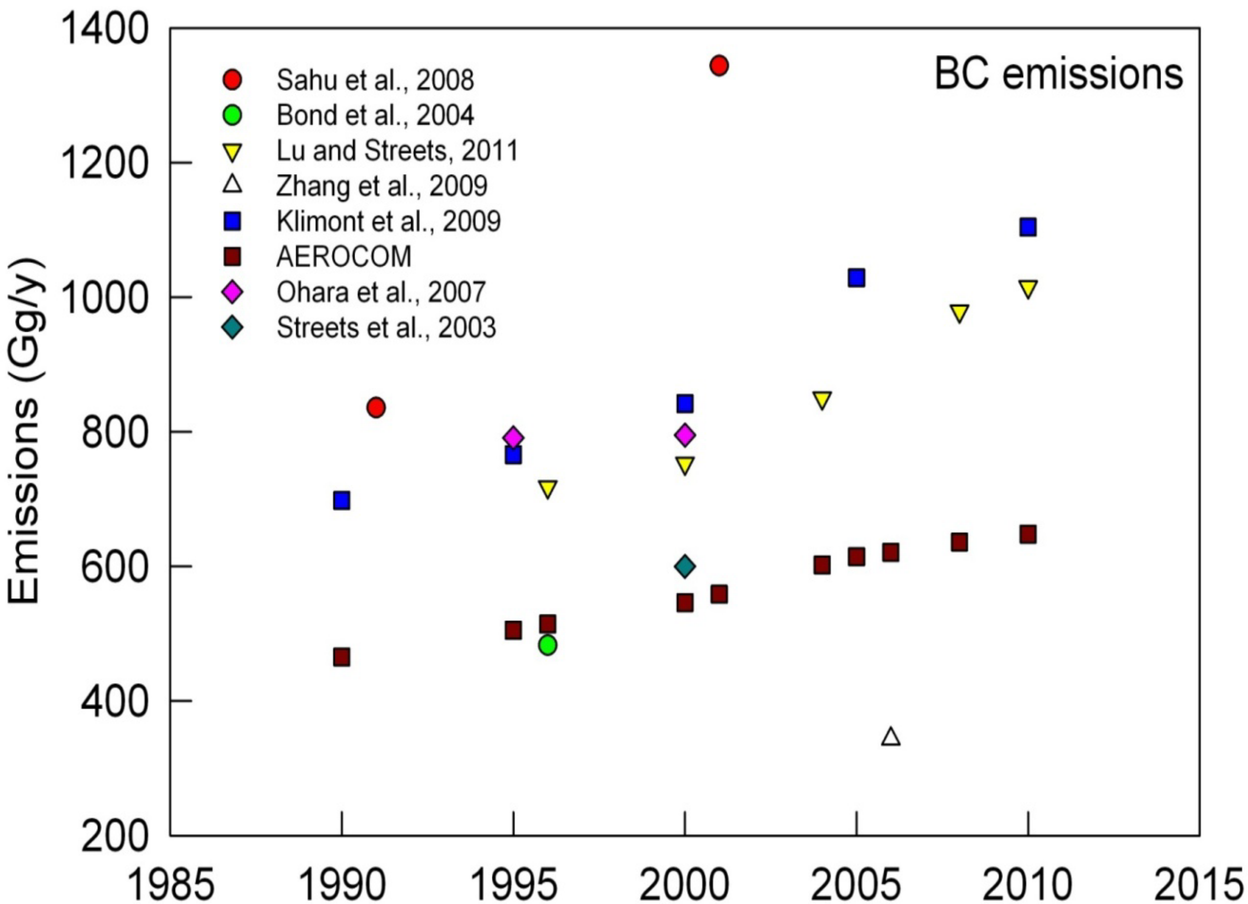


Photo: Sanjeev Verma/Hindustan Times via Getty Images

The ***genesis*** of air pollution and climate change is an ***emission source***

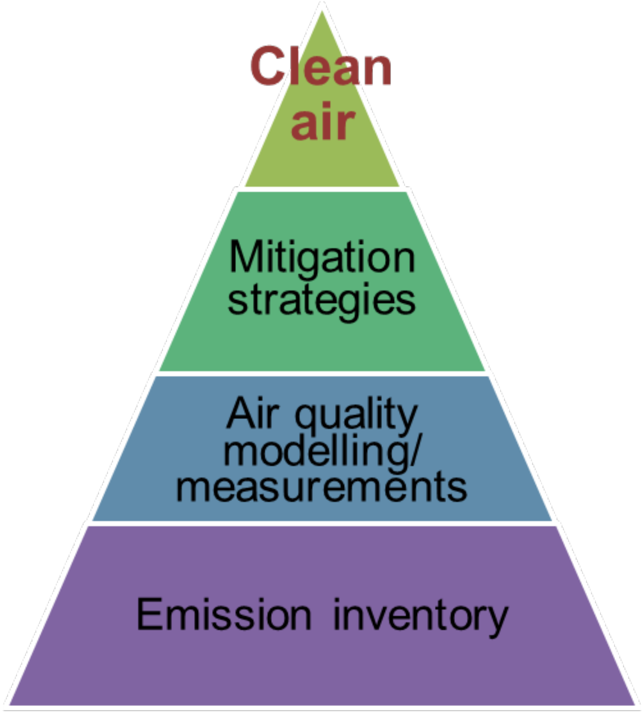
Estimating emissions

Building from globally consistent emission datasets, needs inclusion of regional details, in fuels, technology divisions and energy-use practices, with refined spatial resolution – essential for health burden estimation.



- NATCOM emissions mostly at national level (Tier I).
- Many energy use sectors not well quantified.

Improving emission estimation



Inventory methodology: Tiers of details

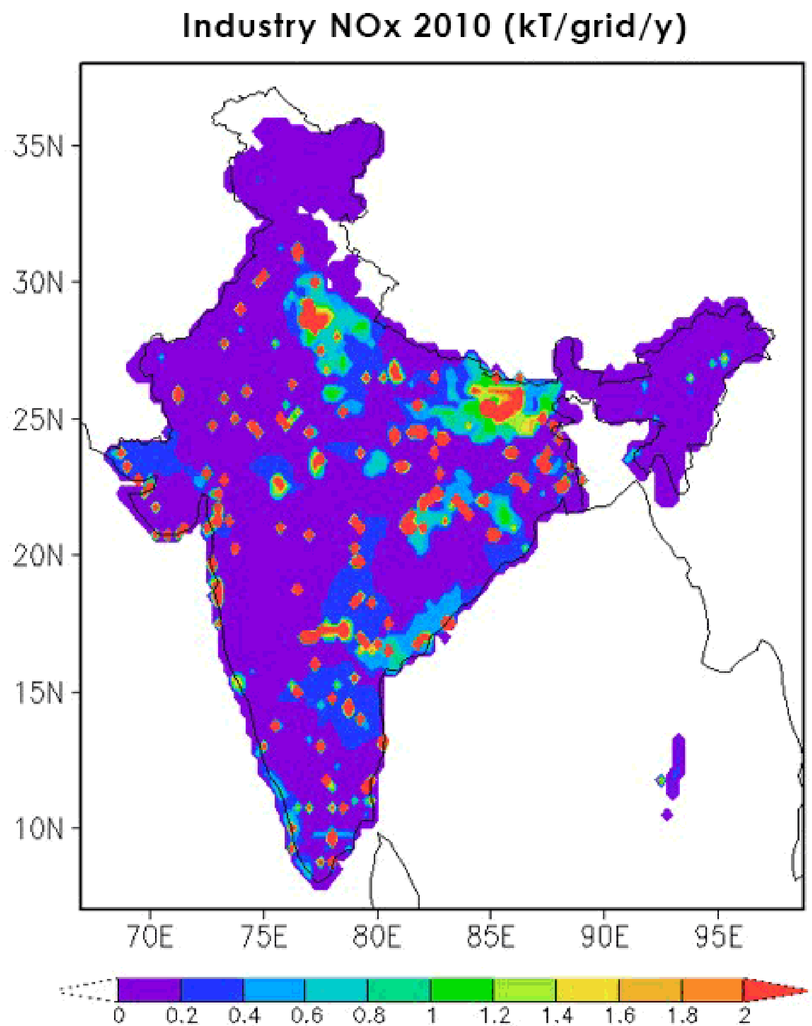
IPCC TIERS

Tier 1	Tier 2	Tier 3
Global tech / fuel / EF	•Country specific fuel characteristics •Technology based EF	•Detailed activity/technology levels •Measured regional EF

ENERGY SECTORS

Sec	Industry	Transport	Residential	Agriculture	Informal
Source Categories	• Thermal power • Heavy industry • Light industry	• On-road gasoline • On-road diesel • Railways /Shipping/ Aviation	• Cooking biofuels • Cooking LPG /kero • Lighting kero lamps	• Agriculture residue burning • Agriculture diesel use	• Brick production • Food processing
Technologies	PC boiler, Stokers, oil-fired boilers, gas turbines, coke ovens, refineries	2-wheelers, 3-wheelers, Cars, LDV, HDV, Buses, CNG vehicles, Super-emitters, age distribution	Traditional biomass stoves, LPG stoves, kerosene stoves, kerosene wick lamps	Open field burning, Different agricultural residues, diesel tractors, diesel pumps	Bull’s Trench Kiln – Fixed and moving chimney, Clamps, Zig-zag firing, VSBKs, wood-boilers

Improving spatial proxies



e.g. shown from NO_X emissions

OLD REPORTED SPATIAL PROXIES

Population based proxies were used for area source categories

No distinction in sources for distributing emissions

NEW SPATIAL PROXIES

LPS – Lat/Lon

Light industry – Urban pop.

Road (g)+Railway-Urban pop.

Road (d) – Road network

Residential cooking – cooking-fuel based user fraction (Census & NSS)

Res. lighting – Rural pop.

Ag. Res. Burning – Crop prod.

Tractors and pumps – Irrigated area

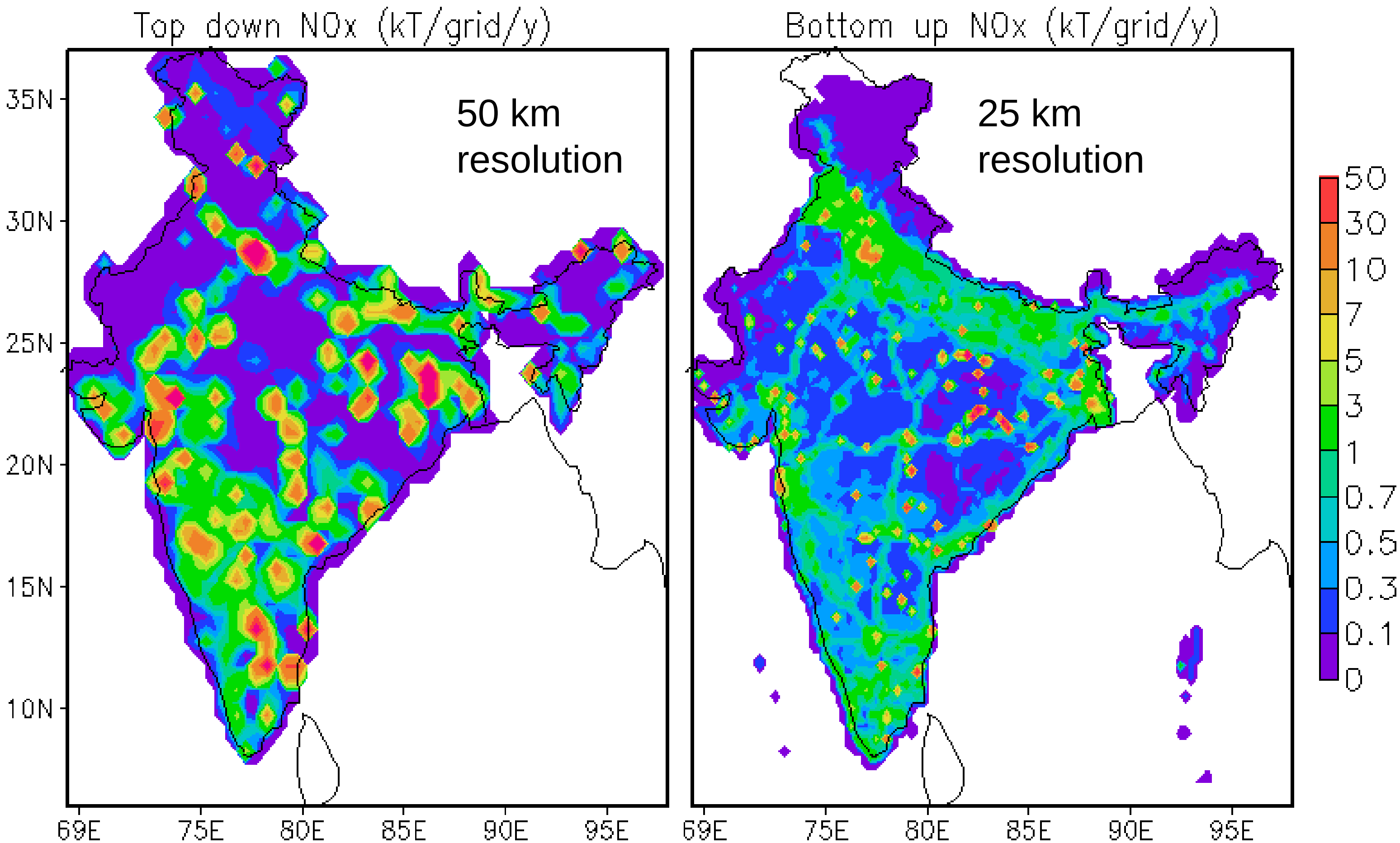
Brick prod. – Brick-walled houses

Informal industry – food and agro-processing (flattened rice, khoya, drying spices, tea, coffee…)

Sadavarte and Venkataraman, 2014 AE; Pandey et al., 2014 AE; Pandey and Venkataraman, 2014 AE

Constraining emissions with satellite-based estimates

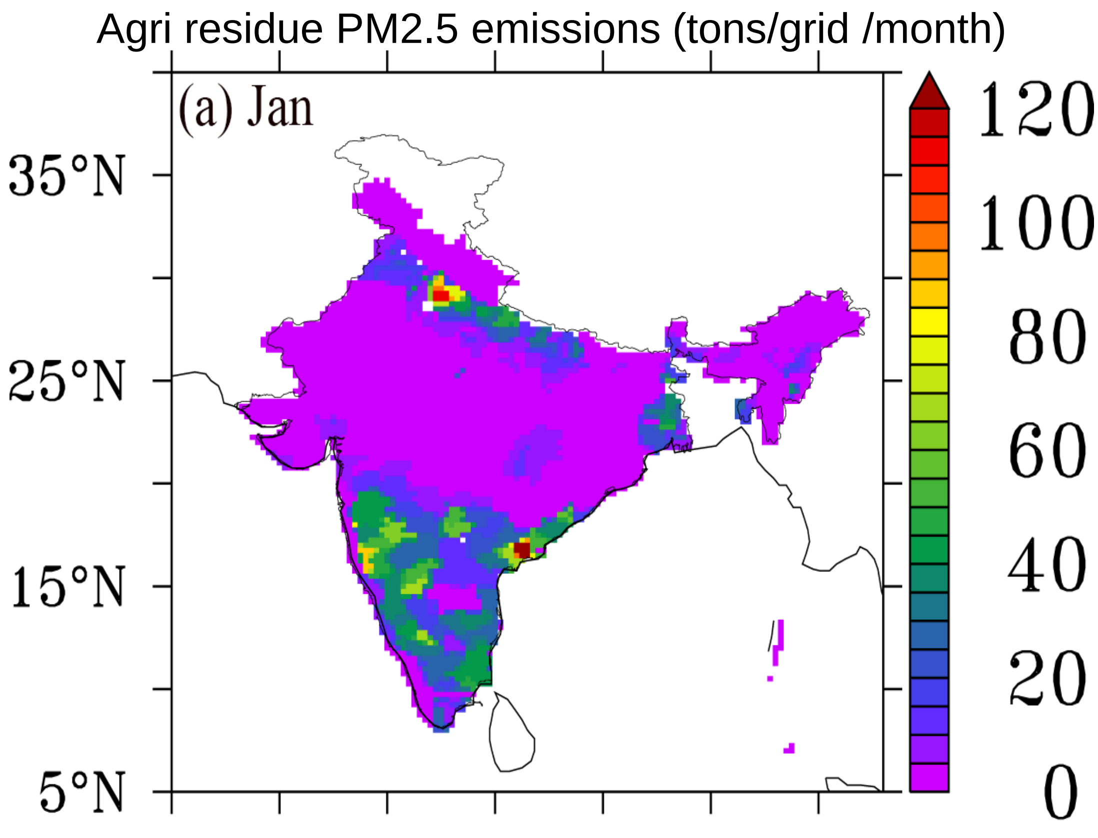
Ghude *et al.*, – 4651 Gg/y **Sadavarte et al.,– 4584 Gg/y**



Magnitude and spatial distribution corrected to capture prominent features of top-down satellite-based emissions.

Sadavarte and Venkataraman, 2014 AE; Pandey et al., 2014 AE; Pandey and Venkataraman, 2014 AE

Harmonizing satellite based (e.g. GFED-4s) and bottom-up emissions from agricultural residue burning



Annual Agri. residue burning PM2.5 emissions:

IITB (bottom-up): 1030 Gg y^{-1}

GFED (top down): 201 Gg y^{-1}

Difference ratio IITB/GFED = 5.1

Uncertainties:

Inventory: Assumed "fraction of residue burned in field" and "waste to grain ratio"

Satellite based: Satellite detected "burned area" and assumed "biomass density"

Both: Emission factors

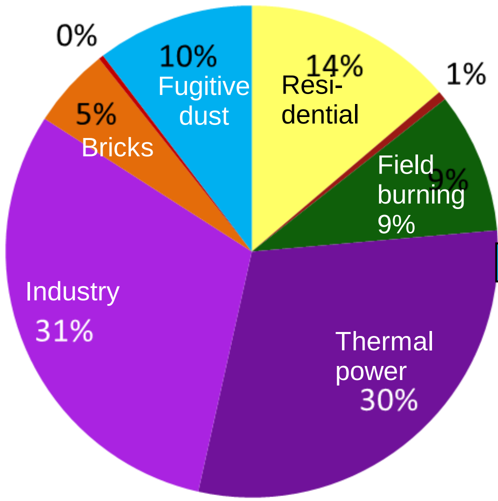
$$F_{ik}=\sum_k CPR_k \; x \; RPR_k \; x \; fB_k \; x \; DMF_k \; x \; BE_k$$

Published reports/ FAI/ Literature

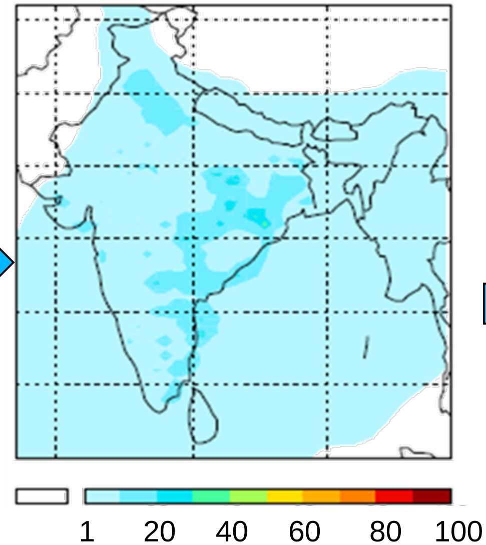
Census/ NSS/ NCAP survey & measurements/BAHS

- $F_{i,k}$ = Amount of crop residue burned in district 'i' of crop type 'k' (kg/yr)
- CPR_k = total crop produced in district 'i' (from state level food production data)
- RPR_k = Waste to grain ratio
- fB_k = fractional amount of residue burnt in the field
- DMF_k = Dry matter fraction
- BE_k = Burning efficiency

Detecting missing sources – anthropogenic dust – using ground measurements

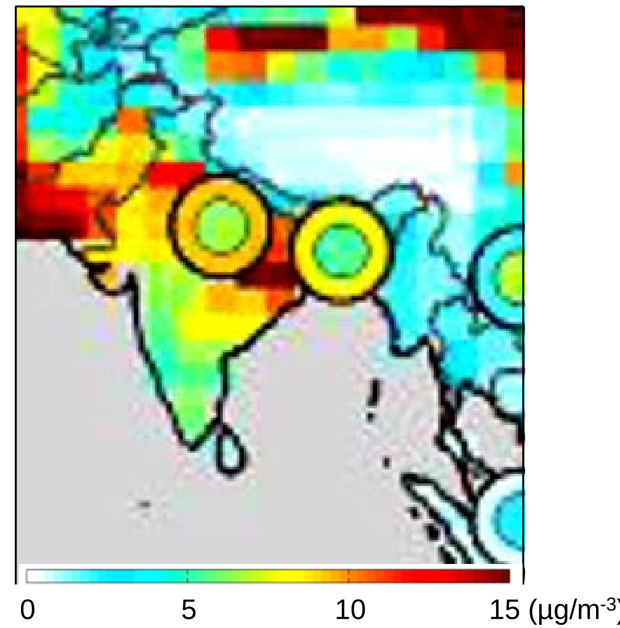


AFCID
2015 emissions
3.2 MT y^{-1}



AFCID
% contribution to
ambient PM2.5 conc.

Total Dust



Annual mean PM2.5 total dust concentrations (µg/m^{-3})

(GEOS-Chem simulated; SPARTAN campaign measurements (inner circle))

AFCID = Anthropogenic, Fugitive, Combustion and Industrial Dust

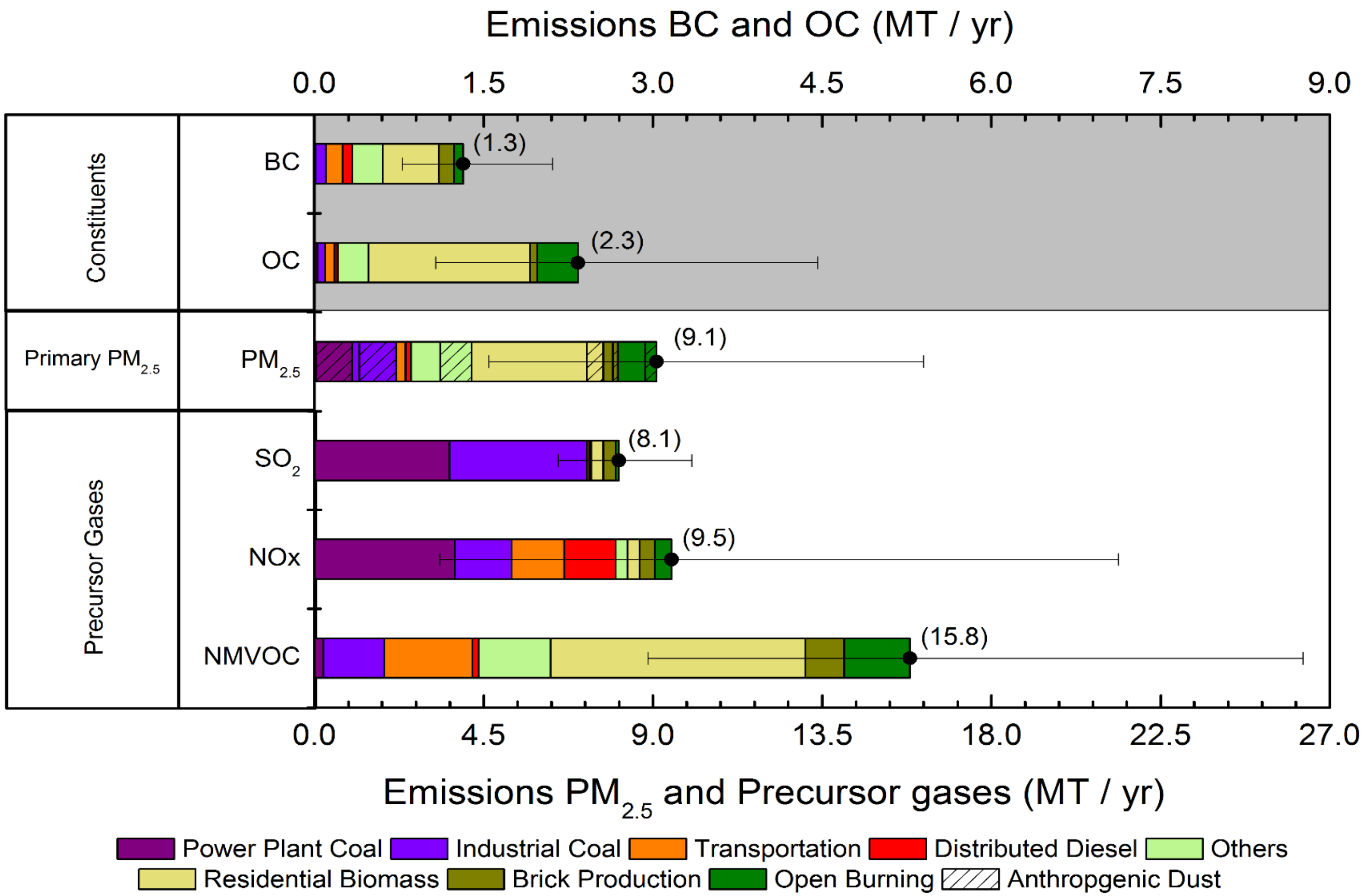
AFCID: coal fly ash, mineral matter from combustion, fugitive dust (re-suspended road dust, and dust from construction).

Including AFCID improves measured vs modelled total dust globally (R^2 from 0.06 to 0.66; SPARTAN sites).

Simulations including AFCID reduce the bias in total dust measured over Asia from -17% to -7%.

Philip, …, Venkataraman et al., 2017 ERL

Present-day emission magnitudes



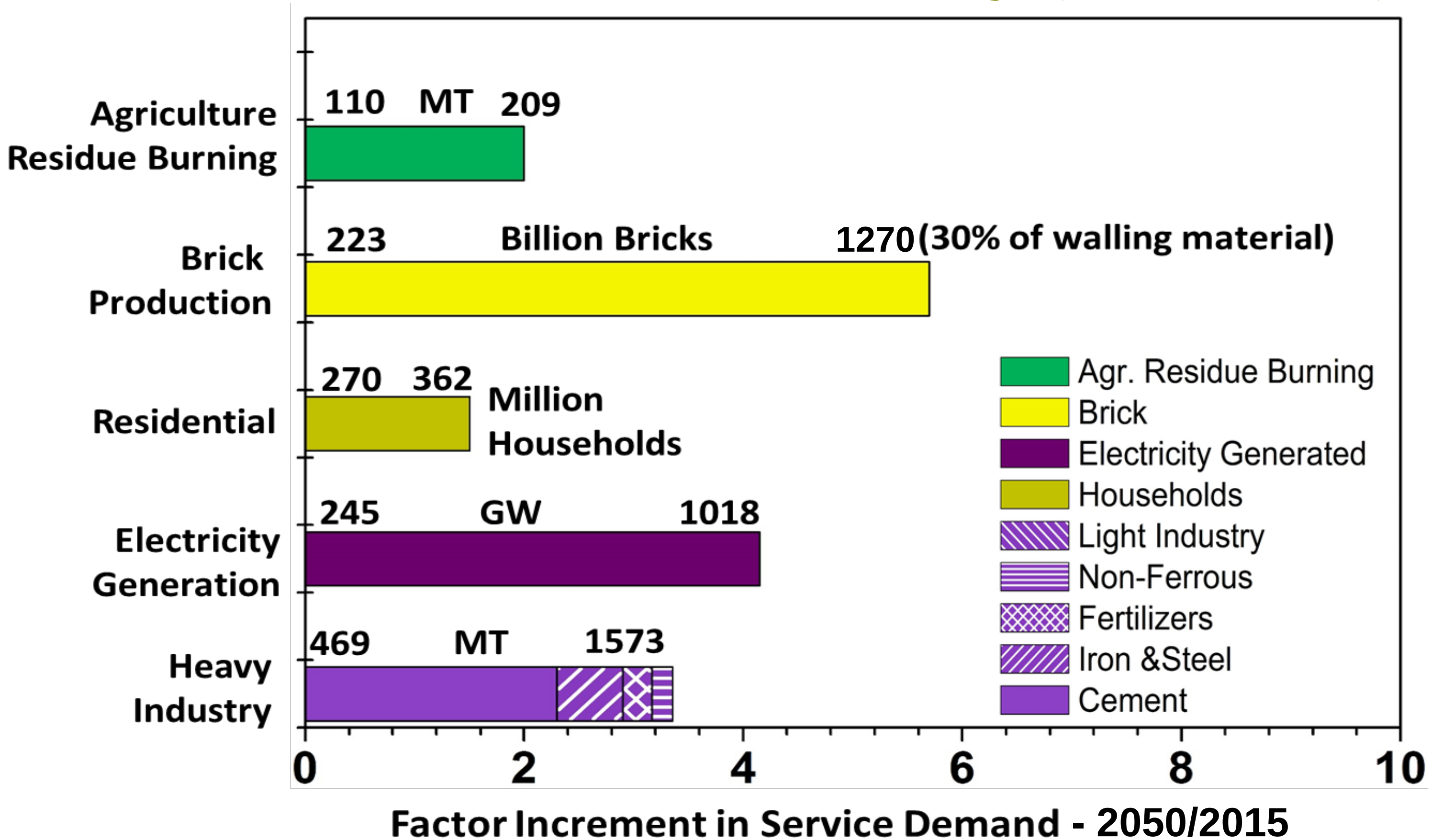
("Others" category includes residential lighting (kerosene lamps), informal industry (food and agro-product processing), trash burning and fugitive dust)

Residential biomass, open burning and informal industry emit 2/3rd of present day primary PM-2.5. Major sources of emissions of BC, OC, CH_4, NMVOC and CO.

Electricity generation, industry (using coal) and transport emit high NO_X and SO_2, which form secondary PM-2.5

Sadavarte and Venkataraman, 2014 AE; Pandey et al., 2014 AE; Pandey and Venkataraman, 2014 AE

Growth in sectoral demand / activity (2015-2050)



Demand or activity projected from annualized growth rates by sector, for 2015-30 and 2030-50, developed from literature.

- Building sector grows 5.7 times, almost 80% of built environment to be constructed.
- Electricity generation grows 4.2 times.
- Growth rates differ in industrial sectors, highest in cement, overall 3.4 times.
- Residential growth tracks population projection at 1.25% per year, grows ~1.4 times.
- Agricultural growth tracks food production, grows ~2 times.

[NITI Aayog 2015; MoEFCC, 2011; Firoz, 2014; Maithel et al., 2012; Ray et. al., 2009; PNG regulatory board, 2013; Murthy, 2014]

Shifts in technologies and practices

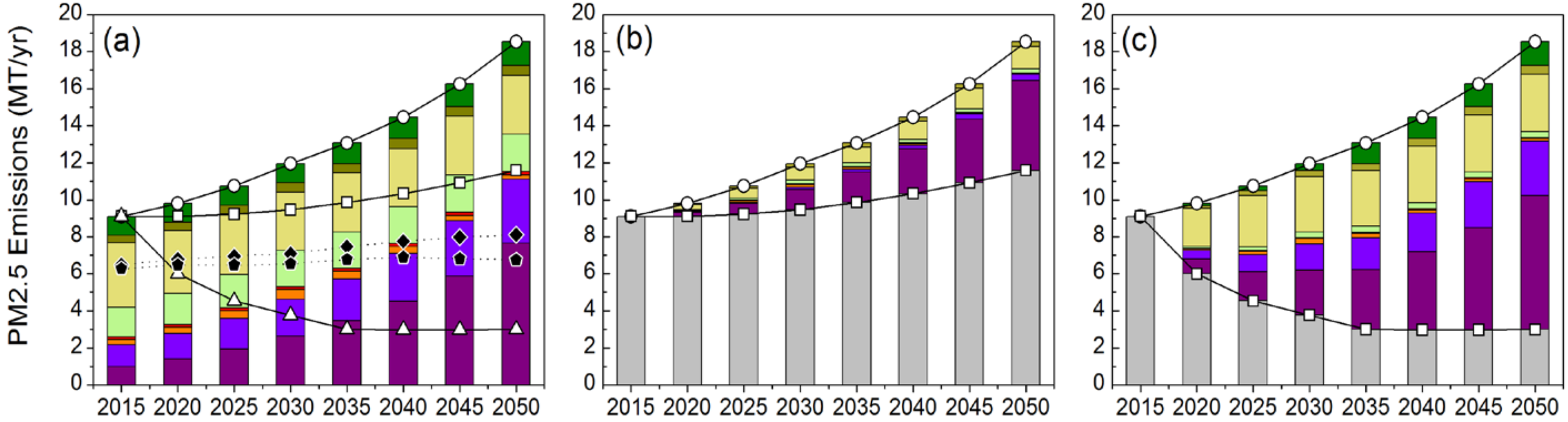
S2 - Promulgated policies

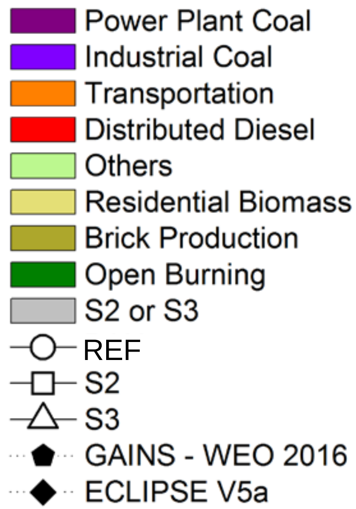
Power plant	Share of renewable energy (40% by 2030) as targeted in India's NDC; negligible flue gas desulphurization from a slow adoption of recent regulation (MoEFCC, 2015).
Industry	Modest increases in energy efficiency (62-84%) under the Perform Achieve and Trade (PAT) scheme (Level 2, IESS, Niti Aayog, 2015).
Transport	Promulgated growth in public vehicle share (25-30%) (NTDPC, 2013; Guttikunda and Mohan, 2014; NITI Aayog, 2015); slow shifts to BS-VI standards (MoRTH, 2016 ICRA, 2016).
Bricks & Informal Ind.	Modest increases in non-fired-brick walling materials (30-45%) (UNDP, 2009; Maithel, personal communication, 2016); slow shift to zig-zag fired brick kilns / clean tech in informal industry.
Residential	Modest shift (55% in 2030 and 70% in 2050) to energy efficient technologies and fuels (Level 2, IESS, Niti Aayog, 2015).
Open burning	No shift away from agricultural residue burning.

S3 - Future policies

Power plant	Large shift (75-80%) to non-fossil power generation (Anandarajah and Gambhir 2014; Shukla and Chaturvedi 2012; Level 4, IESS, Niti Aayog, 2015); 80-95% use of flue gas desulphurization.
Industry	Near complete shift to high efficiency (85-100%) industrial technologies (Level 4, IESS, Niti Aayog, 2015).
Transport	Large shifts to public vehicles (40-60%) (NITI Aayog, 2015), BS-VI syandards, efficient engine technology (MoP, 2015), electric/CNG vehicle share (20-50%) (NITI Aayog, 2015).
Bricks & Informal Ind.	Large share of non-fired brick walling materials (40-70%), complete move to zig-zag fired / VSBK kilns; gasifiers / clean technologies in informal industries (65-80%).
Residential	Large shifts (90% in 2030 and 100% in 2050) to LPG/PNG/electric cooking (Level 4, IESS, Niti Aayog, 2015), (100% in 2030) electric and solar lighting (National Solar Mission 2010).
Open burning	Shift away from (35% phase out by 2030) and complete phase-out (2050) of agricultural residue burning to mulching/deep-sowing technologies/practices (Gupta, 2014).

Projected evolution of Indian PM-2.5 emissions





("Others" includes residential lighting (kerosene lamps), informal industry (food and agro-product processing), trash burning and fugitive dust)

Projected growth in PM-2.5 emissions from 9.1 Tgy^{-1} (2015):

REF: 2015 emission regulations

- 12.0 Tg (2030) and 18.5 Tg (2050)

S2: Minor gains from modest shifts to non-coal power (NDC, 2015); biomass stoves to LPG/gasifiers

- 9.5 Tg (2030) and 11.5 Tg (2050)

S3: Major gains from major shift to non-coal power and industry; complete shift from biomass stoves; complete phase-out of open burning (agricultural residue)

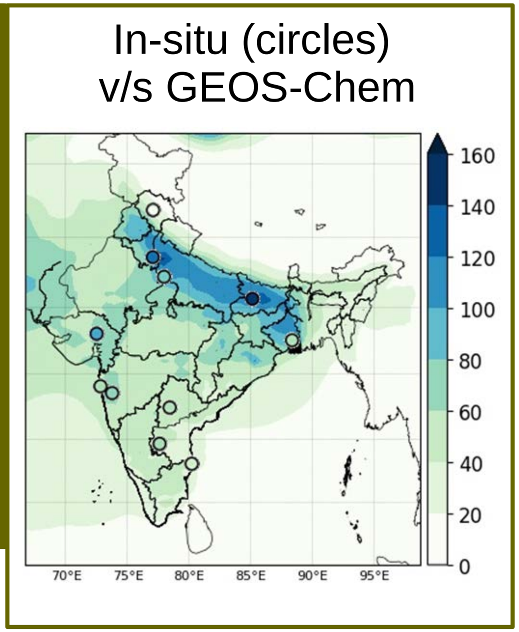
- 3.8 Tg (2030) and 3.0 Tg (2050)

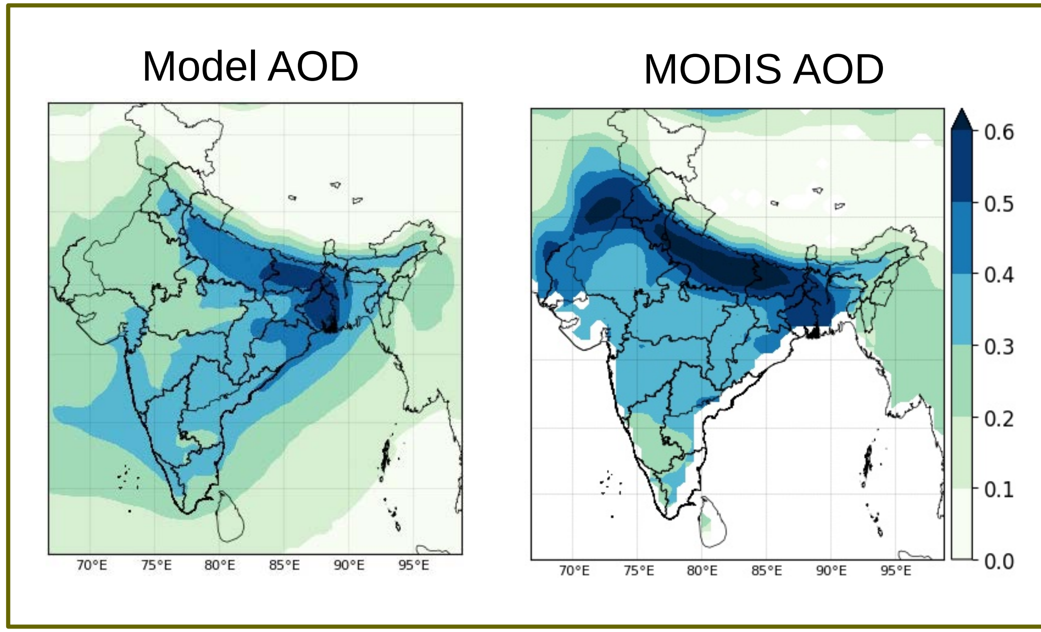
Air quality impacts

Simulations over subcontinent (GEOS-Chem; 50 km x 67 km)

- **11.2% NMB** of model simulated concentrations and in-situ measurements
- **33% NMB** of model simulated vs satellite detected AOD
- Species seasonal cycle OK; wintertime underestimation

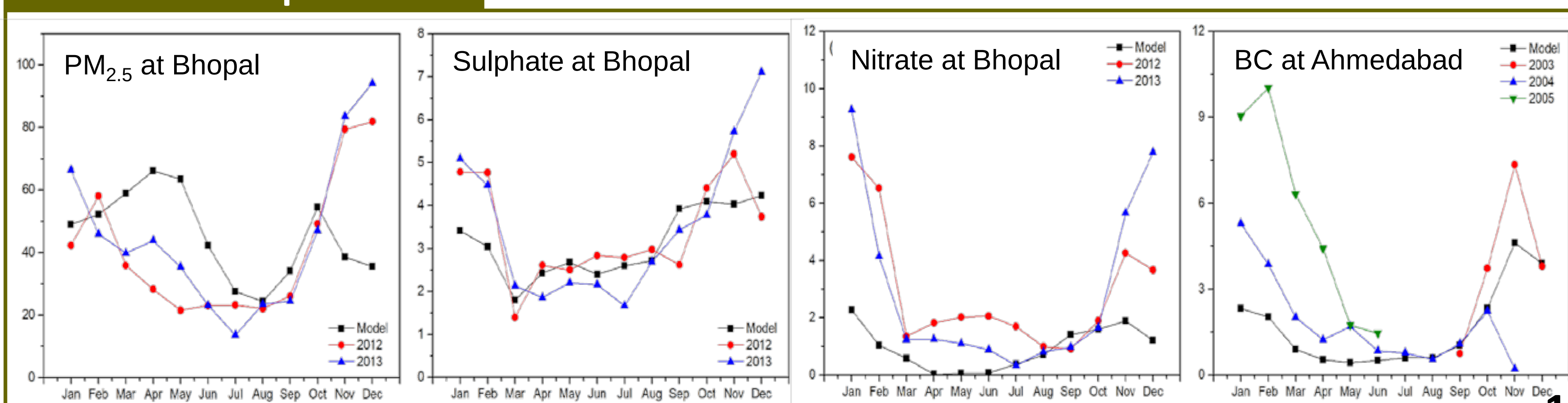
Concentrations (µg/m^{-3})





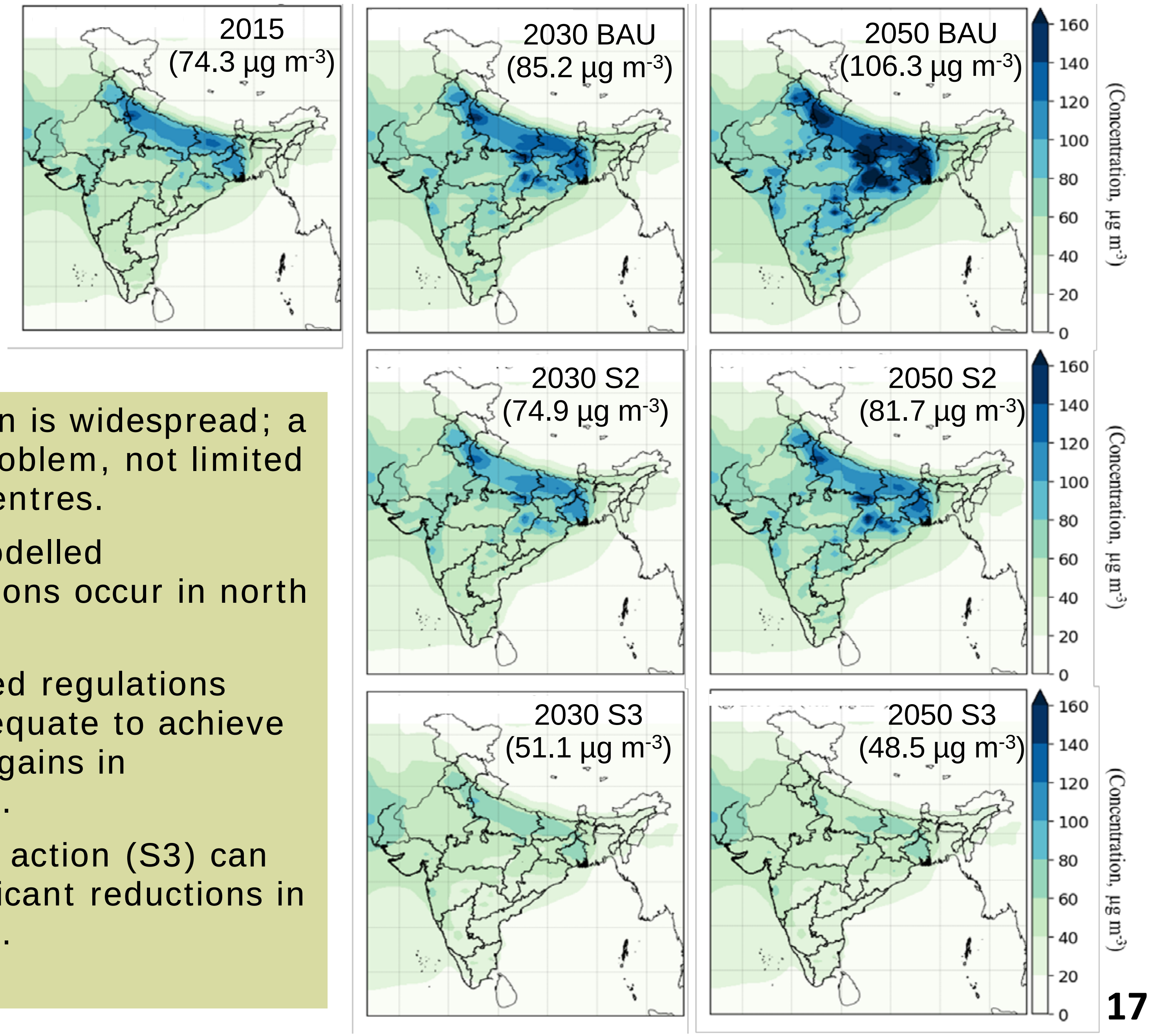
AOD

Chemical species



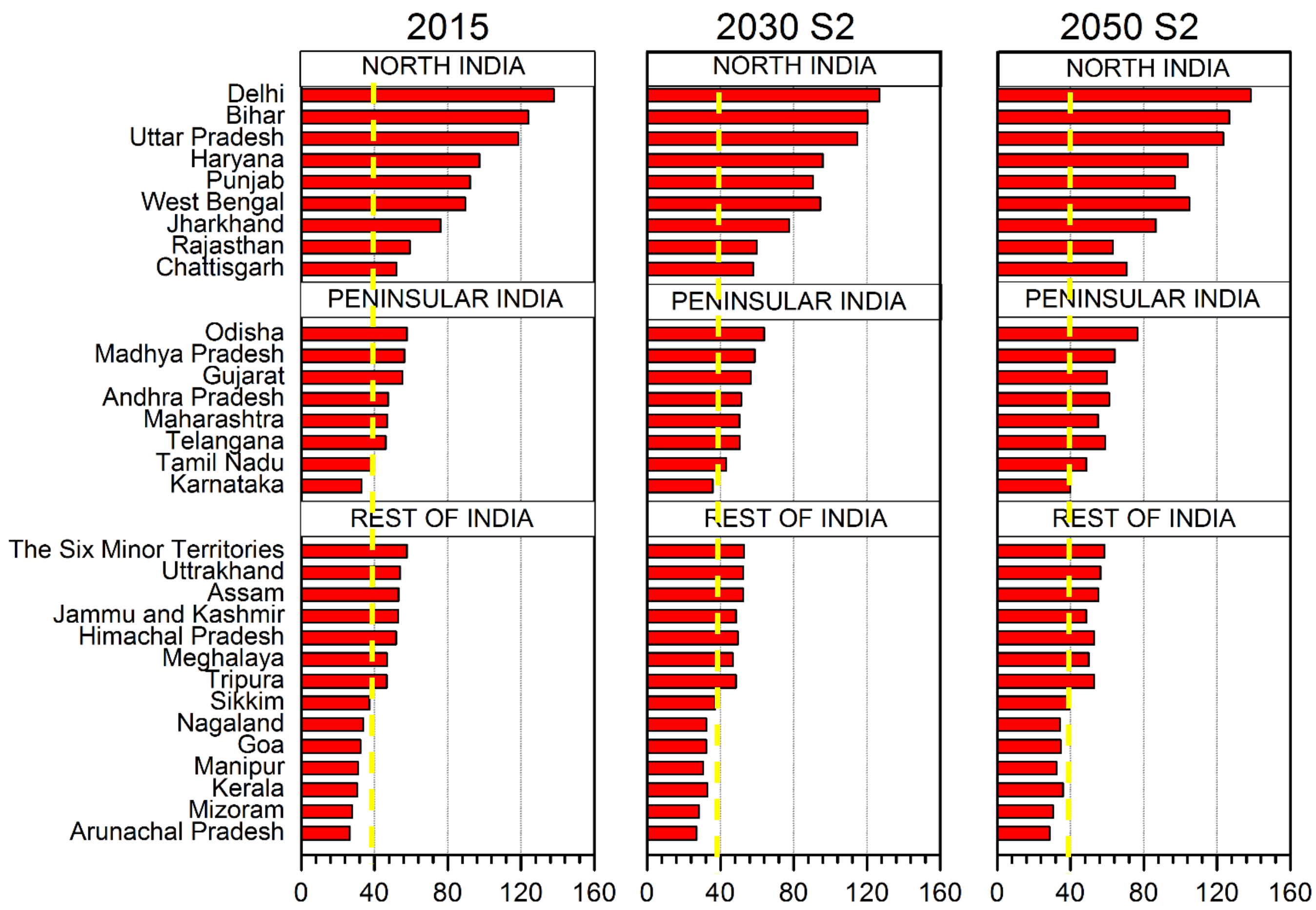
Venkataraman et al., 2017, ACPD

Annual mean population weighted PM-2.5 concentrations



- Air pollution is widespread; a national problem, not limited to urban centres.
- Largest modelled concentrations occur in north India.
- Promulgated regulations (S2), inadequate to achieve air quality gains in 2030/2050.
- Aggressive action (S3) can yield significant reductions in 2030/2050.

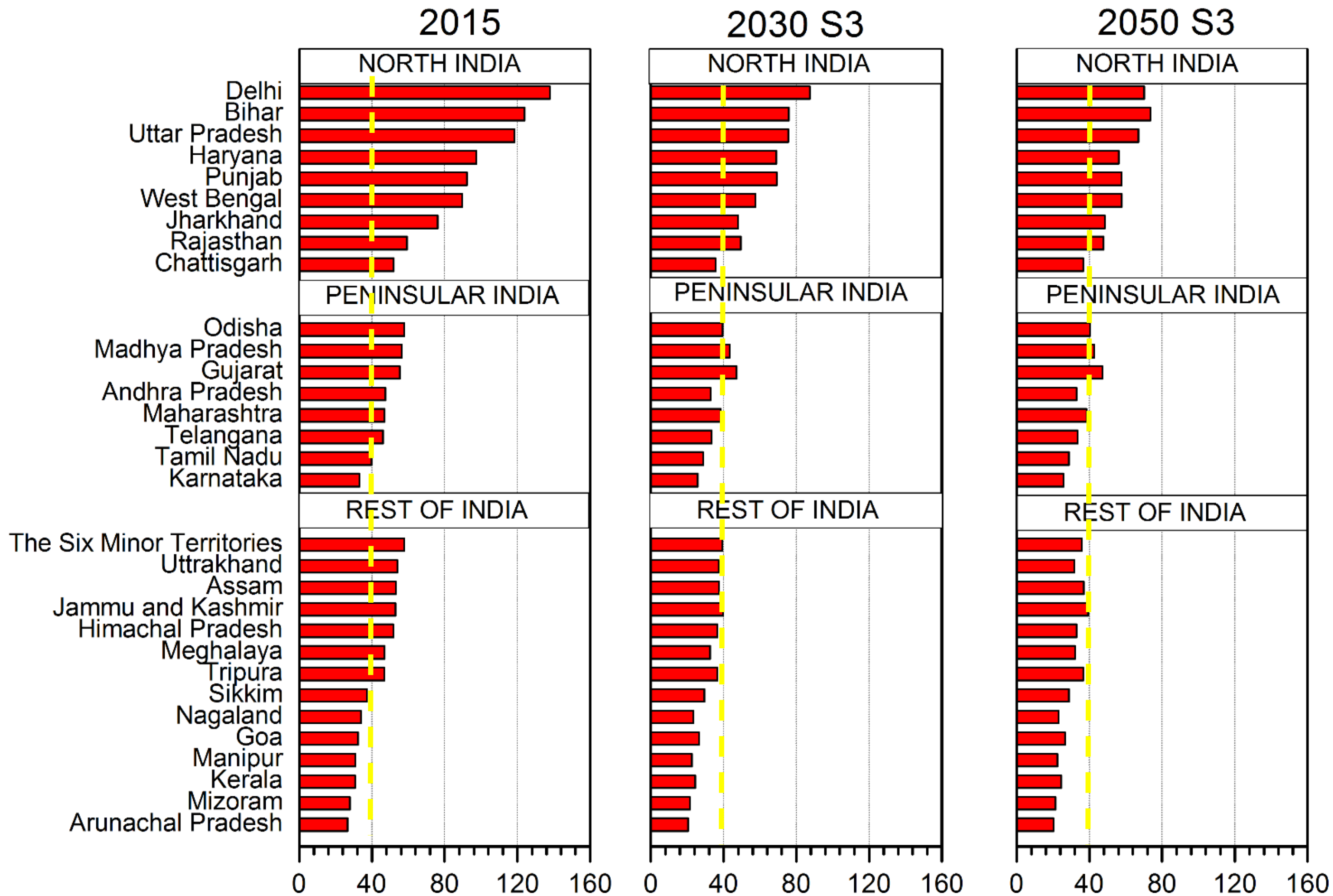
State-level population weighted PM-2.5 concentrations: present day and under promulgated regulations (S2)



- Wide differences among modelled concentrations across states. In 2015 all exceed WHO or US-NAAQS and most exceed Indian annual PM-2.5 standard (40 μg m^{-3}).
- Under promulgated regulations (S2), growth in industrial and energy demand, neutralizes gains in emission reductions, yielding no air quality benefits in 2030, with modest worsening in 2050.

Venkataraman et al., 2017, ACPD

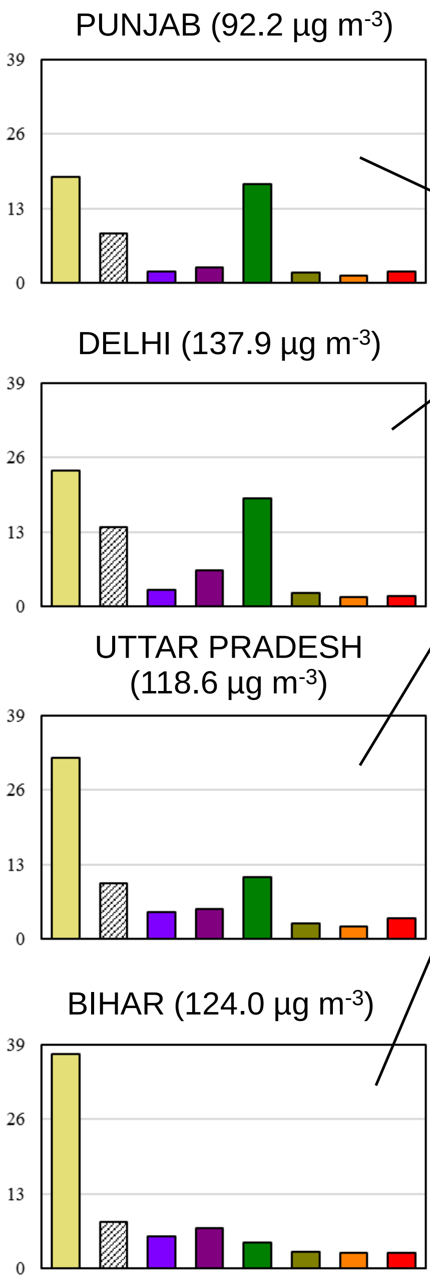
State-level population weighted PM-2.5 concentrations: present day and under ambitious action scenario (S3)

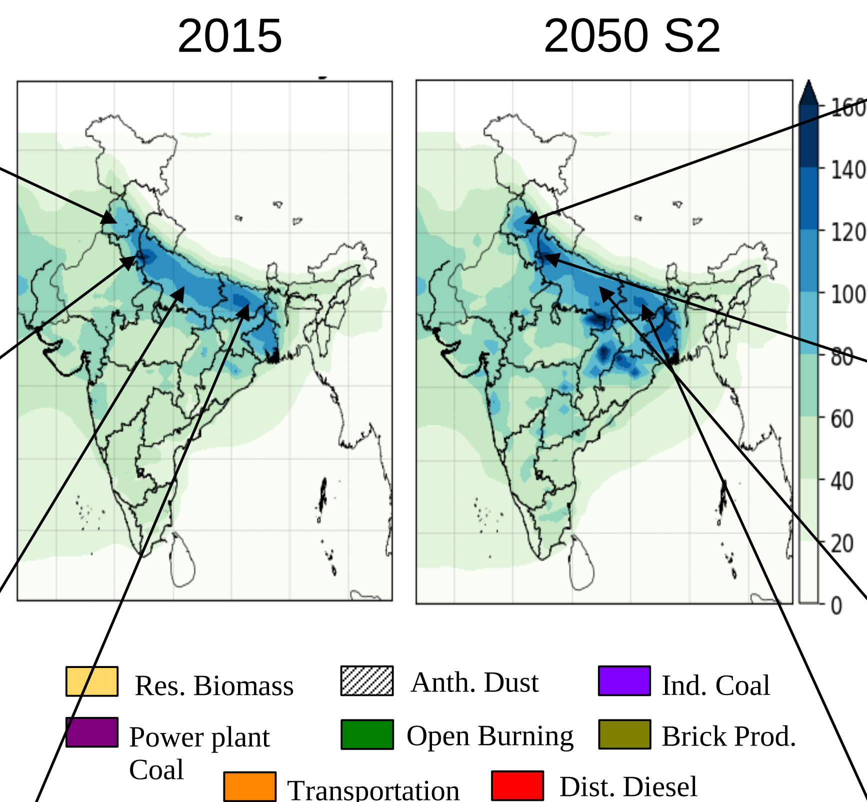


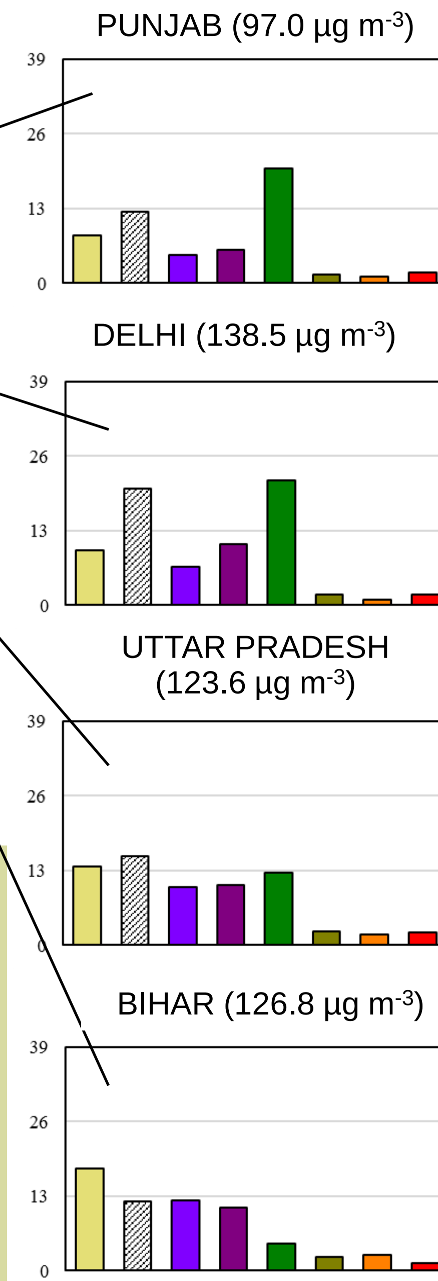
- Large shifts away from residential biomass stoves and agricultural open burning, along with large shifts away from industrial coal use, necessary for future improvements in air quality.
- Modelled concentration in about 10 states still exceed the ambient PM-2.5 standard in 2050, but most fall below it.

Venkataraman et al., 2017, ACPD

Present-day and future source contributions, S2: North India

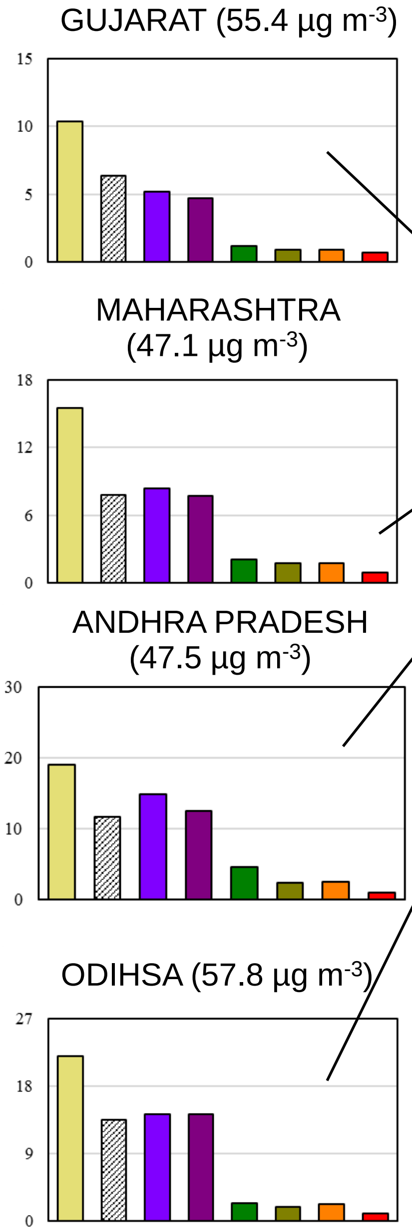


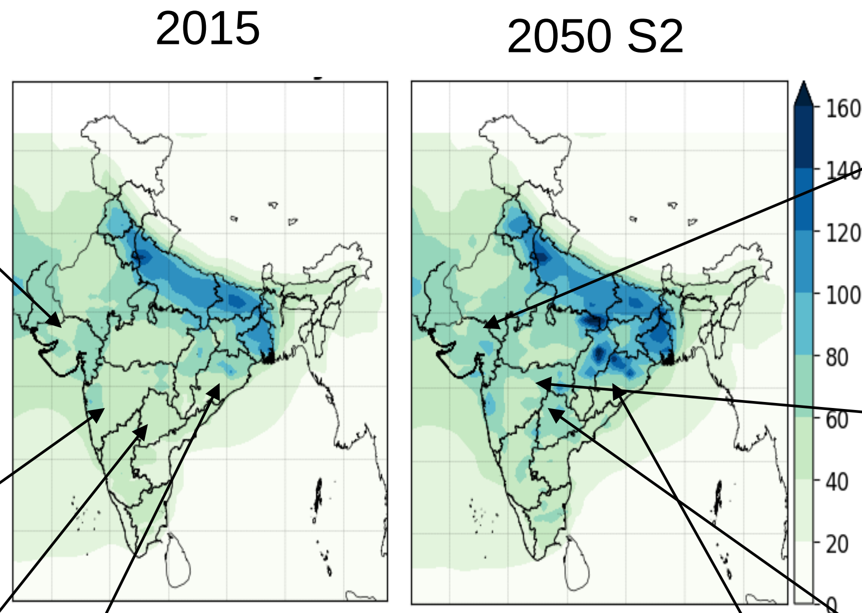


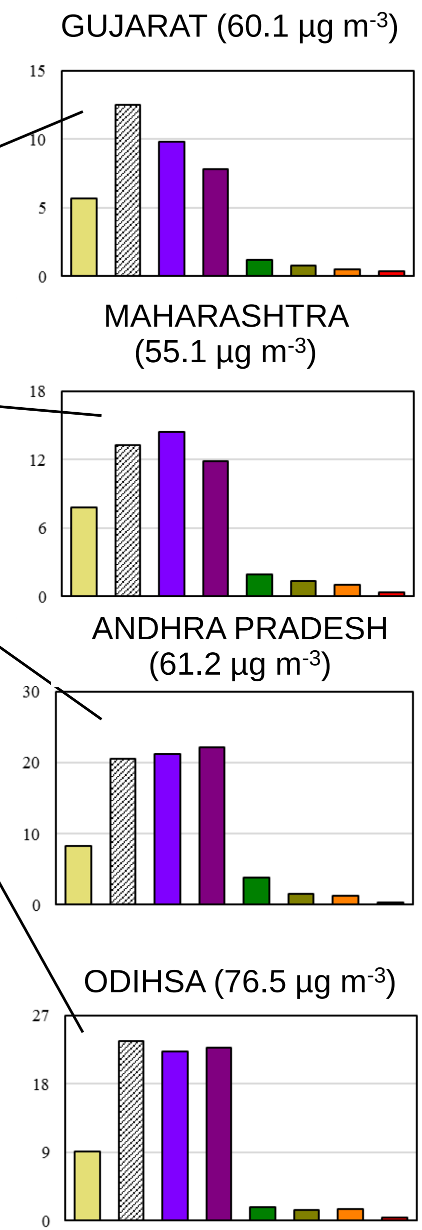


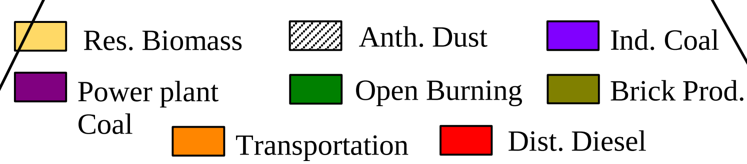
- In 2015, *residential biomass use* and agricultural residue burning have largest influence on *outdoor air pollution* in north India.
- Followed by power plant/industrial coal and anthropogenic dust (mainly coal fly-ash).
- In 2050, under S2, while power plant/industry influence grows, residential and agricultural emissions do not reduce enough.
- More accurate capturing of spatial gradients from local sources like transport, needs nested higher resolution simulations.

Present-day and future source contributions, S2: Peninsular India



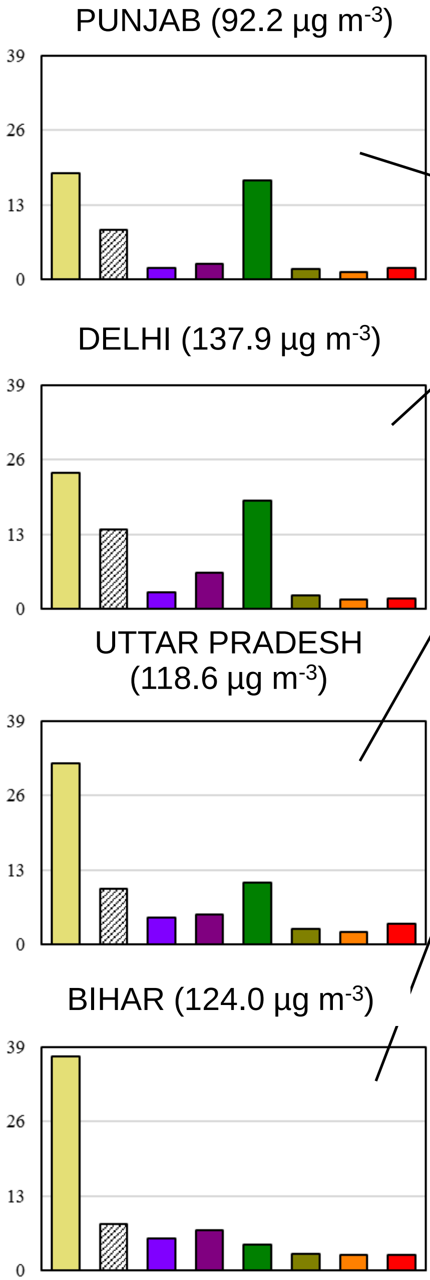


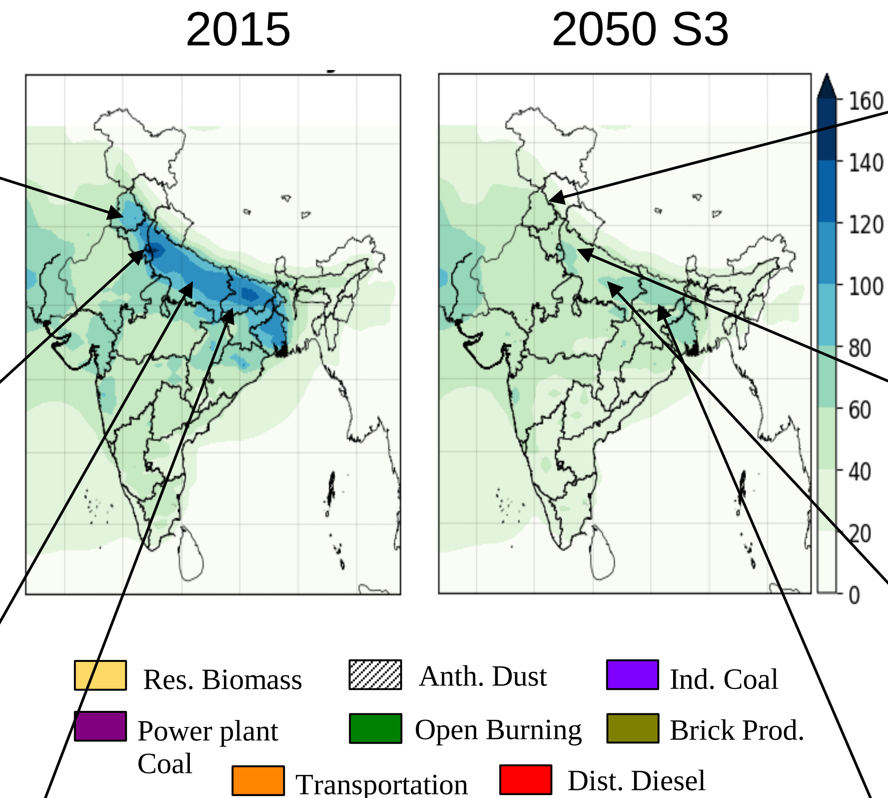


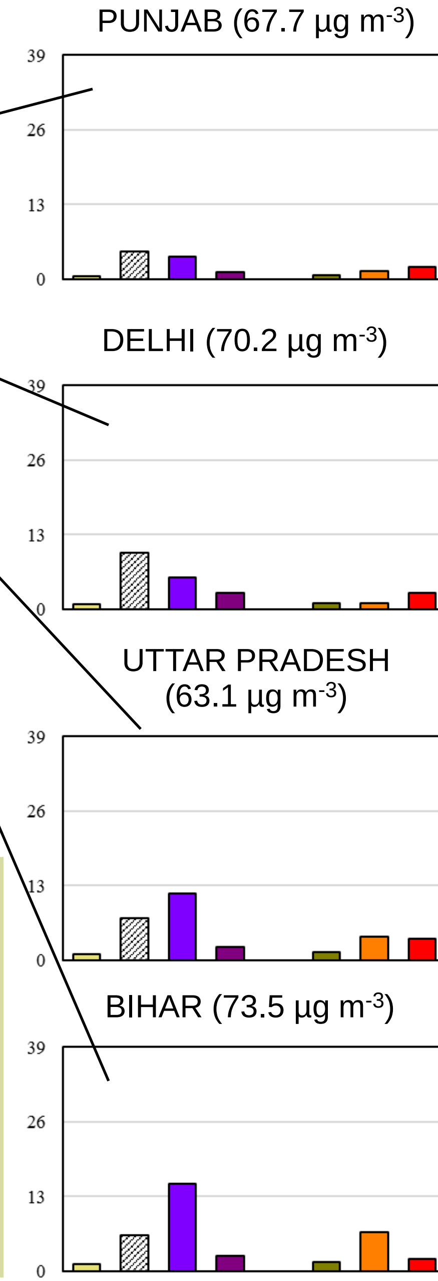


- In 2015, *residential biomass use* influence in peninsular India as well.
- Industrial/power plant coal and anthropogenic dust have next largest influence; open burning not significant.
- In 2050, under S2, power plant/industry influence grows sharply from influence of power and cement plants.
- Factor of ~1.5 increase in modelled PM-2.5 concentrations in Andhra Pradesh and Odisha.

Future source contributions, S3: North India

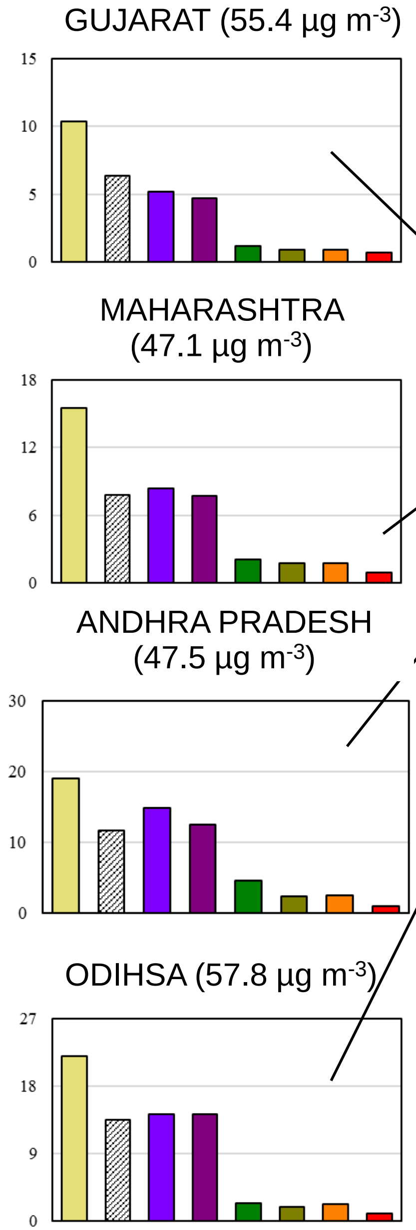


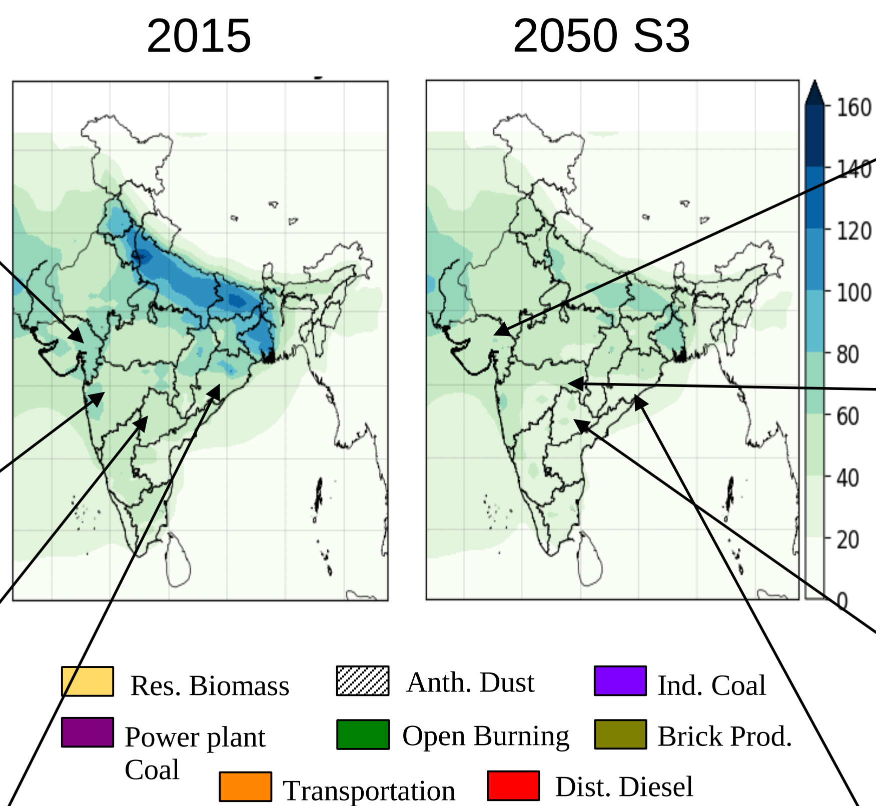


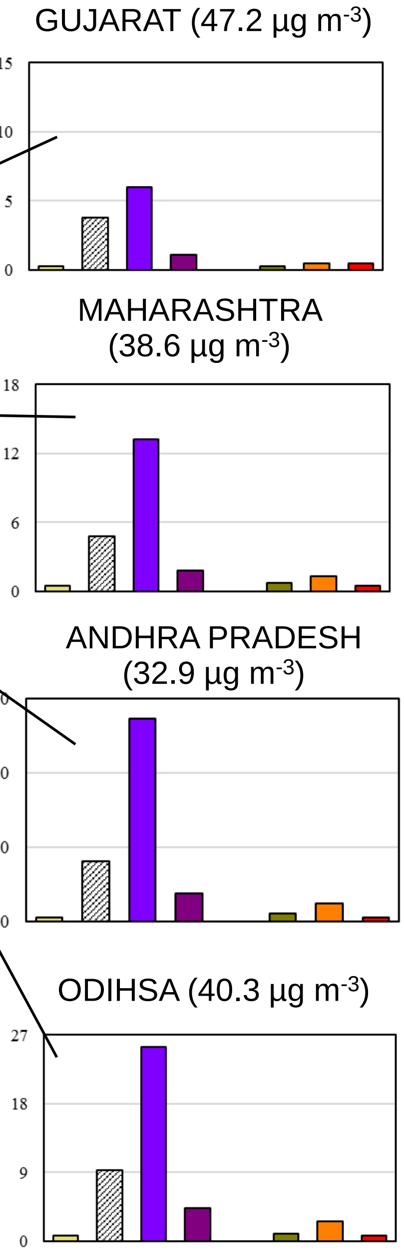


- Under S3, ambient PM-2.5 concentrations fall by factor of ~1.5-2; residential and agricultural residue burning contribution falls to 1-2%.
- Industrial and power plant coal / anthropogenic dust (urban fugitive), followed by transportation and distributed diesel, become relatively more important.
- Balance from "total dust", "natural dust" and "others" (urban fugitive dust / trash burning).

Future source contributions, S3: Peninsular India







- Under S3, ambient PM-2.5 concentrations fall only slightly by factors of ~1.2; residential contribution falls to 1-2%.
- However, Industrial coal / anthropogenic dust, becomes significantly important, in peninsular states.
- Cement, Iron and steel sector growth neutralizes PAT gains – further sectoral analysis needed - fugitive emissions from crushing / grinding operations, etc.

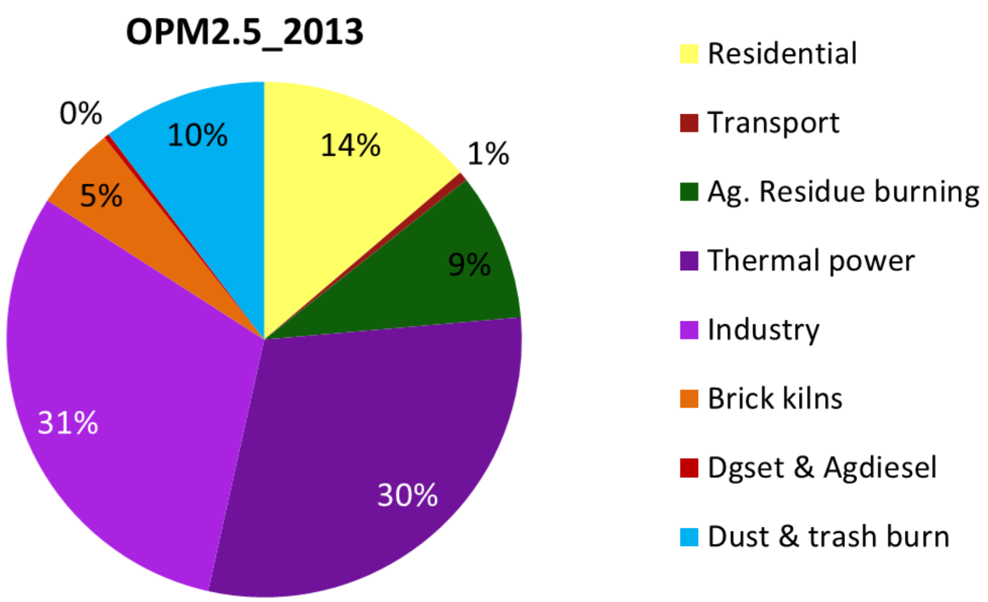
Perspective

- Simulations on a regional domain reveal air pollution is a *pan-India problem*.
- Large regional background pollution, underlying local sources.
- Regional background (*residential biomass, open burning, coal-industry/power),* local sources *(transportation, brick kilns, diesel generators, trash burning)*.
- *Residential biomass* dominates *outdoor air pollution* (in addition to large HAP exposures, not examined here).
- To mitigate air pollution, India needs stringent targets, beyond ones promulgated, for a three-pronged switch away from:
  - traditional biomass technologies
  - open burning of agricultural residues
  - coal-burning in industrial / power
- Residential clean energy solutions are essential, including "ultra-low-emission gasifier stoves," LPG/PNG/ electric stoves, and electric/solar lighting.
- Shifts away from agricultural residue burning to mulching/deep-sowing practices essential to improving north India air quality.

**Thank you,
Questions welcome!**

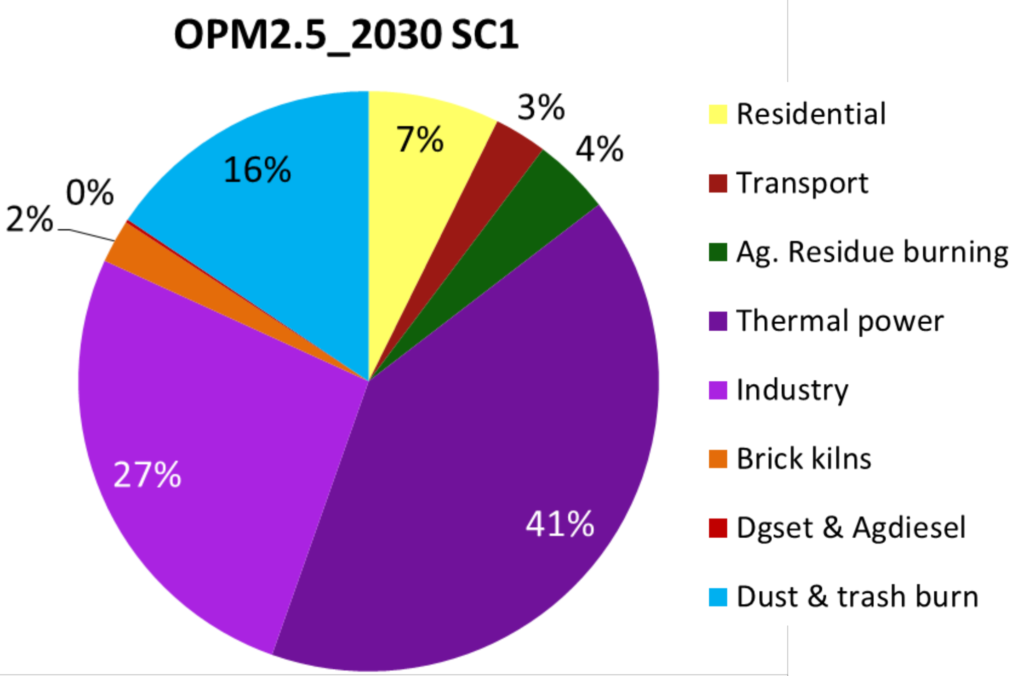
Extra slides

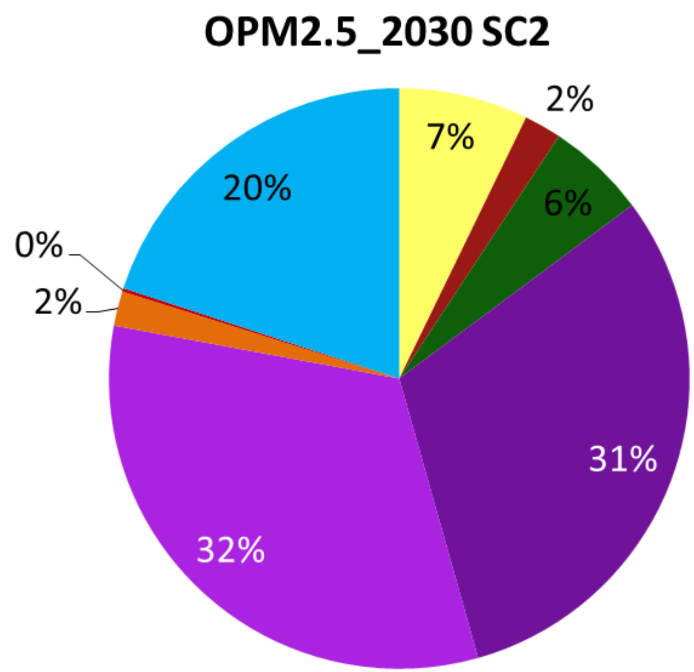
OPM2.5 sectoral distribution

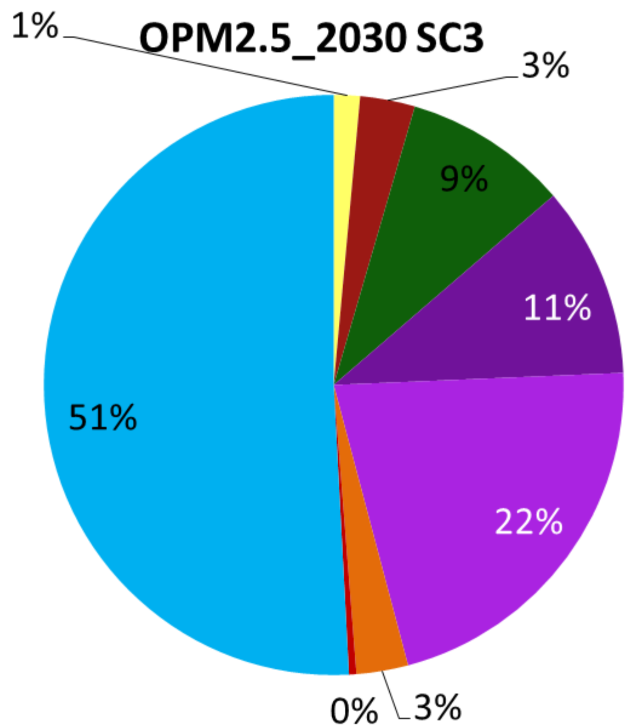


Total emissions

- $OPM_{2.5}$ 2013: 3220 Gg
- $OPM_{2.5}$ 2030 Sc1: 6315 Gg
- $OPM_{2.5}$ 2030 Sc2: 4933 Gg
- $OPM_{2.5}$ 2030 Sc3: 1937 Gg
- $OPM_{2.5}$ 2050 Sc1: 12436 Gg
- $OPM_{2.5}$ 2050 Sc2: 7204 Gg
- $OPM_{2.5}$ 2050 Sc3: 1866 Gg

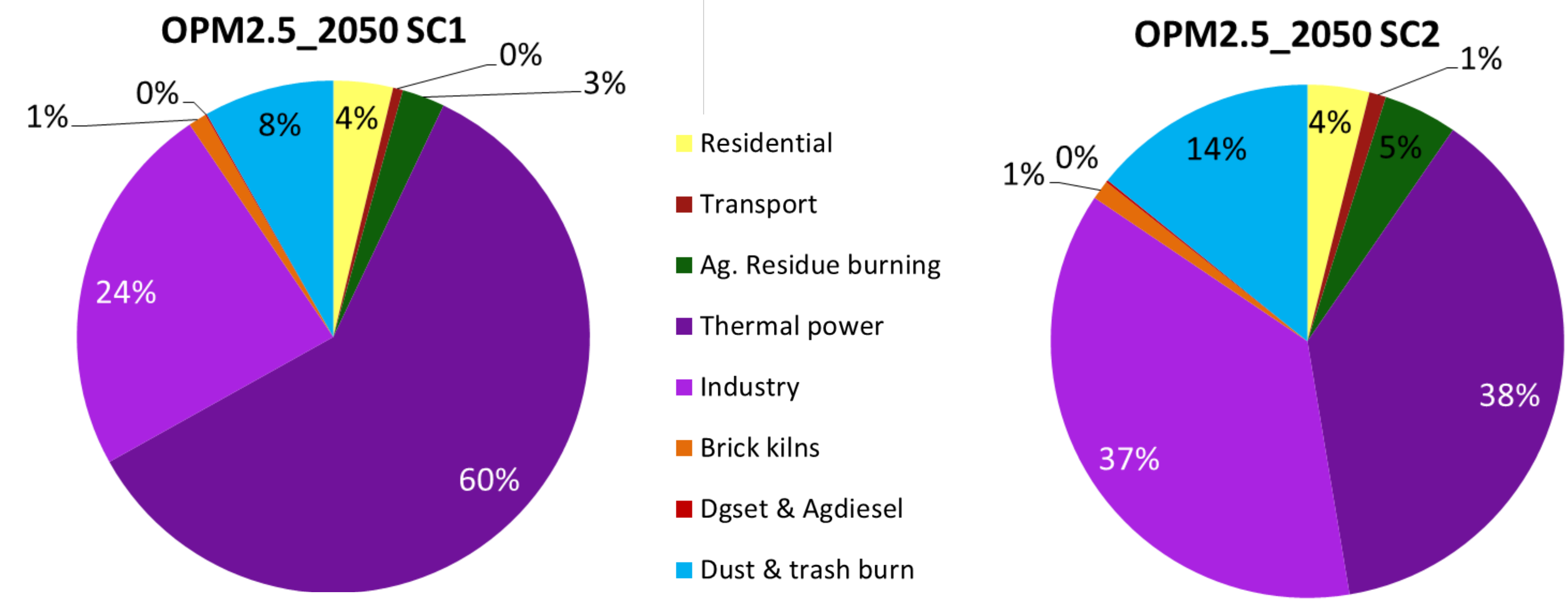


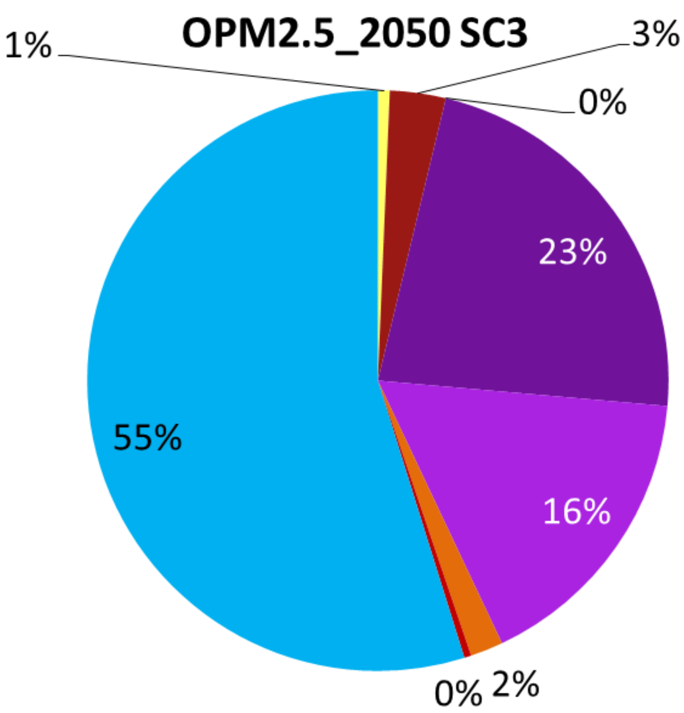




<u>Total emissions</u>

- $OPM_{2.5}$ 2030 Sc1: 6315 Gg
- $OPM_{2.5}$ 2030 Sc2: 4933 Gg
- $OPM_{2.5}$ 2030 Sc3: 1937 Gg





Total emissions

- $OPM_{2.5}$ 2050 Sc1: 12436 Gg
- $OPM_{2.5}$ 2050 Sc2: 7204 Gg
- $OPM_{2.5}$ 2050 Sc3: 1866 Gg

Ongoing activities

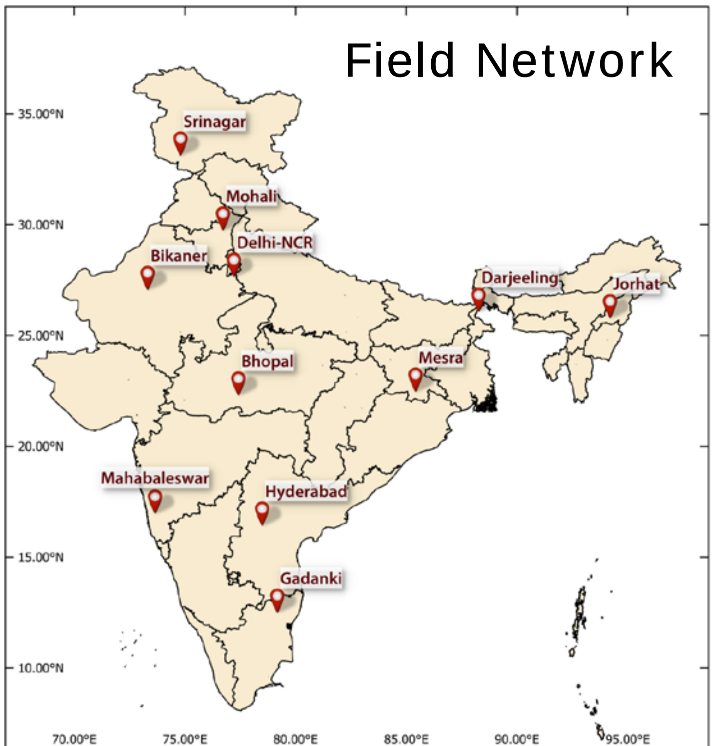
Carb**O**naceous
Aeroso**L** **E**missions
Source
Apportionment &
Climat**E** Impacts

National Carbonaceous Aerosols Programme — COALESCE Project

Ministry of Environment, Forest and Climate Change
↓
National Committee
↓
National Project Co-ordinator and Lead Institute IIT Bombay

Associate Institutions:
- IIT Kanpur → Bose Inst Darjeeling, NEIST Jorhat
- IIT Delhi → IISER Mohali, University of Kashmir
- IISER Bhopal → IISER Bhopal, BIT Mesra; NARL Gadanki
- IIT Madras → NARL Gadanki
- NPL New Delhi
- IIT Kharagpur
- CSIR (4PI)
- PRL Ahemdabad

Field Institutions:
- IIT Hyderabad
- IITM Pune



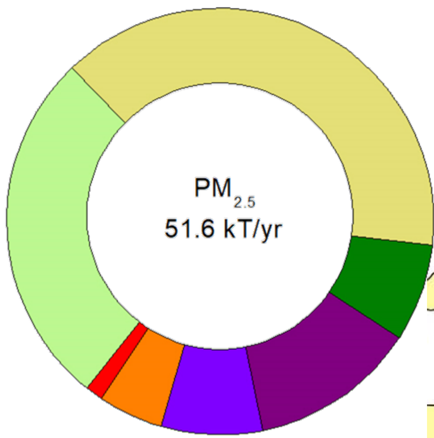
WP1: Source measurements and emission inventory.

WP2: Regional source identification and apportionment.

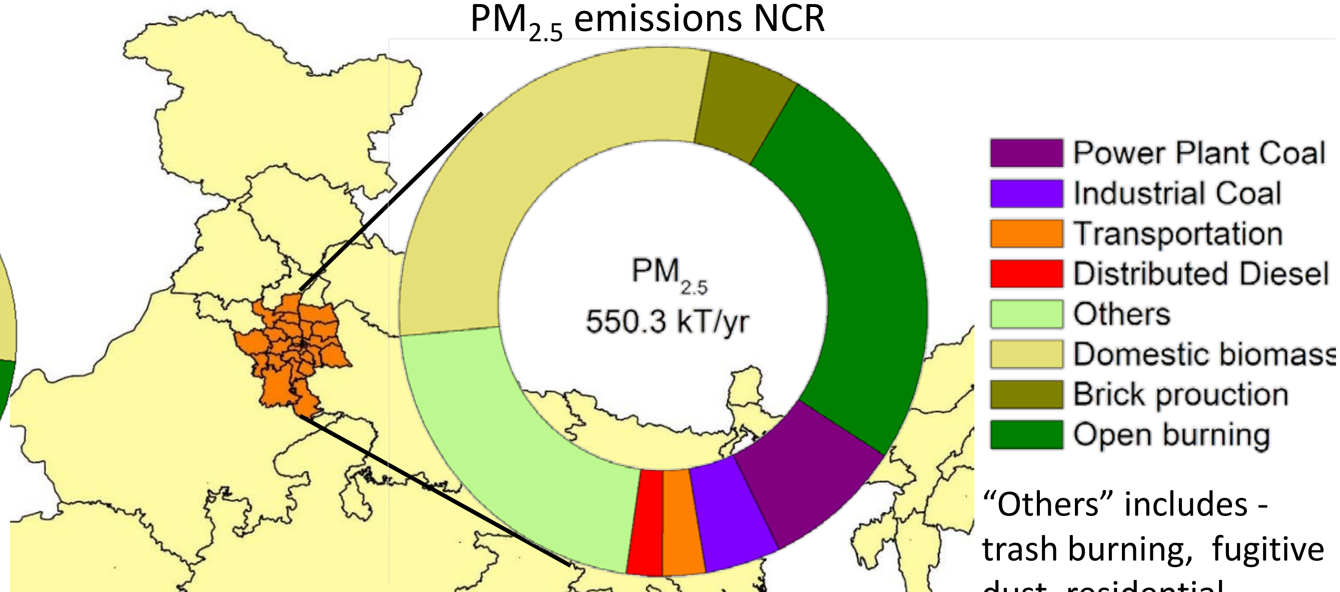
WP3: RCM and GCM multi-model ensemble simulations.

The Delhi/NCR story: Source contribution to emissions and PM-2.5

$PM_{2.5}$ emissions Delhi

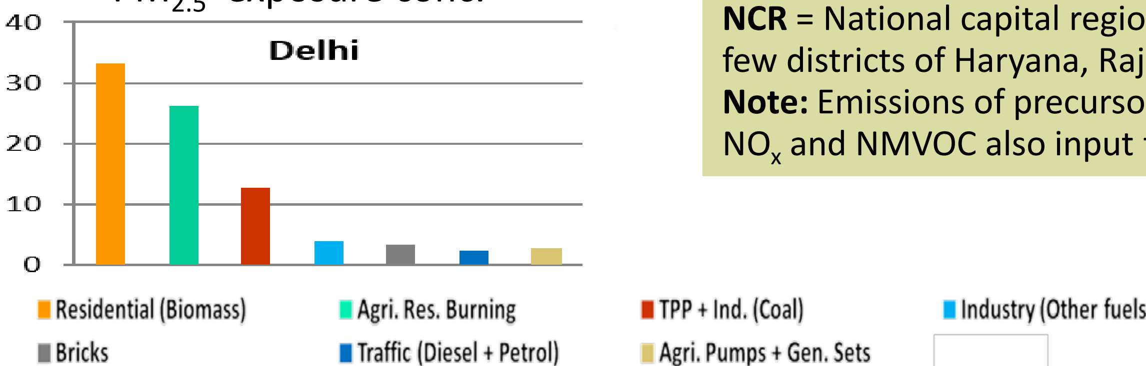


$PM_{2.5}$ emissions NCR



"Others" includes - trash burning, fugitive dust, residential lighting (kerosene lamps), informal industry (food and agro-product processing)

$PM_{2.5}$ exposure conc.



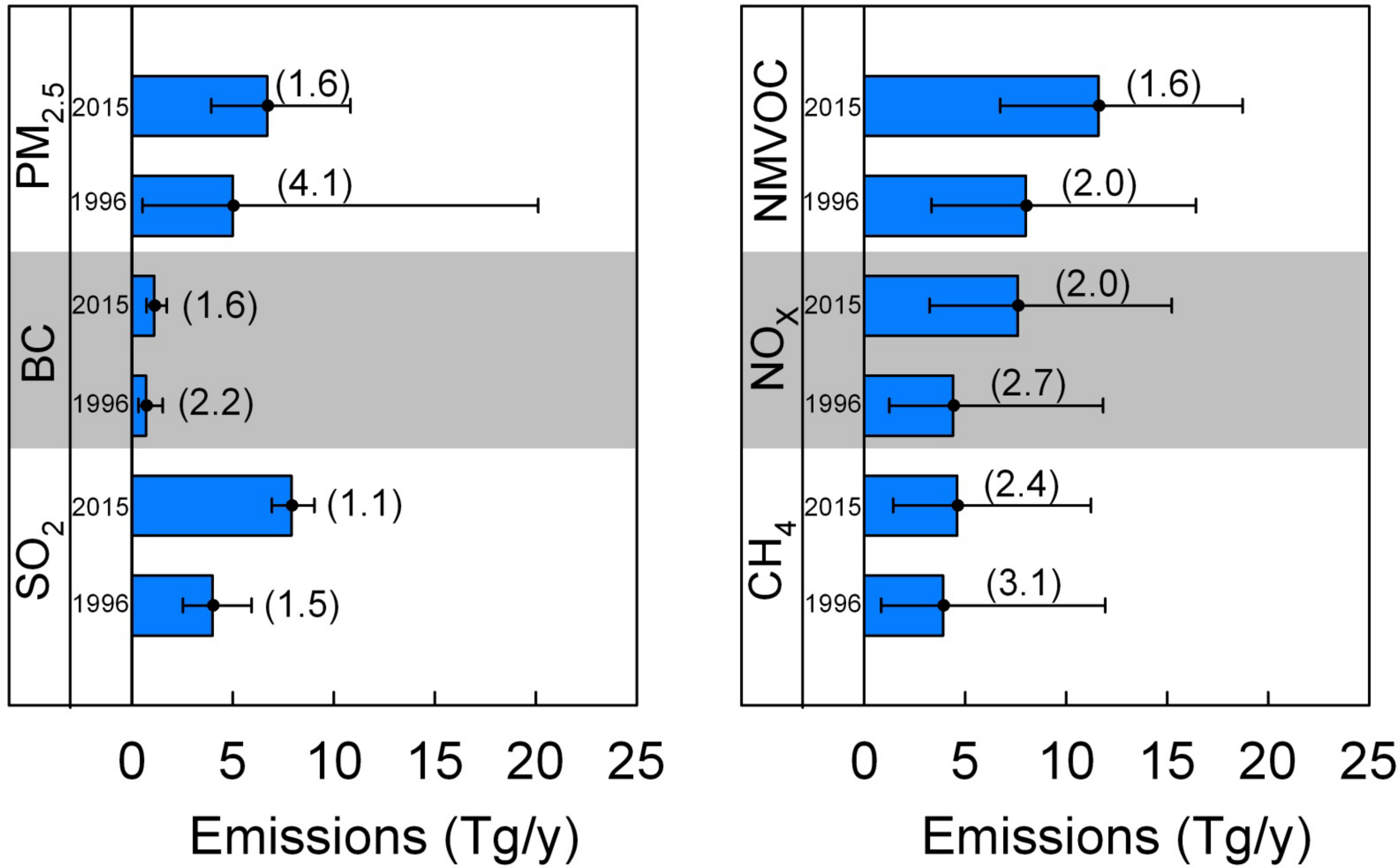
NCR = National capital region: Delhi + a few districts of Haryana, Rajasthan and UP.
Note: Emissions of precursor gases SO_2, NO_x and NMVOC also input to model.

- *Residential, "other" (trash burning, fugitive dust, etc) and open burning (agricultural)* categories account about 70% of PM2.5 emissions over Delhi and the larger NCR region.
- Relatively coarse model grid (50 km x 67 km) makes is difficult to capture concentration gradients on finer spatial scales.
- To better capture vehicular / distributed diesel, need nested inventory and simulations at say 1 km x 1 km resolution or finer, over high pollution areas, within regional domain.

Summary of available emission inventories

	Name	Time-Period	Sources	Resolution	Species
Global	AEROCOM	1750 - 2000	Anthropogenic, Natural	1 x 1 deg	BC, OM, SO_2, dust, sea-salt, volcanic SO_2
	EDGAR v4.2	1970 - 2008	Anthropogenic, Biomass burning	0.5 x 0.5 deg	CO_2, CH_4, N_2O, NOX, CO, NMVOC, SO_2
	RETRO	1960 - 2000	Anthropogenic, Biomass burning	0.5 x 0.5 deg	CO_2, CH_4, N_2O, NOX, CO, NMVOC, SO_2
	Bond et al., 2004	2000	Anthropogenic	-	BC and OC
Regional	GAINS		Anthropogenic	0.5 x 0.5 deg	
	REAS	1980-2020	Anthropogenic	0.5 x 0.5 deg	CO_2, CH_4, CO, NOX, NMVOC, BC, OC, SO_2
	TRACE-P	2000	Anthropogenic	0.5 x 0.5 deg	
	INTEX-B	2006	Anthropogenic	0.5 x 0.5 deg	PM2.5, PM10, BC, OC, SO_2, NOx, CO, NMVOC
	Lu and Streets, 2011	1996-2010	Anthropogenic	0.5 x 0.5 deg	BC, OC and SO_2

Present day emission uncertainties



Technology-linked methodology reduces uncertainty compared to Tier-I estimates for 1996.

Large uncertainty in emission factors, because of lack of measurements.

Large uncertainty in activity data in sectors like residential, brick production and agricultural sectors.