**Supplementary Information**

Mitigation pathways towards national ambient air quality standards in India

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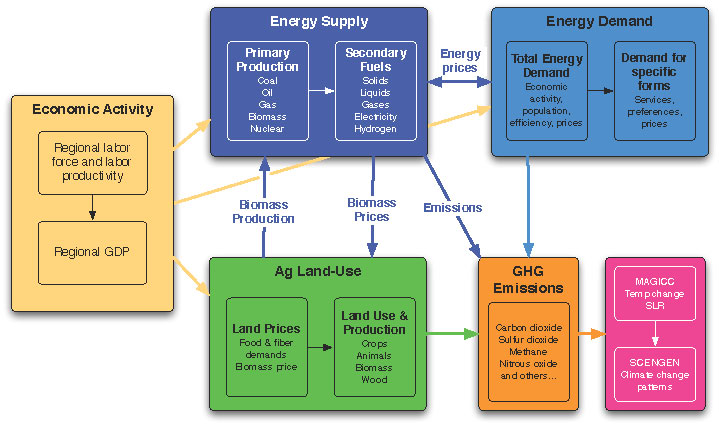
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# S.1. The Global Change Assessment Model (GCAM)

GCAM is a dynamic-recursive model with technology-rich representations of the economy, energy sector, land use and water linked to a climate model that can be used to explore climate change mitigation policies including carbon taxes, carbon trading, regulations and accelerated deployment of energy technology (Edmonds et al., 1997; McJeon et al., 2014). Regional population and labor productivity growth assumptions drive the energy and land-use systems employing numerous technology options to produce, transform, and provide energy services as well as to produce agriculture and forest products, and to determine land use and land cover. Using a run period extending from 1990 – 2100 at 5 year intervals, GCAM has been used to explore the potential role of emerging energy supply technologies and the greenhouse gas consequences of specific policy measures or energy technology adoption including; CO2 capture and storage, bioenergy, hydrogen systems, nuclear energy, renewable energy technology, and energy use technology in buildings, industry and the transportation sectors. In GCAM-IIMA building sector, following are the services along with the alternation fuel sources: (i) Cooling and heating are fueled by electricity, (ii) Cooking is fueled by LPG/natural gas, biomass, coal and electricity, (iii) Lighting is fueled by electricity and kerosene, and (iv) Appliances (TV, fridge, etc.) are fueled by electricity. Model descriptions for the residential and commercial building sector can be found in Eom et al. (2012) and (Chaturvedi et al., 2014), and for the transportation sector in Kyle and Kim (2011) and Mishra et al. (2013). The GCAM industrial module distinguishes various industrial sectors like steel, paper, cement, etc. (Zhou et al., 2013). On the supply side, electricity production is modeled in detail considering nine fuels competing for electricity production, with more than one technology within each fuel.



**Figure A.1:** **Schematic representation of Global Change Assessment Model (GCAM)**

**Source: Joint Global Change Research Institute/Pacific Northwest National Laboratory, USA**

# S.2. The GAINS model

The GAINS (Greenhouse gas-Air Pollution Interactions and Synergies) model explores cost-effective multi-pollutant emission control strategies that meet environmental objectives on air quality impacts (on human health and ecosystems) and greenhouse gases. GAINS, developed by the International Institute for Applied Systems Analysis (IIASA), brings together data on economic development, the structure, control potential and costs of emission sources, the formation and dispersion of pollutants in the atmosphere and an assessment of environmental impacts of pollution (http://gains.iiasa.ac.at).



GAINS addresses air pollution impacts on human health from fine particulate matter and ground-level ozone, vegetation damage caused by ground-level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition to soils, in addition to the mitigation of greenhouse gas emissions. GAINS describes the interrelations between these multiple effects and the pollutants (SO2, NOx, PM, NMVOC, NH3, CO2, CH4, N2O, F-gases) that contribute to these effects at the European scale.

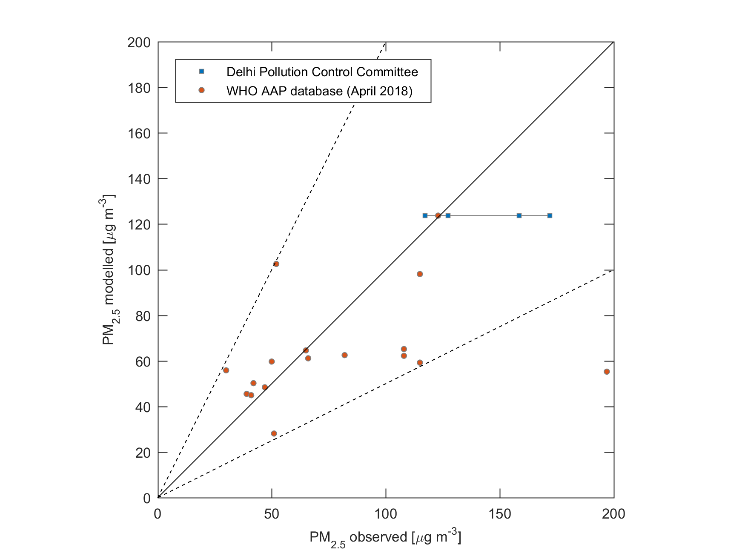
GAINS explores, for each of the source regions considered in the model, the cost-effectiveness of more than 2000 measures to control emissions to the atmosphere. It computes the atmospheric dispersion of pollutants and analyses the costs and environmental impacts of pollution control strategies. In its optimization mode, GAINS identifies the least-cost balance of emission control measures across pollutants, economic sectors and countries that meet user-specified air quality and climate targets.

The Indian version of the GAINS model that is used for this study employs a spatially disaggregated representation of India using 23 sub-regions[[2]](#footnote-3). The national energy projections supplied by GCAM are allocated across Indian States using the proportional downscaling algorithm reported by Rafaj et al. (2013). Total energy consumption data provided by national energy projections is distributed across States based on shares derived from subnational energy and industrial statistics. These statistics were compiled initially for the first version of the GAINS-India model (Purohit et al., 2010), and later updated for the GAINS-City model for Delhi and its neighboring States (Amann et al., 2017; Bhanarkar et al., 2018), as well as for the World Energy Outlook 2015 study focusing at India (Cofala et al., 2015). The downscaling procedure also allocates energy consumption to subsectors and fuel types that are not explicitly provided by the energy model. These include various transport categories (road/off-road; cars/trucks/buses; land-based/ships), industrial demand activities (cement/metals/chemicals/others; furnaces/boilers), and fuel conversion (refineries/coking/others).

For each of the States/regions considered in GAINS, emission estimates for a particular emission control scenario consider (1) the detailed sectoral structure of the emission sources that emerges from the downscaling of the activity projection described above, (2) their technical features (e.g., fuel quality, plant types, etc.), and (3) applied emission controls (GAINS includes a database of over 1000 technical measures). For each key source sector, the spatial patterns of PM and its precursors emissions are then estimated at a 0.5⁰ × 0.5⁰ longitude–latitude resolution (Klimont et al. 2017), based on relevant proxy variables. These estimates rely on the most recent updates of data on population distribution, road networks, plant locations, open biomass burning, etc. that were originally developed within the Global Energy Assessment project (GEA, 2012).

## **S.2.1. Comparison of modelled to observed PM2.5**

Figure A.2 shows a comparison of ground-level ambient PM2.5 concentrations calculated with the GAINS model to observations as far as available for the year 2015 from the World Health Organization (WHO) Ambient Air Pollution Database and the Delhi Pollution Control Committee (DPCC) website. Unfortunately, limited information is available for many of the monitoring data points, particularly regarding the station types and positioning, and data coverage. In general, agreement seems reasonable; with one exception, modelled concentrations in all cities are within a factor 2 of the measured values. The outlier in Muzaffarpur with measured PM2.5 concentrations of 197 µg/m3 seems rather questionable since PM10 concentrations are reported at 214 µg/m3 at the same location and year, implying a very unusual PM2.5/PM10 ratio of 0.92.



**Figure A.2. Validation of modelled PM2.5 against observations in 2015. Observation points for the same city (Delhi) are connected.**

# S.3. Data sources and assumptions for the GCAM scenarios

## **S.3.1 Energy supply**

The GCAM-IIMA version starts with the base year 2010 and operates at five years’ time steps till 2100. For 2015, data on electricity generation and capacity are based on the publicly available statistics from the Central Electricity Authority (CEA) and Energy Statistics.

The future demand for electricity generation and other forms of energy is determined in each end use sector, where the penetration of electricity-based technologies (e.g., air-conditioning) and other-fuel based technologies (e.g., oil-based cars) grows with increasing income. The distribution of electricity generation across different technologies responds to the relative cost of generating electricity, based on stakeholder consultations with power sector experts (including renewable energy developers, National Thermal Power Corporation (NTPC) Ltd, and experts from the Ministry of Power (MoP)).

## **S.3.2 Energy demand**

The buildings sector distinguishes commercial buildings, rural residential, and urban residential sectors. Energy service demand is modelled for air-conditioning (high and low efficiency), cooking (biomass, coal, electricity, LPG, and natural gas), lighting (fluorescent bulbs, incandescent bulbs, kerosene lamps, and LEDs), refrigeration (high and low efficiency), ventilation (low and high efficiency ceiling fans), television, water heaters (electricity, LPG, solar) and ‘other appliances’. The demand for each energy service responds to changes in income levels, service prices, and growth in floor space). Data on electricity demand from the building sector in 2015 was provided by the Central Electricity Authority (CEA), Ministry of Power (MoP).

For the transport sector, energy demand is modelled for passenger transport (road, rail and aviation), freight transport (road and rail), and international shipping (MoR, 2018; MoRTH, 2016a; National Transport Development Policy Committee, 2014), driven by per-capita GDP and population. Data on fuel consumption from the transportation sector in historical years (2010 and 2015) was provided by the Petroleum Planning and Analysis Cell (PPAC), Ministry of Petroleum & Natural Gas (MoPNG).

The industrial sector in GCAM-IIMA is modelled in an aggregate way. Demand for industrial services responds to income growth and fuel prices. Fuels (biomass, coal, electricity, natural gas and oil) compete on the basis of relative prices for providing energy services to meet industrial energy demand. The current GCAM model version only tracks the energy mix and emissions at an aggregated level for all industrial sectors. This category also includes the agricultural sector, whose electricity consumption is almost half of that of the industrial sector. Data on energy consumption from the industrial sector in 2010 and 2015 was provided by the Central Statistics Office (CSO), Ministry of Statistics & Programme Implementation (MoSPI).

## **S.3.3 Socio-economic variables**

In GCAM, population and income (GDP) act as exogenous drivers of energy supply and demand. Assumptions on population growth are in line with the UN population projection (medium variant) (UN, 2015). For GDP, the assumptions for this study follow the medium economic growth rate projections of NITI Aayog, with an annual growth rate of 6.7 percent from 2012 to 2047.

## **S.3.4 Energy access**

GCAM contains a detailed representation of energy service demands for the urban and rural residential sectors. Demands are responsive to costs as well as income. As affordability of services increase, the demand for energy services increases both in urban and rural areas. The current policies related to energy access are represented in the analysis in the following way:

1. Urbanisation rate: The rate of urbanisation is modelled as a function of economic growth. Higher the economic growth, higher is the transition towards urbanisation. Coherent with the data in GAINS, is an increase of urbanization to 50% in 2050 is assumed for the medium economic growth scenario.
2. Urban rural income divide: While the framework can model increasing inequalities in incomes, a stylised representation has been adopted for this study, reflecting an optimistic assumption of the state of urban-rural divide in India’s future.
3. Clean cooking access: The Indian government has embarked on an ambitious programme to provide clean fuel, mainly LPG to Indian households. For this study we assume that biomass will be entirely replaced by alternative cooking fuels by 2040. We also model an alternative policy failure scenario in which the biomass use remains significant for meeting cooking energy demands even in 2050.
4. Efficient lighting: With a thrust on the LED programme, we assume that the penetration of LEDs increases at a fast pace. Incandescent bulbs will be phased out from Indian households by 2030 across all scenarios. The incandescent bulbs will be replaced by LEDs as well as CFLs.

# S.4. Source contributions to PM2.5 annual concentration by State/region

Figures in this Section show source contributions to population-weighted annual mean ambient PM2.5 concentrations under the 2018 legislation scenario for all States (GAINS regions). Contributions are specified by spatial origin (x axis), chemical speciation (PPM/secondary aerosols) and economic source sector for primary PM (colors).

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| **2015** | **2030** | | **2050** |
| 1. **Andhra Pradesh** | | | |
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| 1. **Assam** | | | |
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| 1. **Bihar** | | | |
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| 1. **Chhattisgarh** | | | |
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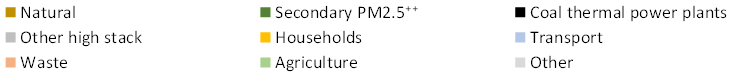
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| **2015** | **2030** | **2050** |
| 1. **Delhi** | | |
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| 1. **Goa** | | |
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| 1. **Gujarat** | | |
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| 1. **Haryana** | | |
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| 1. **Himachal Pradesh** | | |
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| 1. **Jammu & Kashmir** | | |
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| 1. **Jharkhand** | | |
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| 1. **Karnataka** | | |
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| 1. **Kerala** | | | | |
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# S.5 Sectoral policies and measures incorporated in the energy baseline projection

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| **Sector** | **Policies and measures** |
| Cross-cutting | * National Mission on Enhanced Energy Efficiency (GoI, 2008). * National Clean Energy Fund to promote clean energy technologies based on a levy of INR 400 (USD 6) per tonne of coal (Purohit, 2014). * ‘Make in India’[[3]](#footnote-4) campaign to increase the share of manufacturing in the national economy. * NDC GHG target: reduce emissions intensity of GDP 33-35 percent below 2005 levels by 2030 (UNFCCC, 2015). * NDC energy target: achieve about 40 percent cumulative installed capacity from non-fossil fuel sources by 2030 with the help of technology transfer and low-cost international finance (UNFCCC, 2015). * Efforts to expedite environmental clearances and land acquisition for energy projects. * Open the coal sector to private and foreign investors. |
| Power sector | * Renewable Purchase Obligation (RPO) and other fiscal measures to promote renewables. * Increased use of supercritical coal technology. * Environmental (Protection) Amendment Rules. * Universal electricity access achieved by 2025. * Strengthened measures such as competitive bidding to increase the use of renewables towards the national target of 175 GW of renewables capacity by 2022 (100 GW solar, 75 GW non-solar). * Expanded efforts to strengthen the national grid, upgrade the transmission and distribution network and reduce aggregate technical and commercial losses to 15 percent. * Increased efforts to establish the financial viability of all power ‘market participants, especially network and distribution companies. |
| Transport sector | * Increasing blending mandate for ethanol (Purohit and Dhar, 2015). * Support for alternative-fuel vehicles. * Support for alternative-fuel vehicles, including 2020 National Electric Mobility Mission Plan; subsequent support for electric two/three-wheelers, cars and buses. * Increased support for natural gas in road transport, particularly urban public transport. * Dedicated rail corridors to encourage shift away from road freight. |
| Industrial sector | * Energy Conservation Act: * Mandatory energy audits. * Appointment of energy managers in seven energy-intensive industries. * National Mission on Enhanced Energy Efficiency (NMEEE): * Cycle II and III of the Perform, Achieve and Trade (PAT) scheme, which benchmarks facilities’ performance against best practice and enables trading of energy savings certificates. * Income and corporate tax incentives for energy service companies, including the Energy Efficiency Financing Platform. * Framework for Energy-Efficient Economic Development offering a risk guarantee for performance contracts and a venture capital fund for energy efficiency. * Energy efficiency intervention in selected SME clusters including capacity building. * Further implementation of the NMEEE’s recommendations including: * Tightening of the PAT mechanism under Cycle III. * Further strengthening of fiscal instruments to promote energy efficiency. * Strengthen existing policies to realize the energy efficiency potential in SMEs. |
| Building sector | * Rural electrification under Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) scheme. * Promotion of clean cooking access with LPG, including free connections to poor rural households through Pradhan Mantri Ujjwala Yojana. * Energy Conservation Building Code 2007 with voluntary standards for commercial buildings. * “Green Rating for Integrated Habitat Assessment” rating system for green buildings. * Promotion and distribution of LEDs through the Efficient Lighting Programme. * Standards and Labelling Programme, mandatory for air conditioners, lights, televisions, and refrigerators, voluntary for seven other products and LEDs. * Phase out incandescent light bulbs by 2020. * Voluntary Star Ratings for the services sector. * Measures under the National Mission on Enhanced Energy Efficiency. * Enhanced efforts to increase electricity access for households. |

Source: (GoI, 2014, 2008; GOI, 2006; MNRE, 2010; MoEFCC, 2015; Purohit and Fischer, 2014; MoP, 2014; UNFCCC, 2015)

# S.6. Pollution control legislation considered in the 2018 legislation scenario

The 2018 legislation scenario considers all measures and standards that were in force in mid-2018. In particular, it includes measures to control emissions of dust from the power plants and industrial combustion sources (MoEFCC, 2015). To meet the new pollution norms for SO2, coal thermal power plants are required to retrofit or install flue-gas desulfurization (FGD) which removes Sulphur dioxide from exhaust flue gases. In order to meet the 100 mg/Nm3 NOx standard, new plants will have to employ Selective Catalytic Reduction (SCR) to achieve compliance. For existing plans, the 300 mg/Nm3 standard can potentially be attained through a combination of primary measures such as combustion controls, Selective Non-catalytic (SNCR), and in some cases SCR. Table A.2 presents the key air pollution prevention policies in the power and industry sectors considered in the 2018 legislation scenario for India.

Controlling emissions from mobile sources (road and off-road, incl. non-exhaust sources) is essential for air pollution abatement in India. Unit emissions from road vehicles depend mostly on the fuel used (gasoline, diesel or CNG) and on the emission control technology. Adoption of emission control technologies is in turn driven by legislation. The National Auto Fuel Policy (2003) mandates that all new four-wheeled vehicles in 11 cities meet Bharat Stage III emission norms for conventional air pollutants (similar to Euro III emission norms), and comply with Euro IV standards by 2010 (MoPNG, 2003). The Auto Fuel Vision and Policy 2025 was published in May 2014 to update the 2003 document with more stringent fuel and emissions standards (MoPNG, 2014).

**Table A.2: Current legislation and Air pollution prevention policies implemented in the CLE scenario for India**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No.** | **Sector** | **Policy** | | **Remarks** |
| 1. | Power plants | * Electrostatic precipitators (ESPs) to curb particulate matter * Flue gas desulphurization (FGD) to minimize SO2 and mercury * Selective catalytic converters (SCRs) and selective non-catalytic converters (SNCRs) to reduce NOx. | | (MoEFCC, 2015) |
| 2. | Transport | India 2000 | 2000– Nationwide | (ICCT, 2016; MoRTH, 2016b) |
| Bharat Stage II | 2001 - National Capital Region (NCR) of Delhi, Mumbai, Kolkata, Chennai |
| 04/2003 - NCR, 13 Cities[[4]](#footnote-5) |
| 04/2005 – Nationwide |
| Bharat Stage III | 04/2005 - NCR, 13 Cities |
| 04/2010 – Nationwide |
| Bharat Stage IV | 04/2010 - NCR, 13 Cities |
|  | 04/2017 – Nationwide |
| Bharat Stage V | (to be skipped) |
| Bharat Stage VI | 04/2018 - Delhi NCR |
|  | 04/2020 (proposed) - Nationwide |
| 3. | Industry | All new brick kilns shall be allowed only with zig-zag or vertical method of brick making. | | (MoEFCC, 2018a) |
| New emission standard norms of SO2 and NOx for five industries – ceramic, foundry industries (furnaces based on fuel), glass, lime kiln and reheating furnace. | | (MoEFCC, 2018b) |
| Ban on per coke and furnace oil in Industrial sector in NCR States[[5]](#footnote-6) | | (MoEFCC, 2018c, 2018d) |
| 4. | Agriculture | Bharat (Trem) Stage III A for agricultural tractors from April 2010. Bharat (Trem) Stage III from October 2005. | |  |
| 5. | Waste | Ban on open burning of wastes in Indian cities. | | (MoEF, 2010) |
| Ban on crop residue burning in five States — Punjab, Haryana, Rajasthan, Uttar Pradesh and Delhi. | | (CSE, 2017) |
| Solid Waste Management Rules 2016 | | (MoEFCC, 2016) |

For historic years we model the actual introduction of the different Indian emission control stages (Bharat[[6]](#footnote-7)); for the future years (2020 onwards) measures are accounted for to leapfrog directly to Bharat State (BS)-VI for all on-road vehicle categories[[7]](#footnote-8) (MoRTH, 2016b). Specifically, for passenger cars, light-duty and heavy-duty trucks BS-III is in force from 2010. For two-wheelers standards equivalent to the European Euro-III are in force since 2010. More stringent emission controls for cars and trucks (Bharat-IV), and an associated supply of low-sulphur fuels, are mandated in Delhi and 19 other ‘advanced’ cities since April 2010. Apart from Delhi, these cities have a share of about 10%-14% of the population in their respective State, yet a higher share in the vehicle population. Heavy duty vehicles are often registered outside the city with more stringent emission control, thereby effectively circumventing the most advanced controls (Cofala et al., 2015). Therefore, we assume that only a share of up to 10% of all State’s vehicles is complying with the most advanced controls. BS-IV air pollutant emission norms have been in force across India since April 2017. Additionally, India has also adopted nationwide fuel efficiency standards for light-duty vehicles. A transition to BS-VI norms is expected from 1st April 2020 (ICCT, 2016). Figure A.3 presents the penetration of the Bharat Emission standards for passenger cars in Delhi and the rest of the country. The Indian emission control system follows largely the European standards and technologies, with adjusted driving cycle and temperature controls. We therefore use adjusted European emission factors to model exhaust emissions in India (Guttikunda and Mohan, 2014). Emission controls up to Stage III are assumed for agricultural tractors and construction machinery as well as Stage I for diesel generators.



Figure A.3: Penetration for Bharat emission standards for passenger cars in India

Similar to the power and transport sectors, all recently implemented environmental pollution control norms at the State level and national level are simulated in GAINS for industry and waste sources. According to the Environment (Protection) Amendment Rules, as of 2018 all new brick kilns shall be allowed only with zig-zag or vertical method of brick making and shall comply to the new standards as stipulated in this notification (MoEFCC, 2018a). Existing brick kilns which are not using zig zag or vertical methods of brick making shall be converted so as to adopt zig zag or vertical methods within one year for kilns located near non-attainment cities, and within two years for other both kilns. The Environment Ministry has expanded the ambit of emission standard norms of SO2 and NOx for five industries – ceramic, foundry industries (furnaces based on fuel), glass, lime kiln and reheating furnace (MoEFCC, 2018b).

In the latest effort to curb rising air pollution, India’s Ministry of Environment, Forestry and Climate Change (MoEFCC) placed restrictions on the use of petroleum coke and furnace oil to power up industries in the national capital territory (NCT) of Delhi and its surrounding region (MoEFCC, 2018c, 2018d). While India’s government plans to propose banning the use of petroleum coke as a fuel nationwide as part of a long-running case to clean the country’s air, the scenario in this study assume the ban of petroleum coke is in Delhi and it’s three neighboring States (i.e., Haryana, Rajasthan and Uttar Pradesh).

The municipal solid waste management rules promulgated in 2000 prohibit the open burning of waste in Indian cities (MoEF, 2010). The 2016 solid waste management rules require segregation, processing and recycling of waste (MoEFCC, 2016). The rules hold urban bodies, administration as well as users at source responsible for managing the waste. In November 2015, the National Green Tribunal banned crop residue burning in five States — Punjab, Haryana, Rajasthan, Uttar Pradesh and Delhi in which the government plans to spend $230 million over two years to prevent crop residue burning (Reuters, 2018).

# Figures

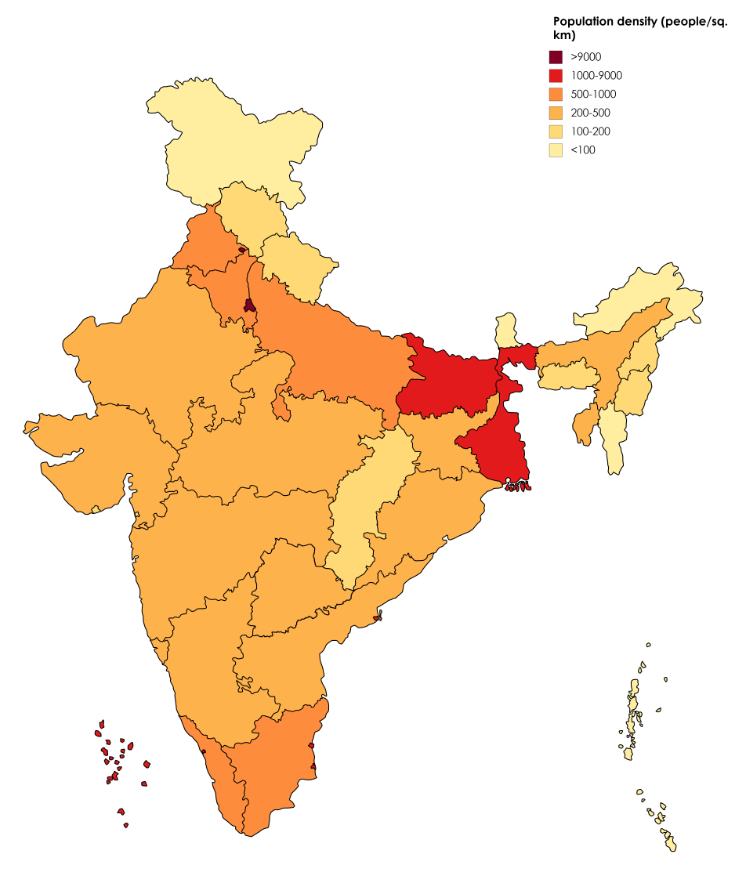


**Figure S1: PM2.5 concentrations in select Indian cities for the year 2016.**

**Source:** (WHO, 2018)



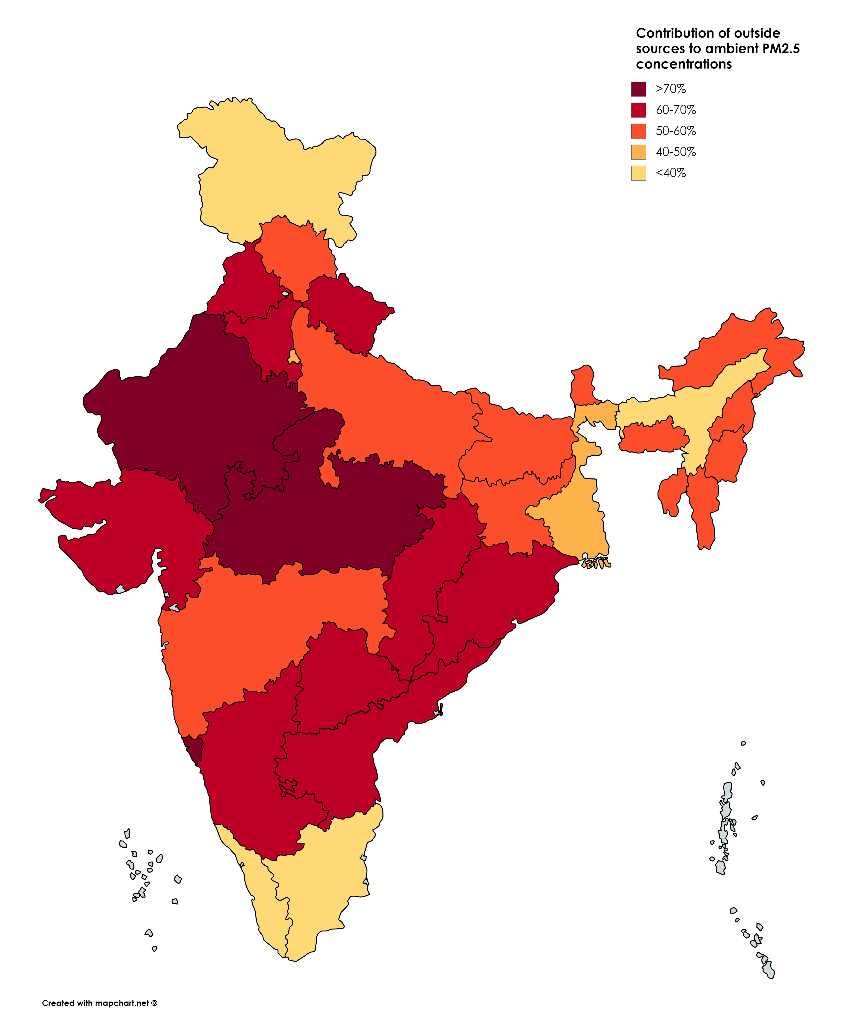
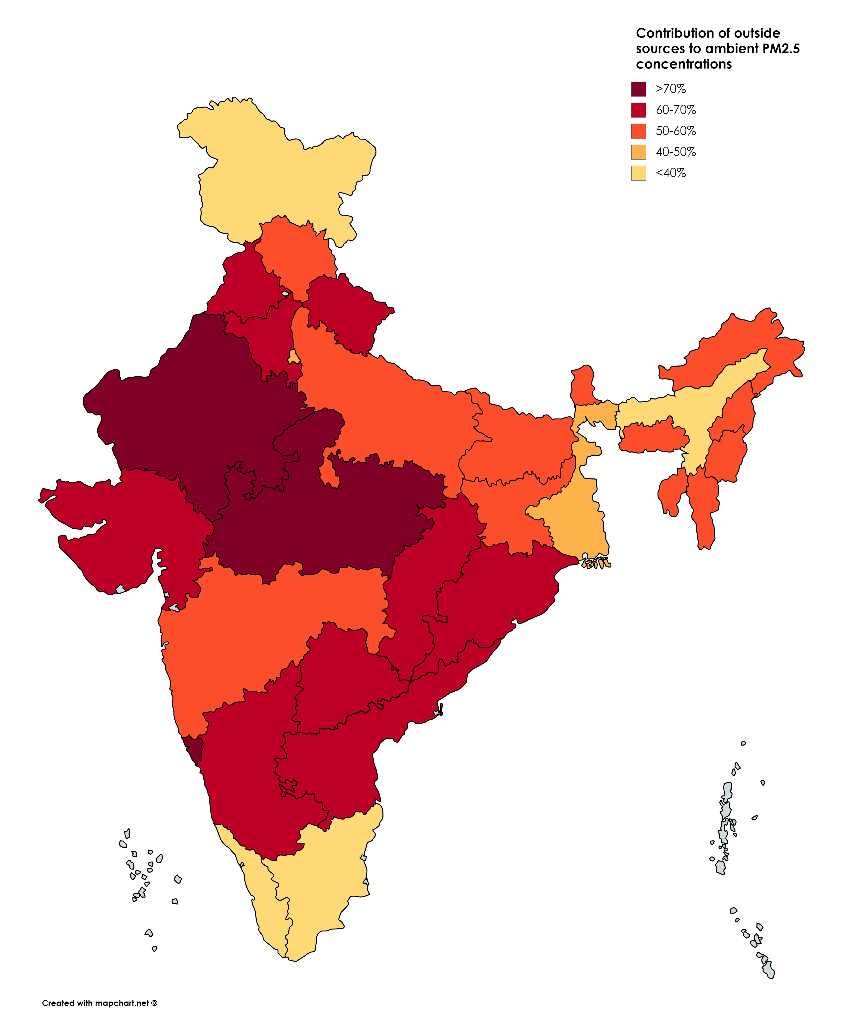
**Figure S2: The relative contributions of different sectors to the precursor emissions of PM2.5 in the Indian States, GAINS estimate for 2015**



**Figure S3: Population density of India (GoI, 2011)**



**Figure S4: Distribution of population exposure to ambient PM2.5 in 2015 (GAINS estimates)**



**Figure S5: Contributions of emissions from other regions to population-weighted ambient PM2.5 concentrations in each State/region**

|  |  |
| --- | --- |
| **(a) Macro-economic indicators** | **(b) Primary energy consumption (in EJ/year)** |

**Figure S6: Assumed baseline trends of macro-economic development and energy consumption.**

|  |  |
| --- | --- |
| **(a)** |  |
| **(b)** |  |

**Figure S7: a) Population-weighted PM2.5 concentrations, for the full and effective implementation of the 2018 legislation and the benefits from the post-2015 legislation, for India (left panel) and Delhi NCT (right panel); b) Potential benefits of the emission control packages on population-weighted PM2.5 concentrations, for all of India (left panel) and Delhi NCT (right panel)**

# Tables

**Table S1: Macro-economic development and energy consumption of the baseline projection**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Macro-economic parameters/Fuel** | **Unit** | **2015** | **Annual growth rate 2015-2030** | **2030** | **Annual growth rate 2030-2050** | **2050** |
| Population1) | Million | 1263 | 1.21% | 1513 | 0.46% | 1659 |
| Per-capita income1) | Euro | 1336 | 6.12% | 3252 | 5.69% | 9830 |
| GDP1) | Billion € | 1686 | 7.40% | 4921 | 6.18% | 16307 |
| Vehicle mileage2) | Billion km | 791 | 6.28% | 1973 | 5.35% | 5596 |
| Energy intensity2) | MJ/€ GDP | 19 | -3.40% | 12 | -2.87% | 6 |
| Total primary energy consumption2) | PJ | 32625 | 3.74% | 56622 | 3.14% | 105093 |
| Biomass consumption2) | PJ | 6509 | -2.07% | 4753 | -3.90% | 2141 |
| Coal use2) | PJ | 16773 | 3.91% | 29830 | 2.81% | 51911 |
| Liquid fuels2) | PJ | 6825 | 4.55% | 13306 | 3.99% | 29062 |
| Gaseous fuels2) | PJ | 1361 | 8.01% | 4326 | 3.71% | 8958 |
| Renewable energy2) | PJ | 558 | 9.87% | 2293 | 6.49% | 8061 |
| Other forms of energy2) | PJ | 599 | 8.78% | 2114 | 4.36% | 4961 |

1) Assumption, following the medium growth scenario of NITI Aayog

2) Result from the GCAM model

**Table S2: Policies and measures considered in the 2015 legislation scenario**

|  |  |
| --- | --- |
| **Sector** | **Policies and measures** |
| Power | * Mix of sub critical technology and super critical technology in coal power plants after 2015 * Increased efforts to establish the financial viability of all power market participants, especially network and distribution companies * Strengthened measures such as competitive bidding to increase the use of renewables towards the national target of 175 GW of renewables capacity by 2022 (100 GW solar, 75 GW non-solar) * Renewable Purchase Obligation (RPO) and other fiscal measures to promote renewables * Particulate matter controls: Electrostatic precipitators (ESPs) * SO2 controls: Very small share of FGD (<2%) in power plants (only 3 power plants). |
| Mobile sources | * Passenger cars: Baharat Stage III (nationwide from 2010) * Passenger cars: Baharat Stage IV (NCR and 13 cities from 2010). * Light and heavy-duty trucks: Bharat Stage III (nationwide from 2010). * Light and heavy-duty trucks: Bharat Stage IV (NCR and 13 cities from 2010) * Two- and Three-wheelers: Bharat Stage III (from 2010). * Agricultural tractors/construction machinery: Bharat (Trem) Stage III (from 2011). * FAME[[8]](#footnote-9) scheme 1: Incentives for increasing adoption of electric vehicles (EVs) |

**Table S3: Additional policies and measures considered in the 2018 legislation scenario (over and above 2015 measures scenario)**

|  |  |
| --- | --- |
| **Sectors** | **Policies and measures** |
| Power plants | * Complete move towards Super-Critical technologies in Coal Power Plant * Reverse bidding of solar and wind power plants * Flue gas desulphurization (FGD) for SO2 * Selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) for NOx |
| Mobile sources | * Bharat Stage VI controls (all road vehicles) from 2020 onwards. * Bharat (Trem) Stage IV controls (non-road machinery) from 2020 onwards and Stage V from 2024 * FAME scheme 1: Incentives for increasing adoption of EVs and removing the barriers of infrastructure in India |
| Industry | * Full compliance with the PAT-I[[9]](#footnote-10) and PAT-II cycle. * Zig-zag or vertical shaft kilns for all new brick production installations * New emission standards for SO2 and NOx for five industries (ceramic, foundry industries (furnaces based on fuel), glass, lime kiln and reheating furnaces) * Ban of coke and furnace oil in industry in the NCR States |
| Other sectors | * Ban of open burning of waste (trash) in Indian cities and crop residue burning in NCR States * Solid Waste Management Rules 2016. |

**Table S4: Population-weighted annual mean PM2.5 concentrations expected in Indian States under the 2018 air quality legislation scenario.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Regions** | **PM2.5 concentration (µg/m³)** | | |
| **2015** | **2030** | **2050** |
| Delhi | 126.5 | 114.4 | 136.1 |
| West Bengal | 67.4 | 60.1 | 70.7 |
| Haryana | 63.2 | 59.8 | 69.5 |
| Uttar Pradesh | 58.7 | 53.4 | 61.5 |
| Jharkhand | 58.6 | 50.1 | 64.6 |
| Bihar | 56.6 | 48.8 | 53.4 |
| Punjab | 51.9 | 53.3 | 64.1 |
| Gujarat | 42.5 | 37.0 | 44.6 |
| Odisha | 42.4 | 35.8 | 44.5 |
| Rajasthan | 40.8 | 39.4 | 45.8 |
| Chhattisgarh | 39.4 | 34.3 | 42.9 |
| Maharashtra | 38.9 | 31.5 | 37.9 |
| Madhya Pradesh | 38.0 | 33.1 | 39.1 |
| Uttarakhand | 32.7 | 26.1 | 30.2 |
| North East | 31.5 | 23.5 | 26.0 |
| Andhra Pradesh\* | 30.4 | 24.7 | 30.3 |
| Goa | 26.6 | 20.4 | 24.6 |
| Assam | 24.1 | 24.9 | 24.3 |
| Karnataka | 21.2 | 16.6 | 20.1 |
| Kerala | 20.3 | 13.7 | 13.5 |
| Tamil Nadu | 18.9 | 14.9 | 18.1 |
| Jammu and Kashmir | 15.8 | 13.2 | 13.0 |
| Himachal Pradesh | 14.6 | 14.0 | 15.9 |

**Table S5: Distribution of population exposure in 2015 and for the 2018 legislation scenario in 2030 and 2050 (million people exposed to different levels of PM2.5)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **2015** | **2030** | **2050** |
| Above 40 µg/m3 | 677 | 674 | 930 |
| Between 40 µg/m3 and 25 µg/m3 | 389 | 466 | 404 |
| Less than 25 µg/m3 | 227 | 367 | 341 |

**Table S6: Additional policies and measures assumed in the advanced measures scenario (additional to 2018 legislation)**

|  |  |
| --- | --- |
| **Sector** | **Policies/measures** |
| Power plants | * High efficiency PM controls at power plants * Selective catalytic reduction (SCR) at existing and new oil and gas power plants |
| Industry | * High efficiency PM controls for boilers * More stringent PM controls for furnaces * Combustion modification and selective catalytic reduction (SCR) on oil and gas boilers and furnaces * Stringent emission controls for industrial processes, including   + Ferrous and non-ferrous industry   + Refineries   + Coke plants   + Carbon black production   + Fertilizer plants   + Brick kilns (increasing capacity of tunnel kilns) * Improved control of flaring in refineries * Suppressing fugitive emissions during coal handling |
| Households | * Annual inspection and maintenance of residential oil boilers * Replacement of wick kerosene lamps with Hurricane lanterns * Nationwide ban on open burning of solid waste (trash) |
| Agriculture | * Improved enforcement of bans on agricultural waste burning, * Improved manure management in livestock production * Efficient use of urea based mineral fertilizers * Suppressing dust emissions from storage and handling of agricultural crops * Low-till farming, alternative cereal harvesting |

**Table S7: Population-weighted annual mean ambient PM2.5 concentrations (µg/m³) by State, in 2015 and for the Advanced Control Technology scenario variants in 2030 and 2050**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **GAINS regions** | **Population-weighted annual mean ambient PM2.5 concentrations (µg/m³)** | | | | | | |
| **2015** | **2030** | | | **2050** | | |
| **2018 legislation** | **Advanced controls with clean household fuels** | **Advanced controls without clean household fuels** | **2018 legislation** | **Advanced controls with clean household fuels** | **Advanced controls without clean household fuels** |
| Delhi | 126.5 | 114.5 | 108.2 | 111.2 | 136.1 | 110.5 | 112.6 |
| West Bengal | 67.4 | 60.2 | 54.6 | 59.0 | 70.5 | 49.9 | 55.3 |
| Haryana | 63.3 | 59.6 | 56.5 | 58.4 | 69.6 | 57.9 | 60.2 |
| Jharkhand | 58.7 | 50.1 | 44.4 | 46.8 | 64.6 | 42.8 | 45.8 |
| Uttar Pradesh | 58.6 | 53.4 | 49.9 | 52.9 | 61.6 | 48.6 | 52.0 |
| Bihar | 56.7 | 48.8 | 45.1 | 48.9 | 53.3 | 40.5 | 44.9 |
| Punjab | 51.9 | 53.3 | 50.8 | 52.3 | 63.9 | 55.5 | 56.8 |
| Gujarat | 42.6 | 36.9 | 35.2 | 36.2 | 44.6 | 37.8 | 38.7 |
| Odisha | 42.4 | 35.6 | 32.2 | 34.0 | 44.4 | 30.9 | 33.0 |
| Rajasthan | 41.0 | 39.6 | 38.1 | 38.9 | 45.7 | 40.5 | 41.3 |
| Chhattisgarh | 39.6 | 34.3 | 31.1 | 32.3 | 43.0 | 30.8 | 32.1 |
| Maharashtra | 38.8 | 31.3 | 29.2 | 30.6 | 38.1 | 29.9 | 31.3 |
| Madhya Pradesh | 38.0 | 33.1 | 31.3 | 32.5 | 38.9 | 32.2 | 33.4 |
| Uttaranchal | 32.8 | 26.0 | 24.4 | 25.7 | 30.1 | 23.6 | 25.0 |
| North East | 31.7 | 23.5 | 22.5 | 23.7 | 25.9 | 22.9 | 24.3 |
| Andhra Pradesh | 30.5 | 24.8 | 22.6 | 24.0 | 30.3 | 22.4 | 23.5 |
| Goa | 26.6 | 20.1 | 19.0 | 19.4 | 24.5 | 19.5 | 19.9 |
| Assam | 24.2 | 24.8 | 23.6 | 25.1 | 24.4 | 20.1 | 22.1 |
| Karnataka | 21.2 | 16.7 | 15.4 | 16.2 | 19.9 | 15.2 | 16.0 |
| Kerala | 20.1 | 13.7 | 12.5 | 13.7 | 13.4 | 10.2 | 11.6 |
| Tamil Nadu | 19.1 | 14.8 | 13.4 | 14.5 | 18.0 | 13.2 | 14.0 |
| Jammu and Kashmir | 15.7 | 13.2 | 12.4 | 13.6 | 12.8 | 10.7 | 12.0 |
| Himachal Pradesh | 14.7 | 14.1 | 13.2 | 13.8 | 16.0 | 12.3 | 12.9 |

**Table S8: Additional policies and measures assumed in the sustainable development scenario**[[10]](#footnote-11) **(additional to 2018 legislation and advanced measures case)**

|  |  |
| --- | --- |
| **Sector** | **Additional policies and measures** |
| Power plants /industry | * Variable Renewable Energy integration cost will be borne by the government. * No CCS technology introduction due to high technology cost as compared to conventional technology * Increase in domestic manufacturing of solar panels * Industrial energy efficiency improvements by 54% penetration of electricity in total fuel mix. * Increase in energy efficiency of industrial sector * Near doubling of non-fossil electricity generation capacity by 2050 * Increased share of renewables in industry |
| Mobile sources | * Improvements in energy efficiency * Increased incentives for greater adoption of EVs * Improved public transport infrastructure and capacity in the cities * Road dust control (road paving, cleaning, increasing green areas) |
| Households | * Increased efficiency improvements in buildings and appliances * Replacement of kerosene lamps with LED lamps for domestic lighting * Advanced cookstoves for the remaining population using solid fuels for cooking * Phase-out of biomass use in domestic cooking by 2040 in rural area and by 2030 in urban area |
| Agriculture | * More stringent policies for manure management and fertilizer application * Efficient enforcement of ban of agricultural waste burning |

**Table S9: Sulfur dioxide (SO2) emissions by State/region**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **State/region** | **2018 legislation scenario** | | | **Advanced control scenario** | | **Sustainable development scenario** | |
| **2015** | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** |
| Andhra Pradesh† | 853.3 | 438.3 | 807.0 | 363.1 | 456.2 | 352.4 | 264.2 |
| Assam | 57.9 | 38.1 | 64.8 | 31.9 | 37.4 | 30.5 | 24.5 |
| Bihar | 176.5 | 79.0 | 131.9 | 67.4 | 75.6 | 63.3 | 44.6 |
| Chhattisgarh | 497.7 | 216.6 | 364.4 | 186.5 | 211.8 | 173.9 | 88.3 |
| Delhi | 79.9 | 30.2 | 43.3 | 25.4 | 25.0 | 9.9 | 5.4 |
| Goa | 36.7 | 12.6 | 20.8 | 12.0 | 15.6 | 11.6 | 8.9 |
| Gujarat | 1038.3 | 585.2 | 1092.1 | 476.2 | 624.9 | 429.7 | 268.5 |
| Haryana | 381.1 | 123.3 | 245.9 | 101.4 | 118.9 | 177.1 | 239.2 |
| Himachal Pradesh | 23.3 | 20.8 | 37.7 | 16.5 | 19.2 | 16.3 | 12.1 |
| Jammu & Kashmir | 27.9 | 11.3 | 18.3 | 10.2 | 11.6 | 10.0 | 7.2 |
| Jharkhand | 601.2 | 298.9 | 503.1 | 250.0 | 269.0 | 227.1 | 74.6 |
| Karnataka | 438.8 | 190.4 | 365.3 | 153.9 | 180.4 | 161.2 | 117.5 |
| Kerala | 170.4 | 82.8 | 132.9 | 70.5 | 74.5 | 73.1 | 43.3 |
| Madhya Pradesh | 548.4 | 203.7 | 383.2 | 172.4 | 223.4 | 160.1 | 115.8 |
| Maharashtra | 1222.2 | 387.3 | 664.0 | 344.0 | 417.0 | 354.0 | 275.8 |
| North East‡ | 55.7 | 21.3 | 27.9 | 18.8 | 15.4 | 21.0 | 9.4 |
| Odisha | 406.0 | 239.1 | 424.5 | 194.8 | 224.5 | 189.6 | 118.7 |
| Punjab | 309.3 | 132.0 | 248.1 | 117.2 | 147.4 | 257.7 | 315.8 |
| Rajasthan | 715.3 | 577.0 | 1112.9 | 533.8 | 907.6 | 839.0 | 1236.1 |
| Tamil Nadu | 708.7 | 335.9 | 612.5 | 289.6 | 376.8 | 277.5 | 175.7 |
| Uttar Pradesh | 896.7 | 345.3 | 618.9 | 302.9 | 386.1 | 823.9 | 1081.5 |
| Uttarakhand | 29.3 | 17.1 | 30.9 | 14.3 | 17.0 | 14.7 | 11.8 |
| West Bengal | 511.6 | 210.9 | 347.4 | 183.1 | 201.2 | 188.5 | 120.7 |
| **Total** | **9786.3** | **4597.1** | **8297.7** | **3936.1** | **5036.4** | **4862.1** | **4659.7** |

‡Including Telangana

‡Excluding Assam

**Table S10: Nitrogen oxides (NOx) emissions by State/region**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **State/region** | **2018 legislation scenario** | | | **Advanced control scenario** | | **Sustainable development scenario** | |
| **2015** | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** |
| Andhra Pradesh† | 555.9 | 710.5 | 960.7 | 641.8 | 678.1 | 575.5 | 332.8 |
| Assam | 89.0 | 95.8 | 97.5 | 91.3 | 80.7 | 84.0 | 58.5 |
| Bihar | 191.1 | 209.0 | 263.6 | 198.9 | 212.0 | 170.7 | 127.9 |
| Chhattisgarh | 277.7 | 358.0 | 481.5 | 333.8 | 386.7 | 286.5 | 119.4 |
| Delhi | 173.4 | 145.5 | 119.5 | 145.5 | 111.8 | 86.8 | 50.0 |
| Goa | 35.7 | 38.8 | 38.8 | 36.3 | 31.6 | 34.0 | 16.4 |
| Gujarat | 629.5 | 689.1 | 813.9 | 650.6 | 646.3 | 610.7 | 304.0 |
| Haryana | 355.9 | 357.1 | 319.3 | 350.2 | 268.7 | 291.3 | 136.0 |
| Himachal Pradesh | 59.8 | 67.6 | 73.1 | 62.5 | 48.9 | 58.4 | 31.2 |
| Jammu & Kashmir | 52.0 | 53.6 | 48.5 | 51.6 | 40.7 | 47.1 | 25.7 |
| Jharkhand | 306.2 | 390.6 | 524.2 | 383.1 | 479.8 | 321.7 | 113.5 |
| Karnataka | 358.7 | 393.2 | 461.3 | 362.6 | 331.6 | 338.3 | 196.0 |
| Kerala | 281.3 | 267.2 | 165.3 | 257.5 | 144.8 | 251.0 | 100.0 |
| Madhya Pradesh | 388.4 | 436.1 | 569.5 | 392.5 | 384.0 | 357.5 | 185.5 |
| Maharashtra | 709.1 | 769.9 | 918.0 | 729.6 | 737.1 | 660.2 | 315.3 |
| North East‡ | 93.5 | 95.5 | 73.8 | 89.6 | 55.7 | 86.9 | 38.8 |
| Odisha | 255.1 | 302.0 | 387.5 | 287.6 | 321.7 | 249.1 | 119.7 |
| Punjab | 227.4 | 249.4 | 298.5 | 240.4 | 246.1 | 196.8 | 117.2 |
| Rajasthan | 478.4 | 529.3 | 662.8 | 486.8 | 424.0 | 473.3 | 462.1 |
| Tamil Nadu | 685.8 | 724.1 | 717.2 | 669.3 | 510.8 | 632.3 | 265.2 |
| Uttar Pradesh | 582.2 | 650.9 | 876.0 | 642.1 | 715.8 | 578.9 | 457.7 |
| Uttarakhand | 37.9 | 45.5 | 61.0 | 41.6 | 43.0 | 37.3 | 25.9 |
| West Bengal | 392.9 | 430.3 | 498.7 | 414.9 | 425.2 | 359.6 | 180.9 |
| **Total** | **7216.8** | **8009.1** | **9430.3** | **7560.1** | **7325.2** | **6787.9** | **3779.5** |

‡Including Telangana

‡Excluding Assam

**Table S11: PM2.5 emissions by State/region**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **State/region** | **2018 legislation scenario** | | | **Advanced control scenario** | | **Sustainable development scenario** | |
| **2015** | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** |
| Andhra Pradesh† | 431.6 | 377.5 | 430.9 | 314.7 | 187.4 | 121.9 | 91.1 |
| Assam | 130.2 | 90.9 | 62.9 | 81.0 | 36.1 | 22.9 | 18.0 |
| Bihar | 396.0 | 277.7 | 175.7 | 251.3 | 107.2 | 65.2 | 42.3 |
| Chhattisgarh | 212.7 | 246.3 | 327.3 | 192.1 | 128.8 | 80.9 | 40.7 |
| Delhi | 25.1 | 19.0 | 22.5 | 18.4 | 18.5 | 8.4 | 10.7 |
| Goa | 9.8 | 9.4 | 13.1 | 8.1 | 8.0 | 4.6 | 3.8 |
| Gujarat | 332.8 | 255.9 | 294.8 | 221.0 | 172.9 | 107.8 | 89.1 |
| Haryana | 130.6 | 92.1 | 89.9 | 81.3 | 55.7 | 29.1 | 21.8 |
| Himachal Pradesh | 30.2 | 27.3 | 31.1 | 22.8 | 13.8 | 9.6 | 7.7 |
| Jammu & Kashmir | 40.6 | 29.9 | 23.9 | 26.8 | 15.3 | 8.3 | 6.8 |
| Jharkhand | 277.6 | 364.3 | 550.2 | 261.6 | 183.6 | 138.6 | 31.7 |
| Karnataka | 279.9 | 230.8 | 253.6 | 200.0 | 137.1 | 80.6 | 63.3 |
| Kerala | 134.9 | 93.4 | 63.4 | 85.0 | 43.1 | 28.1 | 21.1 |
| Madhya Pradesh | 368.8 | 280.3 | 252.6 | 242.5 | 133.4 | 81.7 | 57.9 |
| Maharashtra | 509.0 | 414.5 | 463.8 | 357.4 | 272.6 | 154.3 | 120.6 |
| North East‡ | 64.7 | 45.7 | 35.1 | 40.1 | 20.1 | 12.4 | 10.0 |
| Odisha | 280.6 | 265.6 | 324.7 | 219.3 | 140.9 | 88.9 | 77.1 |
| Punjab | 124.2 | 107.7 | 123.6 | 92.1 | 70.7 | 32.0 | 29.7 |
| Rajasthan | 357.0 | 293.7 | 293.1 | 250.4 | 156.0 | 72.6 | 71.2 |
| Tamil Nadu | 312.1 | 237.5 | 250.5 | 214.3 | 156.9 | 91.7 | 91.6 |
| Uttar Pradesh | 820.8 | 677.2 | 635.4 | 597.4 | 379.6 | 152.2 | 123.8 |
| Uttarakhand | 37.8 | 26.9 | 25.3 | 23.6 | 13.4 | 7.8 | 7.9 |
| West Bengal | 445.2 | 379.4 | 400.4 | 321.8 | 190.1 | 112.7 | 78.6 |
| **Total** | **5752.3** | **4842.9** | **5143.7** | **4123.0** | **2641.2** | **1512.4** | **1116.5** |

‡Including Telangana

‡Excluding Assam

**Table S12: Ammonia (NH3) emissions by State/region**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **State/region** | **2018 legislation scenario** | | | **Advanced control scenario** | | **Sustainable development scenario** | |
| **2015** | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** |
| Andhra Pradesh† | 714.0 | 924.9 | 1154.6 | 817.8 | 872.7 | 710.0 | 585.4 |
| Assam | 187.4 | 207.9 | 250.8 | 189.8 | 202.4 | 170.9 | 154.6 |
| Bihar | 501.1 | 634.7 | 750.0 | 568.9 | 585.7 | 501.5 | 421.7 |
| Chhattisgarh | 201.3 | 234.6 | 274.0 | 213.8 | 222.9 | 193.2 | 170.8 |
| Delhi | 19.8 | 26.6 | 29.8 | 26.2 | 28.4 | 25.0 | 26.4 |
| Goa | 5.0 | 5.9 | 7.4 | 5.3 | 5.8 | 4.6 | 3.8 |
| Gujarat | 403.1 | 527.6 | 612.2 | 484.3 | 507.4 | 438.5 | 394.4 |
| Haryana | 334.4 | 456.1 | 541.7 | 397.3 | 396.6 | 197.6 | 216.1 |
| Himachal Pradesh | 56.6 | 67.1 | 78.1 | 63.5 | 69.2 | 59.8 | 60.3 |
| Jammu & Kashmir | 98.6 | 124.5 | 148.0 | 116.9 | 128.6 | 109.1 | 109.1 |
| Jharkhand | 171.8 | 198.9 | 248.7 | 183.7 | 207.4 | 170.4 | 163.6 |
| Karnataka | 383.5 | 444.4 | 540.4 | 392.6 | 410.2 | 339.3 | 277.5 |
| Kerala | 61.5 | 56.4 | 62.4 | 53.3 | 55.0 | 49.7 | 47.1 |
| Madhya Pradesh | 555.9 | 666.5 | 770.6 | 613.8 | 641.1 | 558.2 | 509.8 |
| Maharashtra | 623.5 | 760.9 | 909.8 | 680.0 | 708.1 | 595.4 | 499.0 |
| North East‡ | 84.6 | 97.3 | 121.1 | 87.5 | 94.5 | 77.2 | 68.5 |
| Odisha | 286.8 | 326.6 | 382.5 | 300.8 | 317.2 | 275.0 | 251.2 |
| Punjab | 342.9 | 439.3 | 521.0 | 374.8 | 364.2 | 155.3 | 172.9 |
| Rajasthan | 535.1 | 663.1 | 766.7 | 604.4 | 624.1 | 414.8 | 459.5 |
| Tamil Nadu | 400.6 | 514.7 | 666.5 | 456.2 | 506.5 | 397.4 | 339.9 |
| Uttar Pradesh | 1327.7 | 1686.9 | 1965.4 | 1503.6 | 1518.4 | 886.8 | 975.8 |
| Uttarakhand | 76.4 | 92.0 | 107.1 | 84.5 | 88.5 | 76.8 | 69.9 |
| West Bengal | 556.3 | 688.5 | 842.3 | 620.2 | 663.0 | 551.5 | 481.5 |
| **Total** | **7927.7** | **9845.4** | **11751.2** | **8839.0** | **9217.9** | **6958.5** | **6459.0** |

‡Including Telangana

‡Excluding Assam

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2. Andhra Pradesh (including Telangana); Assam; West Bengal; Bihar; Chhattisgarh; Delhi NCT; North East (excl. Assam); Goa; Gujarat; Haryana; Himachal Pradesh; Jharkhand; Karnataka; Kerala; Maharashtra; Madhya Pradesh; Orissa; Punjab; Rajasthan; Tamil Nadu; Uttaranchal: Uttar Pradesh; Jammu and Kashmir [↑](#footnote-ref-3)
3. ‘Make in India’ is a major new national programme of the Government of India designed to facilitate investment, foster innovation, enhance skill development, protect intellectual property and build best in class manufacturing infrastructure in the country. [↑](#footnote-ref-4)
4. Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Lucknow, Sholapur, Jamshedpur and Agra [↑](#footnote-ref-5)
5. Including Delhi, Haryana, Rajasthan and Uttar Pradesh [↑](#footnote-ref-6)
6. Bharat stage emission standards (BSES) are emission standards instituted by the Indian government to regulate the output of air pollutants from internal combustion engines and Spark-ignition engines equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board (CPCB) under the Indian Ministry of Environment & Forests and Climate Change (MoEFCC). [↑](#footnote-ref-7)
7. The Indian Ministry of Petroleum and Natural Gas (MoPNG) has announced a 2-year advancement of the introduction of BS-VI fuel norms from April 1, 2018 in Delhi. [↑](#footnote-ref-8)
8. The FAME India (Faster Adoption and Manufacture of (Hybrid and) Electric Vehicles) Scheme was launched by the Ministry of Heavy Industries and Public Enterprises in 2015 to incentivize the production and promotion of eco-friendly vehicles including electric vehicles and hybrid vehicles. FAME India is a part of the National Electric Mobility Mission Plan. Main thrust of FAME is to encourage electric vehicles by providing subsidies. Vehicles in most segments – two wheelers, three wheelers, electric and hybrid cars and electric buses obtained the subsidy benefit of the scheme. [↑](#footnote-ref-9)
9. Perform Achieve and Trade Scheme (PAT) is a market-based mechanism to enhance the Energy Efficiency in Energy Intensive industries through certification of energy saving which can be traded. In the “first cycle” of PAT (ending in year 2014-15), 478 industries units in 8 sectors (Aluminium, Cement, Chlor-Alkali, Fertilizer, Iron & Steel, Paper & Pulp, Thermal Power Plant, Textile) were mandated to reduce their specific energy consumption (SEC) i.e. energy used per unit of production. Overall, the SEC reduction targets envisaged to secure 4.05% reduction in energy consumption in these industries totalling an energy saving of 6.7 million tonne of oil equivalent (MTOE). The implementation of PAT in large industries has led to energy saving of 8.67 MTOE by year 2014-15 which is about 1.25% of total primary energy supply to the country in the “first cycle”. This energy saving also translates in to mitigating of about 31 million tonne of CO2 emission. The "second cycle" of PAT was notified in March 2016 covering 621 Designated Consumers (DCs) from 11 sectors which include eight existing sectors and three new sectors viz. Railways, Refineries and DISCOMs. PAT in its second cycle seeks to achieve an overall energy consumption target of 8.9 MTOE. [↑](#footnote-ref-10)
10. The Sustainable Development Scenario (SDS) outlines a major transformation of the Indian energy system, showing how India can change course to deliver on the three main energy-related SDGs (SDG7, SDG 13 and SDG 3). We adopts for the energy sector the projection of energy use, energy systems transformation and economic activities that has been developed by CEEW (Chaturvedi et al., 2018) in the context of exploring response strategies to the 2oC temperature increase limit by 2100 (SDG 13). SDS measures assumes large penetration of renewables (solar, wind, biomass, small hydro etc.) and energy efficiency measures (SDG7) alongwith advanced air pollution control technologies (parts of SDG 3). Most importantly, this scenario considers additional emission controls for non-industrial sources (clean cookstoves, efficient enforcement of bans of burning of agricultural/municipal waste and road paving). [↑](#footnote-ref-11)