# FIXING DELHI'S POLLUTION

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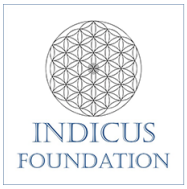


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# FIXING DELHI'S POLLUTION: RECOMMENDATIONS

| | Urgent | Important | Significant | Sustainability | Avoid |
|---|---|---|---|---|---|
| | **Paddy to Other Crops** | **Unprofitable Field Burning** | **LPG Home Stoves** | **Green Belt** | **X** |
| **Biomass Burning** | 1. CG+SG - Incentivize sowing of other crops like pulses, cotton, fruits, vegetables in Kharif. 2. CG - FCI to stop purchases of paddy from Punjab and Haryana. | 1. CG+SG - Coal power plants to include straw in their inputs. 2. CG+SG -Real-time satellite image-based warning mechanism integrated with local police stations. 3. SG - Ensure zero-till machines in every gram panchayat. | 1. Each District Commissioner mandated with ensuring 100 percent coverage of LPG stoves in Delhi, Punjab, and Haryana. 2. Parallel monitoring to ensure uninterrupted supply of LPG in these states. | 1. Thick green belt on the western and northern side of Delhi. 2. In the absence of public land, promote orchards and tree-based farming in western and northern Delhi and bordering areas in Haryana. | 1. Banning crop burning cannot work and will only alienate farmers, it is better to work with them in changing crops and practices. 2. Punishing informal sector workers and businesses also has little environmental impact with great human misery. |
| | **Cleaner fuel** | **Better engines** | **More public transport less private** | **Urban planning & governance** | **X** |
| **Vehicular Pollution** | 1. CG - Import or buy low sulphur petrol and diesel. 2. CG - Accelerate conversion of public sector refineries to low sulphur immediately - not in 2020. 3. CG - Introduce pollution cess that applies to high sulphur fuel, and use it to facilitate conversion to low sulphur fuel. | 1. CG - Lower GST for BSVI compliant vehicles OR High Pollution Cess on non-BS VI vehicles. 2. CG - High R&D funding and awards for 2 wheeled BSVI compliant engines. 3. CG – High R&D funding for operation of electric 2 wheelers to accelerate shift | 1. CG+SG - Doubling of Metro carrying capacity - more cars per train and frequency. 2. SG - Subsidy for public transport including to Metro and DTC/Pvt Buses. 3. SG - Increase state taxes/fees/cesses on private 2, 3, and 4 wheeled vehicles by more than 100% - including taxis. | 1. CG - Urban planning and design centered on public transport and footpaths. Walkability to take precedence over car parking or traveling. 2. MG - Parking of private vehicles (i) at charges pegged to land values, and (ii) not allowed to block footpaths or roads in residential or commercial areas. | 1. Focusing on 4 wheelers or commercial vehicles or luxury vehicles will not solve the problem as more than half the vehicular pollution is caused by 2 wheelers. 2. Electric vehicles are too expensive for now to significantly affect Delhi's pollution. 3. Focusing on old vehicles also ineffective as many more vehicles are added every year. |
| | **Cleaning Emissions** | **Better Coal** | **Less Coal** | **Reducing coal dependence** | **X** |
| **Coal and Fly Ash** | 1. CG - Mandate wet scrubbers and electric precipitators in all coal-using power and industrial plants. 2. CG+SG - 100% disposal of fly ash for example for brick making made mandatory. 3. CG+SG - Community/public real-time emissions monitoring. | 1. CG - Mandate only superior and less polluting coal for plants in North-western India, import if not available in India. 2. CG - Mandate increased use of washed coal in plants in these areas. | 1. CG - Stop all small coal power plants and put up additional capacity in gas-based power plants. 2. Subsidize gas power with high pollution cess on coal power. | 1. CG - Do away with coal power within 10 years. 2. In the interim, only allow the following type of coal plants (a) large and efficient coal power plants that follow strict emission norms, (b) located in high wind areas such as coasts, and (c) located in low population density areas. | Put up more coal power plants, especially in the northern India region spanning Punjab to West Bengal. |
| | **Unsurfaced Roads** | **Poor Quality Roads** | **Unclean Surfaced Roads** | **Rural dust + Implementation** | **X** |
| **Soil and Road Dust** | 1. SG - Converting all Delhi roads to the surfaced category. Similar actions by Punjab, Haryana, Rajasthan, and UP would benefit all, across North India. | 1. SG -Resurface/Repair all roads where bitumen is lose or there are potholes, half the roads of Delhi belong to this category conservatively. | 1. SG+MG - Change subcontracting practices to ensure quick completion of digging related public works and road building. 2. SG+MG - Covering and water spraying of all roads that have been dug. 3. SG+MG - Vacuuming roadsides to have complete coverage over all roads. | 1. SG - Creation of green belt around Delhi either through forests or through orchards or commercial forestry. 2. SG+MG - For proper monitoring of contractors and municipal workers build a community-based monitoring mechanism whose cost to be borne by vehicle registration fees. | Vacuuming roads during high traffic time periods as during that time the fine particles of road dust are already airborne. Best to vacuum roadsides during low traffic times - night times and early mornings. |
| | **Remove waste rapidly and burn less** | **Existing waste plants** | **Waste disposal capacity** | **Segregation** | **X** |
| **Solid Waste Burning** | 1. CG/SG+MG - Make local police and municipal officers responsible in case burning is detected. 2. Make the process of handing out burning related challans simpler and less time intensive. 3. Municipal commissioners should be made liable for non-collection of waste or open dumping. | 1. SG-Ensure proper maintenance and 100% capacity utilization of all plants in Delhi and surrounding areas. 2. SG - Ensure 24x7 monitoring of emissions and maintenance. | 1. CG - put up new waste to energy plants with latest emission control technologies. 2. CG - Establish new landfills on land owned by government agencies. | 1. SG+MG - Segregation of garbage works everywhere in the world. It requires a system of rewards and liabilities for non-performance or non-delivery, and this is possible with a more empowered set of RWAs to monitor and enforce the rules at ground level and made liable for them as well. | Burning of waste in energy plants or elsewhere without 24x7 monitoring by the community and civil society. |
| | **Construction** | **Electricity is best source** | **Improved technology** | **Point specific monitoring and display** | **X** |
| **Others (industrial, construction, etc.)** | 1. MG - Covering of materials and the area being constructed and also regular spraying. 2. MG - Community and NGO Monitoring and reporting. 3. MG - Simpler challan/Public fining method of construction-related polluters. | 1. CG+SG - Guaranteed 24x7 and 100% supply of electricity for all residential and commercial establishments in Delhi NCR. 2. SG - Eliminate all generators and machinery drawing energy from petroleum fuels in Delhi NCR, only battery-based backup systems should be allowed, apart from emergency services like Hospital, ICUs etc. | 1. SG - Mandatory change of old transformers, generators, etc. 2. SG - Convert presswalas, tandoors etc. to electricity based options, to be done through first, listing of all such units, followed by exchange, involving RWAs and market associations. Some economic incentive and liability required. | 1. SG - Real-time public display of data from each of the pollutant made available on the cloud. 2. SG+CG - Use airborne infrared monitoring to detect pollution in hard to get areas such as slum interiors. | 1. Stopping or banning economic activity without access to an economically viable substitute. 2. Government functionaries implement with little day to day answerability or overseeing - instituting liability on the government and its functionaries is critical even if it's minor. 3. Retaining current system of challans without a simple small fee-based punishment regime is avoidable. |

CG = Central Government, SG = State Government, MG = Municipal Government

# FIXING DELHI'S POLLUTION: MECHANICS

| | Key Data | Science | Economics | Technology | Policy |
|---|---|---|---|---|---|
| **Biomass Burning** | 1. 14.4 mill ha. kharif rice. 2. 5.3 mill households in Delhi, Punjab, and Haryana use biomass/coal for cooking. 3. Similar levels of particulate matter released by burning fields and biomass stoves. | 1. Paddy straw has high silica, is hard and difficult to process and is also bulky - high volume to weight ratio. 2. Biomass stoves create both indoor and outdoor pollution. | 1. Collection and disposal of straw and stubble are expensive, and its price low because of few uses. 2. Difficult to supply LPG universally. | 1. Mechanical harvesters spread straw on the field and leave more stubble than manual harvesting. 2. Zero-till seed drills are expensive and not yet popular among farmers. 2. LPG stoves create far less pollution and insignificant PM. | 1. The government gives incentives for paddy and purchases a high share from north-west India, is harmful to due to overdrawing of underground water. 2. LPG use expanded after Ujwala Yojana but many households not yet covered. |
| **Vehicular Pollution** | 1. 42.3 lakh 2&3 wheelers account for 56.3% of the PM due to vehicles. 2. 4.7 lakh diesel 4w vehicles account for 9.8%. 3. 11.4 lakh petrol 4w vehicles account for 9.5%. 4. 2.2 lakh commercial vehicles account for 24.2%. | 1. High sulphur content fuels used in India pollute more. 2. Public transport such as metro, trains, and buses pollute less as they carry more people. 3. Pedestrians pollute least. | 1. Profitable public sector oil companies invested in few clean technologies until recently. 2. Import or purchase of cleaner fuel not done. 3. Vehicle costs will rise with less polluting engines so manufacturers reluctant to better standards. 3. Public transport rarely operates efficiently in India. | 1. India is dependent on low-quality coal and high sulphur fuels; investments required to substitute with better inputs and technologies. 2. Currently, two-wheelers pollute the most as they are largest in numbers, but BS6 compliant efficient 2w technology not well developed yet. | 1. BS6 standards operatable in 2020 will improve both fuels and vehicles, however, rapid growth will neutralize the benefits. 2. Govt. pushing electric vehicles, but this will take some years to fructify. 3. Policy focused most on private transport, less on public and none on pedestrians, this needs to be reversed. |
| **Coal and Fly Ash** | 1. 80% of coal despatches in India go for coal power. 2. 27 coal power plants to the west and north-west of Delhi. 3. Most operated by central or state government-run entities. 4. Less than 6% of coal used is washed. 5. Of the 104 units in these 27 power plants, 46 units are 210MW or lower that are most polluting per unit energy. | 1. Indian coal is low in sulphur so desulphurization not historically done; low calorific value requires more coal per MW produced. 2. Coal production releases ash, Nox and Sox compounds. 3. New technologies involve very large power plants that pollute less but much more than other sources. | 1. Coal believed to be 'cheap' as (i) cost of pollution is not considered, (ii) lower emission equipment not used, and (iii) cheap high polluting inputs used till now. 2. Current pricing policies work against the operation of low polluting Natural Gas power plants. Other renewable substitutes can't be scaled currently. | 1. Indian coal power plants among the least efficient and most polluting in the world. 2. Even globally, the latest coal power plants much less dirty but still highly polluting. 3. Coal plants can be converted to Natural Gas or biomass-powered; improved technologies can improve efficiency and emissions, but limited ongoing attempts. | 1. Cash-strapped electricity boards, power, and coal govt. monopolies, little focus on environment till now. 2. No program yet for the improvement/closure of coal power plants. 3. Enforcement of emission regulations susceptible to corruption. 4. Information of pollution from each source point not captured or available publicly. |
| **Soil and Road Dust** | 1. Delhi has 8,686 km of kucha roads. 2. Agriculture land to the west and north-west also contributes unknown amount. 3. Road construction and urban digging for pipes etc. contribute an additional significant amount. | 1. Particles on the road that includes - dust, pollution, tire, bitumen, and exhaust are suspended due to the wind, and kinetic energy from vehicle movement. 2. Dug soil from public works and roads, from agriculture and also sands of Rajasthan further worsen the problem. 3. Delays and poor practices in public and road works. | 1. Vacuuming or washing are expensive solutions to road dust. 2. Poor road maintenance. 3. Together, these create more road dust than well-maintained ones. 4. Delays in payment to contractors lead to dug soil remaining uncovered. | 1. Little understanding of tyre or wheel design, road quality, speeds and how they interact under varying climatic conditions to produce SPM. 2. R&D on the effectiveness of possible solutions such as tire flaps, wheel covers, vacuuming, washing roads, etc. are rare. 3. Reduction in time taken to construct public works/roads needed. | 1. Local govt. unable to monitor own staff or subcontractors. 2. RWAs and Non Profits are neither empowered nor made responsible or liable currently. 3. No liability on city managers for not carrying out functions. 4. Delays in payment to contractors combined with little answerability for delays for both contractors and city managers. |
| **Solid Waste Burning** | 1. Delhi generates 12,000 tonnes of waste daily. 2. About 8,000 tonnes goes to overflowing landfills. 3. Waste to energy plants exist with capacity of more than 6000 tonnes but, cannot be used well as most garbage is not segregated. 4. Much of the garbage is either burnt to create space or rots in the open or is thrown into waterbodies. | If segregated, wet waste can be composted, dry waste such as glass can be recycled, or converted to energy like some plastics. If not segregated, compositing, recycling, and waste to energy - all processes get adversely affected. | 1. Segregation best if done in the household, costlier if done immediately after collection, and inefficient later. 2. Waste to energy and landfills require proper maintenance and outside monitoring of practices, emissions, and quick responsiveness. 3. Informal sector undertakes low-cost segregation but not feasible for items like cheap plastics etc. | 1. Segregation, well-managed landfills, and waste to energy plants are well-known solutions but need subsidization. 2. Proper operating procedures and following best practices are critical and need organizational strengths. 3. Third party or community 24x7 monitoring, and rapid responsiveness has to be an integral component. | 1. Municipal governments under-resourced and incapable, unable to meet the demands of a more service-oriented society. 2. The municipal commissioner is empowered but not liable for poor performance. 3. The political leadership is liable through elections but not empowered. 4. Communities and RWAs not empowered, liable or made responsible. |
| **Others (industrial, construction, etc.)** | 1. Industrial units that use petroleum or coal-based energy or chemicals based processes form about 2/3rd of this component and also include Brick Kilns in and around the city-state. 2. Construction and stone cutting account for about a third. 3. Data on sales of coal suggests that the informal sector (presswalas, tandoor etc.) are a small contributor. | 1. Particles are generated in stone cutting or mining and are also suspended in mixing of cement, sand, concrete etc. 2. Commercial generators, electricity transmission, etc. all naturally generate some emissions. 3. In all such cases, good practices and better technology can substantially reduce pollution. | 1. Sources include those from organized, informal and illegal units. 2. Pollution reduction is costly corruption among government staff is common. 3. Greater stringency in law leads to greater corrupt behaviour, not reduced pollution. 4. Open community monitoring can address both pollution and corruption but has not been tried yet. | 1. Pollution from construction and stone cutting can be reduced by (a) covering of the area/materials and (b) spraying water. 24x7 monitoring difficult for both government and managers of such units. 2. Industrial pollution can be reduced via emission reduction equipment and use of better inputs and technologies. | 1. Corruption and limited abilities of local government staff prevent good implementation of stringent laws. 2. Need to incentivize the use of less polluting inputs and technologies by taxing more polluting ones. 3. The public sector to stop selling polluting fuels such as PET. 4. Incorporate community monitoring, municipal enforcement and liability for non-enforcement in emissions policy. |

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100s of studies quoted in media and references, Environmental and Public Health Researchers

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Conversations with Engineers, Farmers, Doctors, domain experts, Policymakers, and Activists

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# 1. POLLUTION IS A GOVERNANCE PROBLEM

On October 27, 2016, and also few days after Diwali in 2016 Delhiites woke up to a blanket of smoke enveloping their homes and their lives. This was not a sudden occurrence, smoke had been building up for many days, weeks and months, over years and decades, but nothing like this had ever been seen. The government's own Air Quality Index had crossed into the severe domain, across the city meters that measure suspended particulate matter levels (SPM) had reached the maximum they could measure. Schools were closed, children with asthma reported breathing difficulties, hospitals reported an overload of patients knocking on their doors, and even the traffic slowed down due to lack of visibility. The world media meanwhile anointed Delhi as the most polluted city in the world, a position that had been held by Beijing for many years.

On November 8, 2017, the same event played out with similar responses from the government, and once again with negligible impact.

How could this happen? The meteorologists spoke about problems of inversion and wind direction as the chief problem, some reports identified the brick kilns and unorganized sector, yet others blamed road dust, the media identified the burning fields of Punjab, the activists pointed their finger at the government, whoever one spoke to had their favourite reason and culprit. But no one appeared to have a workable solution.

Across Indian cities and even villages, bad air quality has become endemic. It comes from many different sources, and the chief source differs across locations and even seasons. Governments accuse the citizens of not following the law, citizens accuse governments of not imposing the law, and environmental activists accuse both citizens and governments, while the lobbyists accuse environmentalists of extreme views.

Since then much has occurred, the government at the centre and state levels have taken important actions that will go a long way in reducing pollution. However, it will take some years for these actions to play out. More important, even after the benefits of envisaged government actions are realized, the dual pressure of population and a growing environmentally insensitive economy will throw up many such challenges. This is highlighted in the cautious approach of the Economic Survey of India 2016-17 with regard to the promotion of green energy. The Economic Survey has pointed out the social costs associated with encouraging green energy including the impact on banking sector already battered by the bad loans.[1]

The reluctance and in many cases failure of the government to enforce the law has resulted in judiciary becoming active in this field. For instance, in August 2017 the Supreme Court of India issued an order according to which vehicles without valid pollution under control (PUC) certificates will not be eligible for annual insurance. The active involvement of judiciary is only complicating the problem further.

In other words, pollution will not go away, the fields of Punjab may stop burning or coal power plants may reduce their emissions, but India henceforth will have to be always cautious and wary of emerging environmental challenges and forever ready to take quick action.

## CORRECTING HIGH POLLUTION

India may have failed itself in ensuring breathable air for its citizens. But that reality can change fairly rapidly and at low long-term cost. The first step to solving a problem is to identify the specific

[1] "India should calibrate investment in green energy: Eco Survey." The Economic Times: August 13, 2017.

pathways through which the problem travels, grows and spreads. That pollution harms us and our children, is too obvious to warrant repetition but, what is not as well understood is the techno-economic factors that give rise to pollution and the techno-economic solutions that can reduce and even eliminate it. This study has benefitted from scores of studies that enabled us to identify the chief polluters and the forces acting upon them and also the solutions that are the simplest and most practical to implement.

The Air (Prevention and Control of Pollution) Act, 1981 defines "*air pollution as the presence of any solid, liquid, or gaseous substance in the atmosphere in such concentration as may be or tend to be injurious to human beings or other living creatures or plants or property or environment*." There are several types of pollutants in the air that act not only individually but also in coordination with other pollutants to create air pollution. Major air pollutants include sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), ozone ($O_3$), $PM_{10}$ and $PM_{2.5}$.

The present study focuses mainly on the particulate matter (PM) pollution in Delhi. There are three reasons for this. First, over the years levels of other pollutants have come down and have remained mostly below the acceptable limits. This is partly because of government actions and partly because of the peculiar nature of air pollution across northern India. But the biggest culprit currently is suspended particulate matter or SPM. A study published in the respected medical journal Lancet in 2017 found that SPM is the biggest health danger in India. According to the study, the $PM_{2.5}$ alone killed more than 5 lakh Indians in the year 2015[2]. Second, SPM levels tend to be quite correlated with other pollutants such as SOx compounds and addressing the SPM problem will also reduce our exposure to many other pollutants. And third and most important, focusing helps us in elucidating the issues and solutions.

Moreover, though, the present study focuses on Delhi, as already mentioned, pollution is a regional phenomenon where the whole of North India and large parts of the rest of the country suffer from severe pollution. According to The Energy and Resources Institute (TERI)[3], while on average 32% of the $PM_{2.5}$ in Delhi is generated within the city, 25% comes from sources in National Capital Region (NCR) and 43% comes from sources outside NCR. The neighbouring states of Delhi contribute a significant part of the air pollution in Delhi and so does Delhi contribute to other states. Tackling air pollution, therefore, will require actions across many states and may even require national policy changes. For instance, brick kilns that use low quality coal are banned in Delhi but pollution from brick kilns reaches Delhi due to winds from the neighbouring states of Haryana, Punjab and Uttar Pradesh and perhaps even Rajasthan.

## THE POLLUTION PROCESS

Almost all economic activities either cause or create conditions, that cause pollution. No doubt pollution occurs naturally as well – storms and earthquakes are just two examples known to have destroyed multiple ecosystems. However, the high levels of pollution that harm health and life in today's world is largely due to human activities.

How to best deal with air pollution can be understood in the following manner. Consider the accompanying figure.

[2] "One Pollutant Alone Killed 5 Lakh Indians in 2015: Lancet." NDTV: October 31, 2017. https://www.ndtv.com/india-news/new-study-shows-which-pollutant-killed-most-indians-in-a-year-1769126

[3] "Breathing Cleaner Air: Ten Scalable Solutions for Indian Cities." The Energy and Resources Institute: 2016

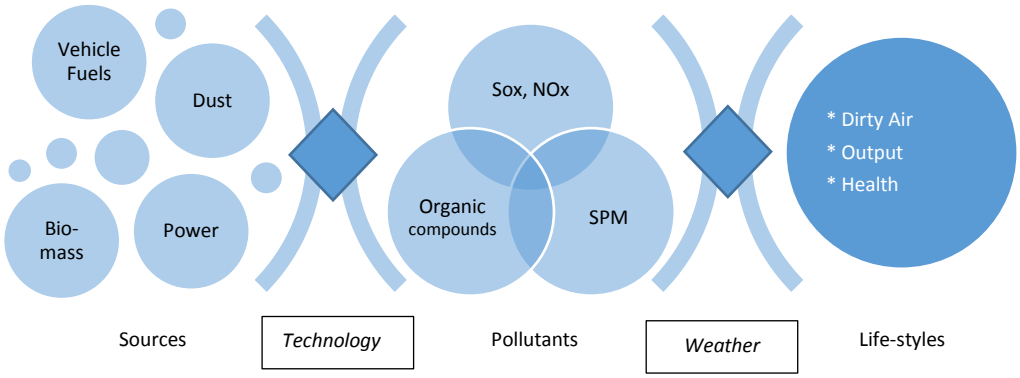
There are many **sources** of air pollution, but the major ones include power plants that burn coal, vehicles using petroleum fuels, biomass burning including crop burning, construction where fine particles are released, dust including road dust and agriculture and digging related dusk, etc.

By themselves, the sources do not harm us or pollute, but interaction with a **technical process** converts their inherent nature and releases some pollutants. In other words, internal combustion is a technical process where diesel or petrol are converted into energy and also release other chemical compounds that pollute. Historically all technical processes have been optimized for maximising productivity not to minimize the polluting by-products.

The **pollutants** that are released then can be extremely harmful, there are hundreds of compounds that we know of which can be quite harmful to health, and others which may not be as harmful to health but destabilize the environment. Pollutants, therefore, not only harm our health, they also harm other animals and plants, and in high enough volume contribute to climate change.

However, there are many locations where substantial amounts of pollutants are released, but they do not cause much harm. This is because weather conditions may either blow them away or help in their dissipation. Delhi and Mumbai being roughly similar-sized cities may create the same level of pollution, however in Mumbai because of winds from and to the sea, the pollutants get dissipated. But in Delhi, the stagnant cold winter air retains the pollutants.

**FIGURE 1: A FRAMEWORK TO HELP UNDERSTAND AIR POLLUTION**



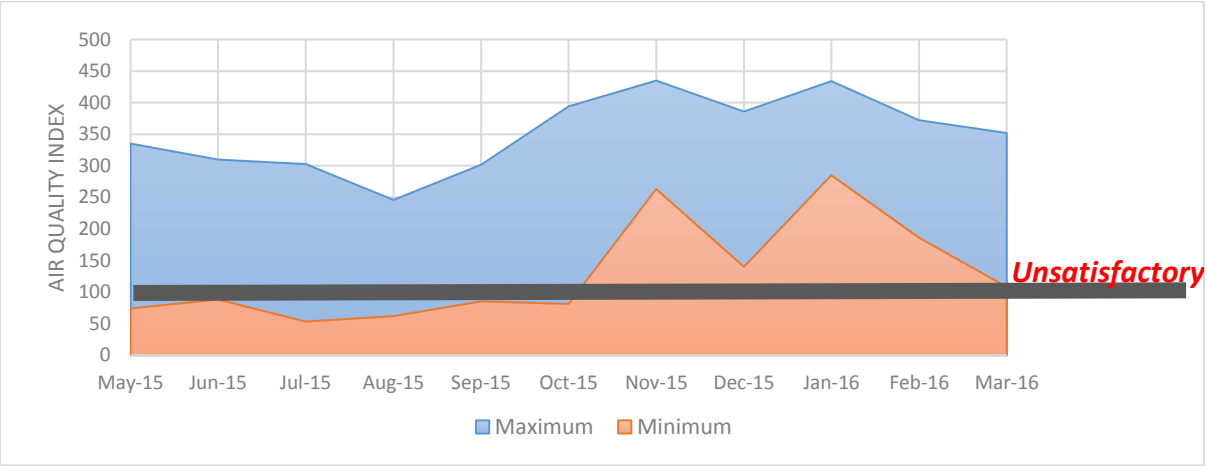

# 2. AIR QUALITY IN DELHI

Delhi has witnessed a consistent deterioration in air quality over the years. This has happened despite government's initiatives such as replacing polluting diesel buses with cleaner CNG buses for public transport as well as its attempt to spread the use of CNG as a general transport fuel. There was some improvement in Delhi's air quality after public transport vehicles running on diesel were banned in 2001, but it deteriorated soon after. This was partly due to the rapid increase in the number of vehicles plying in Delhi including diesel vehicles, but also due to the increase in modern agriculture activity, crop burning, construction, waste burning, not to mention polluting industries such as brick kilns. Deteriorating air quality, especially during the winter season, has now become a common phenomenon with pollutants level surpassing even severe levels.

## AIR QUALITY INDEX

The Central Pollution Control Board (CPCB) is the regulatory authority of the government of India that has come up with the air quality index (AQI) which was launched in the year 2015. The Government of India published the national air quality standards in the year 2009.[4] The AQI helps put in a single number to all the pollutants impacting our lives. The pollutants considered in the calculation of AQI include CO, $NO_2$, $SO_2$, $PM_{2.5}$, $PM_{10}$, $O_3$, $NH_3$ and Pb (lead). Over the years the AQI levels for Delhi have been consistently very high signifying an elevated level of pollution.

**FIGURE 2: CPCB AIR QUALITY INDEX IN DELHI DURING 2015-16**




Source: "NAQI Status of Indian Cities in 2015-16," Central Pollution Control Board.
http://cpcb.nic.in/upload/Latest/Latest_119_NAQI%20Status%20of%20Indian%20Cities%20in%202015-16.pdf

**TABLE 1: AIR QUALITY STANDARDS**

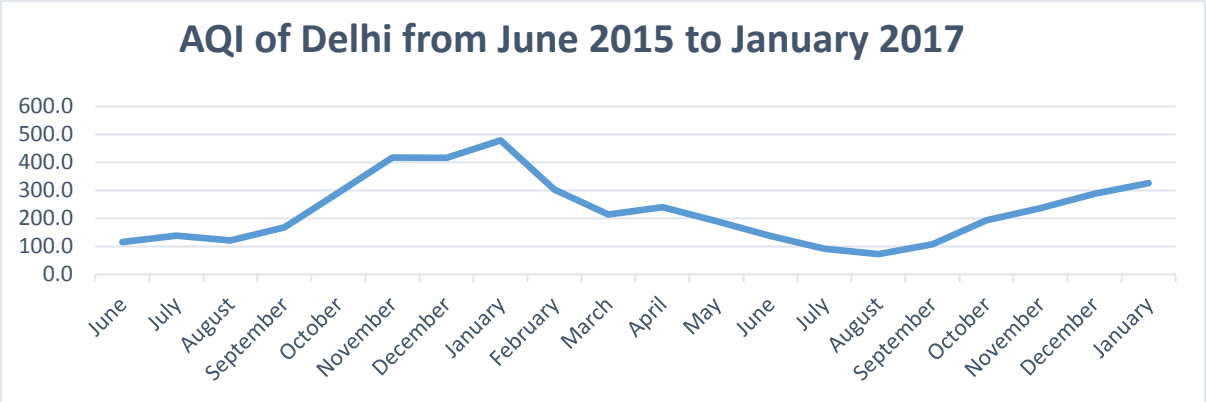
| Air Quality Index Values | Meaning |
|---|---|
| **0 – 50** | Good |
| **51 – 100** | Satisfactory |
| **101 – 200** | Moderate |
| **201 – 300** | Poor |
| **301 – 400** | Very Poor |
| **>401** | Severe |

As the above graph shows during 2015-16, there was not even a single month during which average air quality in Delhi was satisfactory on the average. The summer season enjoys some improvement in the air quality, this is largely due to the winds that tend to be greater in the summer and blow away some of the pollution. Another important thing is that the AQI follows a pattern in which the air quality worsens during the winter season while there is some improvement during the summer

[4] The AQI uses weighted values of individual air pollutants like SO2, PM2.5 and PM10 to create a single number to define the quality of air in a place. The AQI is calculated by following two steps, first being the formation of sub-indices for each pollutant and the second being aggregation of sub-indices to get an overall AQI. The sub-index for each pollutant is calculated so as to represent a relationship between pollutant concentrations and health effects. Moreover, each sub-index also shows that impact on environment as concentration of specific pollutant changes in the environment. The relationship can be linear or non-linear though for AQI linear relationship is taken. Once, each sub-index is calculated, they are combined or aggregated. For the calculation of the AQI the CPCB uses the maximum operator system (i.e., maximum sub-index being the overall index). This is done to avoid the problem of ambiguity and eclipsing that might result with the use of additive or multiplicative aggregation.

season. This is referred to as 'seasonal variability' in pollutant concentrations. This is evident from the following graph that maps the movement in AQI in Delhi during June 2015 to January 2017.

**FIGURE 3: MONTH WISE MOVEMENT OF AIR QUALITY INDEX IN DELHI DURING JUNE 2015 TO JANUARY 2017**

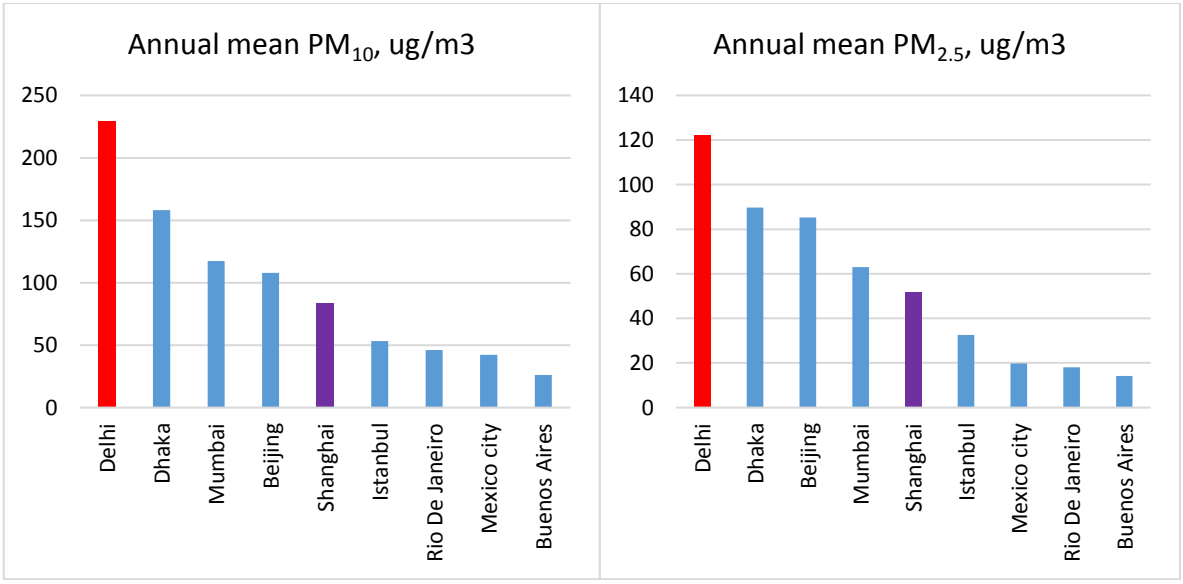



Source: India Open Data Association. http://indiaopendata.com/

Sometimes pollution brings out the best in people and The India Open Data Association is one such non-profit group that has developed low-cost pollution monitoring instruments and has placed them across Delhi. Their instruments also have similar results as those used by the CPCB though of course there are differences. But the advantage of the India Open Data Association's data is that there are many more monitoring points that they cover and also provide detailed data to the analyst.

The seasonal nature of air quality in Delhi is reflected in Figure 3. The air quality decreases as winter approaches and with the beginning of summer, the air quality shows improvement. This is mainly because the washout from the monsoonal rainfall as well as the monsoon winds ensures the air in Delhi is comparatively cleaner during the monsoon season.

**FIGURE 4: ANNUAL $PM_{10}$ AND $PM_{2.5}$ IN SELECTED CITIES ACROSS THE WORLD**




Source: World Health Organization (WHO) Pollution Database 2016.

Today air pollution levels in Delhi are considered to be among the highest in the world, and indeed popularly, Delhi is portrayed as the most polluted city in the world, a position held by Chinese cities such as Beijing and Shanghai a few years back. Over the years government initiatives in China have

ensured substantial improvement in the quality of air in Chinese cities. Delhi is far more polluted than most other cities in the world, a position that this report finds can be changed relatively rapidly.

## POLLUTANTS AND THEIR CONCENTRATIONS[5]

There are several types of pollutants that act not just individually but also in coordination with each other to worsen air pollution levels. Some of these pollutants include Sulphur Dioxide ($SO_2$), Nitrogen Dioxide ($NO_2$), Ozone ($O_3$), $SPM_{10}$ and $SPM_{2.5}$.

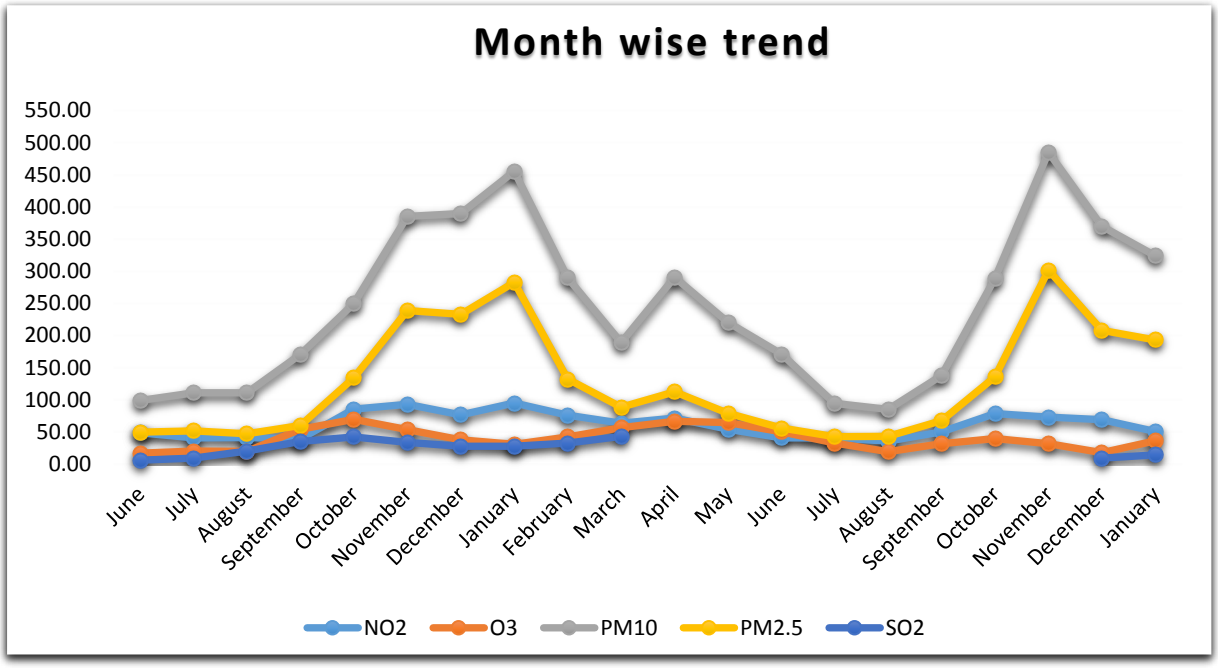
Sulphur dioxide is a colourless heavy gas with a pungent smell, also known to be an irritant. Sources of Sulphur dioxide are combustion of fossil fuels (coal) that contain sulphur, metallurgical operations; smelting of non-ferrous ores of copper, lead, nickel, and zinc; manufacturing of sulphuric acid; conversion of wood pulp to paper; and refuse incineration. As later sections will show, Delhi's high SO2 levels are predominantly due to coal power plants, but also due to manufacturing in its vicinity such as brick kilns. However, over time, SOx interacts with moisture and transforms to particulate matter. It is generally considered that a very large part of particulate matter pollution originates due to SO2.

Nitrogen dioxide ($NO_2$) is a reddish-brown gas, is a strong oxidant, and is soluble in water. $NO_2$ also helps in the formation of ground-level ozone ($O_3$). Sources of $NO_2$ include combustion processes of motor traffic, power production, and the burning of wood and refuse. Tobacco smoking, use of gas-fired appliances, and oil stoves are also some of the other sources. There are also non-combustion processes that are sources of $NO_2$ including the fertilizer industry, manufacturing of nitric acid ($HNO_3$), welding processes, and the explosives industry. Though there are many sources, Delhi's NO2 levels are predominantly by the large number of vehicles running on fossil fuels. Ozone is a pale blue gas and has a sweetish odour. Ground-level ozone is formed in a complex chain reaction involving sunlight, nitrogen oxides (NOx) and hydrocarbons (HCs). High levels of ground-level ozone are typically found in areas with high traffic densities (such as major cities), and where emissions of NOx and HC are high.

Particulate matters (PM) are solid or liquid particles that originate from many sources and are suspended in the air for long periods of time to be potentially inhaled by humans. Suspended particulate matter or SPM is currently the critical problem in Delhi and surrounding areas. SPM includes substances originating from burnt and un-burnt matter emitted from combustion processes, natural and mechanical process like in the transfer and handling of materials such as cement, the particles suspended in the air from vehicle movements such as road dust, and a host of other sources. Two characteristics of particulate matter are important from our perspective: size and composition. These are discussed in a later section in much detail.

[5] Facts on Pollutants. United Nations Environment Programme

**FIGURE 5: Month wise trend of different types of pollutants in Delhi during June 2015-January 2017 (in µg/m3)**




Source: India Open Data Association. http://indiaopendata.com/

## PARTICULATE MATTER

Data from many different sources clearly shows that extremely high levels of particulate matter are observed in Delhi and surrounding areas. It is also generally believed that outer pollutants are less of an issue. This is mainly because of many different sets of actions that have been taken in the recent past by the government and includes:

- Removal of polluting manufacturing away from Delhi (1996)
- Banning of Diesel buses in 2001
- Promotion of CNG in auto rickshaws and taxis in 2001
- Supply of cleaner fuel 2001

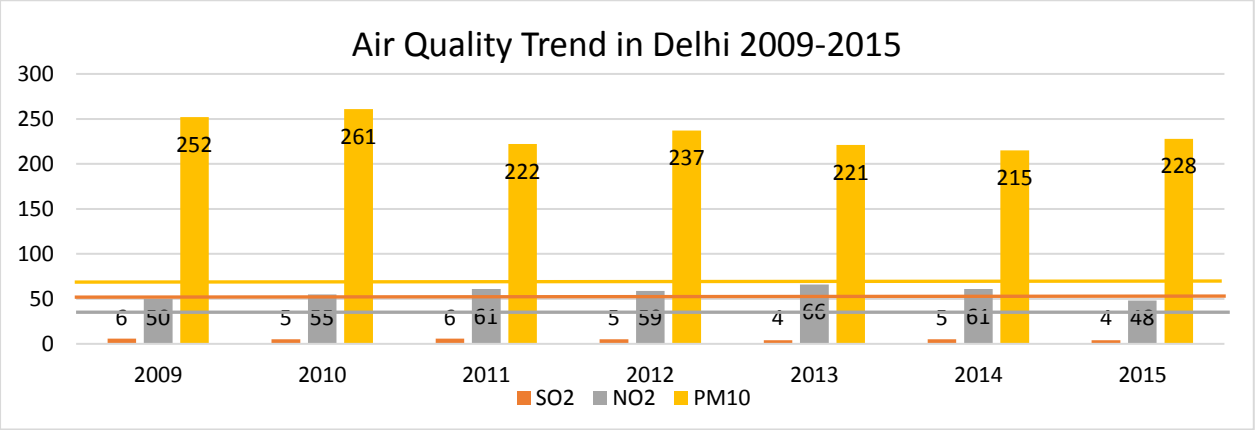
But these are not all, there have been other measures taken as well, such as the staggered pollution fighting mechanism recently announced by the CPCB in January 2017.

While these are discussed later as well, we simply are making the point that government, regulatory or judicial action that is based on good practices and is implemented in a disciplined manner, can make a difference as it has in the past.

Figure 5 and Table 2 clearly show that, while there has been a decreasing trend in the ambient $SO_2$ levels[6] in Delhi and marginally higher levels of $NO_2$, it is the $PM_{10}$ levels in Delhi that have been consistently and significantly higher than the standards over the years.

[6] Government interventions like reduction of sulphur in diesel, increased use of cleaner fuel such as CNG, etc. are expected to be behind the decreasing levels of $SO_2$ in Delhi.

**FIGURE 6: TREND IN THE YEARLY CONCENTRATION OF DIFFERENT POLLUTANTS IN DELHI DURING 2009-15 (IN µG/M3)**




Source: Central Pollution Control Board: http://cpcbenvis.nic.in/envis_newsletter/Air%20pollution%20in%20Delhi.pdf
Note: National Air Quality Standards: $SO_2$ = 50, $NO_2$ = 40 and $PM_{10}$ = 60

**TABLE 2: COMPARISON BETWEEN STANDARDS AND ACTUAL LEVELS OF POLLUTANTS IN DELHI**

| Pollutant | Time Weighted Average used for Standards | Concentration in Ambient Air | |
|---|---|---|---|
| | | Standards | Actual Levels* |
| Sulphur Dioxide (SO2) µg/m3 | Annual | 50 | 9.05 |
| Nitrogen Dioxide (NO2) µg/m3 | Annual | 40 | 72.97 |
| PM10 µg/m3 | Annual | 60 | 485.3 |
| PM2.5 µg/m3 | Annual | 40 | 301.9 |
| Ozone µg/m3 | 8 hours | 100 | 31.9 |

Source: Central Pollution Control Board (CPCB)
http://cpcbenvis.nic.in/envis_newsletter/Air%20pollution%20in%20Delhi.pdf
India Open Data Association: http://indiaopendata.com/
*For $SO_2$ data is for December 2016. For others, data is for November 2016

As the above analysis has shown particulate matter are responsible for much of the poor air quality. Moreover, while other pollutants have generally been under control in the past few years, it is the particulate matters whose concentration has been consistently unsatisfactory over the years.

SPM is a complex mixture of organic and inorganic substances, present in the atmosphere both as solid particles and liquid droplets. They include fumes, smoke, dust, and aerosols etc. All the particles that float in the air are called suspended particulate matter (SPM). SPM is part and parcel of nature, however, when its density goes too high it causes a problem. Almost every economic activity generates some SPM, and some much more than others.

The particles themselves have distinct characteristics in terms of source, composition, and size. The contribution of each component to the ambient PM levels differs from one location to another, from month to month and at times from one village or city to the next and even, from one day to the next.

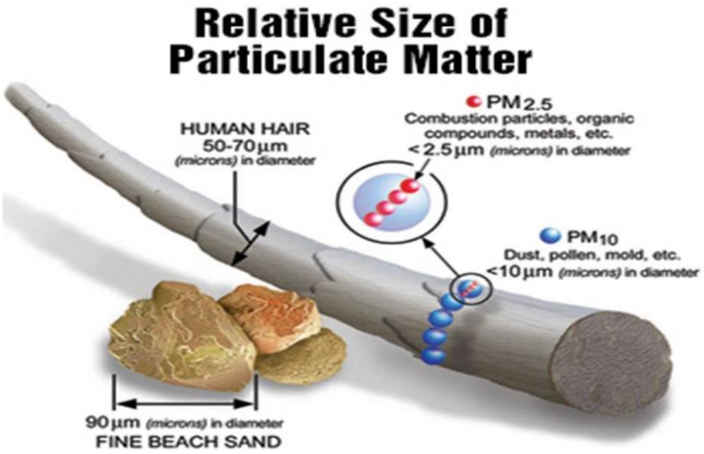
The sources of SPM vary widely, for instance, the ammonia in ammonium sulphate comes mainly from agriculture though there are other sources also, and on the other hand, the sulphates come from sulphur dioxide ($SO_2$) emissions that originate in power plants and industrial units. Some examples include smoke from coal power, cement units, rubber particles or un-burnt residue from

combustion engines that is thrown up by tyres, and household activities such as cooking, cleaning, and dusting also contribute to SPM.

The composition of SPM also varies widely, some are organic such as un-burnt petroleum residue or tyre dust, some are inorganic such as fine pieces of sand. Some are extremely harmful such as heavy metals (originating for example from improperly disposed battery fumes), ammonium sulphates, ammonium nitrates, or fly ash from coal power plants.

Generally, particulate matter (PM) refers to particles in the air of all sizes. But they are typically measured in sizes of SPM 10, SPM2.5 and SPM 1.0. What this implies is that SPM 10 particles are about 30 times smaller than the width of a human hair. As a rough rule, it is generally considered that the smaller the particles, the more likely it can get around the body's defences and is more likely to be absorbed and the more potential damage it can cause.

**FIGURE 7: SIZE COMPARISON OF DIFFERENT PARTICULATE MATTER**




Source: https://insightshealthassociates.wordpress.com/2013/06/23/singapore-haze-how-dangerous-is-pm-2-5/

$PM_{1.0}$: These are the particulate matters that are less than 1 µm in diameter. They are respirable meaning that they can be inhaled through respiration by the human body. They are ultra-fine particles and are usually exhaled but can penetrate into the bloodstream and from there can be transported across the internal organs.

$PM_{2.5}$: These are the particulate matters whose size is up to 2.5 micrometres. Like $PM_{1.0}$, $PM_{2.5}$ is also respirable meaning that it can be inhaled through respiration by human body thereby making it dangerous. Usually, they contain fine particles and contain secondary aerosols, combustion particles and re-condensed organic metallic vapour, and acid components. Fine particles can reach all the way down to the alveoli in the lungs. They can also cross into the arteries, thus hardening them. Coronary heart ailments are the obvious outcome of overexposure to SPM2.5.

$PM_{10}$: These are the particulate matters whose size is up to 10 micrometres. Similar to the $PM_{2.5}$, $PM_{10}$ is also respirable. They contain the dust from roads and industries as well as particles formed under combustion. Depending on their size, coarse particles can lodge in the trachea (upper throat) or in the bronchi and typically contribute to allergic reactions as well as respiratory diseases, as well as impacting general wellbeing.

While dust blown by wind, pollen spores and photo-chemically produced particles are the **natural sources** of SPM, emission from vehicles, pollution from industries and construction activities, burning of wood, coal, oil and gaseous fuels; burning of coal refuse, burning of municipal solid waste; fly-ash emissions from power plants; smelting and mining activities; asbestos factories;

metallurgical industries; ceramic industries; glass industries are some of the **anthropogenic sources** of SPM.

This monograph concentrates on the PM levels not only because it is currently the most serious problem in Delhi, or that controlling PM will require us to take actions that will reduce other pollutants such as SO2 and NO2, but also because particulate matter also further contributes to pollution. The fine particles can combine or react with moisture, other chemicals, ozone, etc. to further worsen pollution levels. [7]

# 3. A SUMMARY OF IMPACTS OF POLLUTION

## HEALTH IMPACT

According to United Nations Environment Programme (UNEP)[8], particulate matter of less than 3 microns in diameter can enter the nose and, reach the lungs. Even finer particles can crossover through the lining into the blood capillaries. And larger particles can get deposited in the respiratory tract. Each of these contributes to a different kind of health problem. Allergies, autoimmune disorders, respiratory tract disorders, cardiac ailments, and a host of other ailments are more likely to come up. Moreover, many of these particles deposited cannot be cleaned by the body and therefore they can cause long-term damage, children being the most sensitive. As pollution levels go up potential damage is greater, and both the likelihood and intensity of ailments increase. The checklist of adverse health impacts due to high SPM levels is long and range from an allergic reaction to cancer to even impacting the reproductive organs, thereby affecting yet unborn generations.

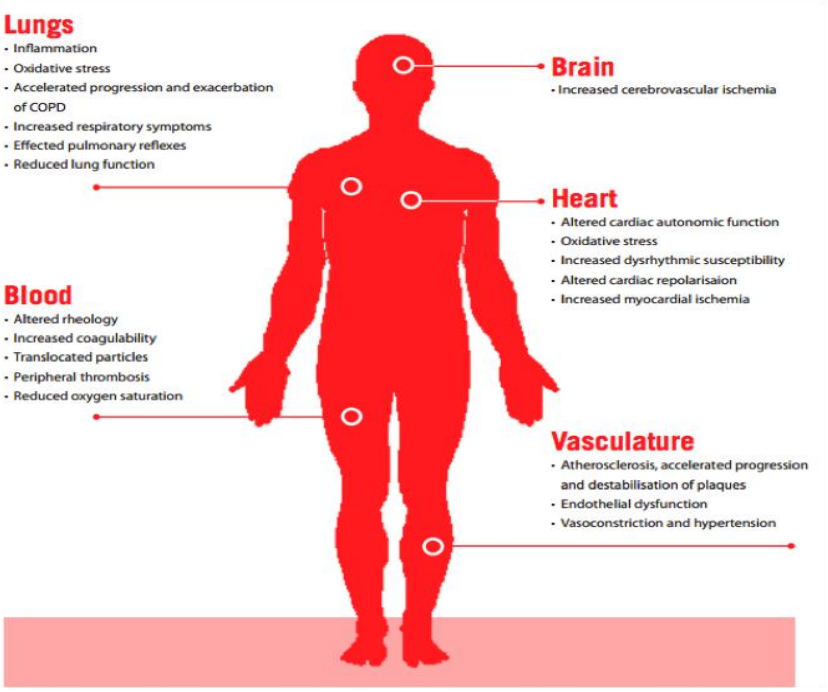
There have been numerous studies on the health impact of air pollution in India. While the figures of different studies seldom matches, one thing that is clear from all these studies is that air pollution in Delhi is at catastrophic levels. If that is the case, why does simple observation not show how pollution is impacting health? The answer lies in the fact that pollution has a delayed impact on many diseases, and worsens the impact of these diseases. No one is listed as having died of pollution, though the heart ailment, or the cancer, or the autoimmune disorder may have been exacerbated or even caused by the pollution. Pollution is not a direct cause of death, it impacts mortality and morbidity indirectly.

There are many studies that have been conducted both in India and abroad, and each study tries to ask a different question. But all studies show a large and negative potential impact on health and lives of Indians. How are these studies done when the link between pollution and ill-health is not direct? It is a two-step process. The first step involves medical micro-studies that have estimated the relationship between exposure to various pollutants with ill-health and even mortality. Most of these studies have been done in other countries, though a few have been done in India as well. The second step is to multiply the relationship with India's population as well as the severity of the pollution. Since the latter two – population and severity – are very high, the adverse impact of pollution is also found to be very high.

[7] In addition to soil related particles, main components of particulate matter (especially $PM_{2.5}$) includes sulphur dioxide ($SO_2$), nitrogen oxides (NOx), and volatile organic compounds (VOC). Moreover, particulate matter, irrespective of whether they are suspended in the atmosphere or are deposited on the surface, also adsorb or absorb acidic gases from other pollutants like $SO_2$ and $NO_2$, thereby serving as nucleation sites for these gases. See Environmental Effects of Particulate Matter. https://www.princeton.edu/step/conferences-reports/reports/ch5.pdf

[8] Facts on Pollutants: Particulate Matter (PM). http://www.unep.org/tnt-unep/toolkit/pollutants/facts.html

**FIGURE 8: HEALTH IMPACT OF PARTICULATE MATTER**

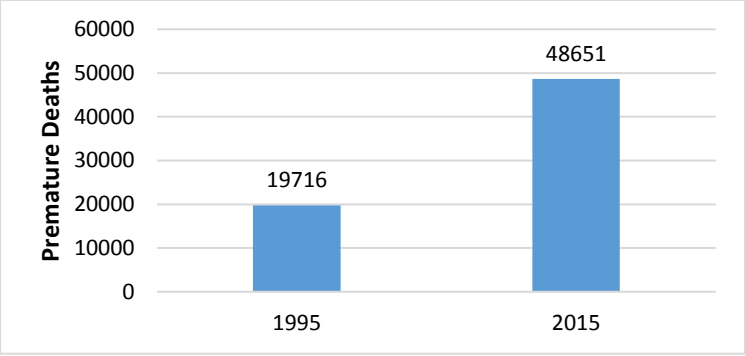



Source: https://nwodniakenst.wordpress.com/

For instance, according to a study by Indian Institute of Technology (IIT), Delhi, between 80,000 to 150,000 people die while more than 20 million people suffer from Asthma due to exposure to particulate matter. According to a study conducted by the World Bank around 1.4 million people die in India due to air pollution.[9] The same study also estimated the loss of welfare and found it to be equivalent to 6.4% of India's Gross Domestic Product (GDP) annually.

Recently researchers at the Indian Institute of Technology (IIT) Mumbai[10] have analysed the health and economic cost of SPM, and following analysis is based on the findings of this report in addition to the World Bank study.

**FIGURE 9A: Premature Deaths (Adult >=30 Years) due to PM10 in Delhi**



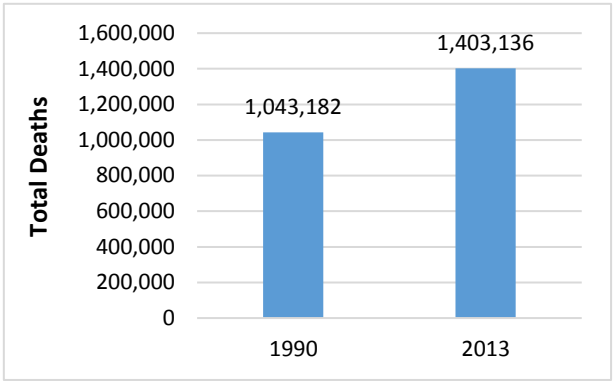

As the figure shows the number of premature deaths in Delhi has increased by about 146% during the period of 1995-2015. The premature deaths due to pollution should be a cause of concern for the country that is depending on its demographic dividend from a relatively higher younger population for its future growth.

Source: Maji et. al. (2016). Environmental Science and Pollution Research [11]

[9] "World Bank; Institute for Health Metrics and Evaluation. 2016. The Cost of Air Pollution: Strengthening the Economic Case for Action. World Bank, Washington, DC. World Bank. https://openknowledge.worldbank.org/handle/10986/25013 License: CC BY 3.0 IGO."

[10] "Disability-adjusted life years and economic cost assessment of the health effects related to PM2.5 and PM10 pollution in Mumbai, and Delhi, in India from 1991 to 2015," by Kamal Jyoti Maji, A. K. Dikshit, and Ashok Deshpande. Environmental Science and Pollution Research: December 2016

**FIGURE 1B: TOTAL DEATHS DUE TO POLLUTION IN INDIA**



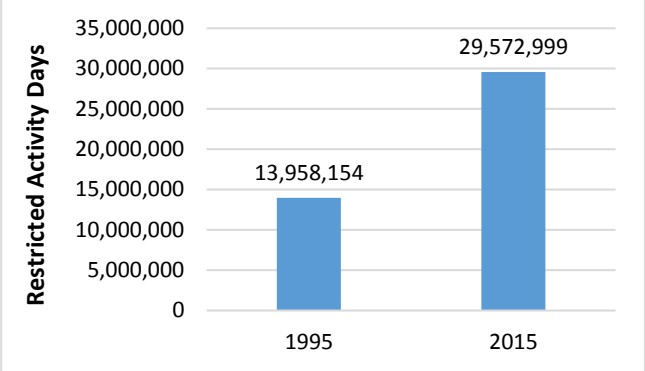

Source: World Bank[12]

However, this phenomenon of increased deaths due to air pollution is not limited only to Delhi. As the Figure 9B shows during the period of 1990-2013, the number of people dying due to air pollution has increased by around 3.5 lakhs in India.

.

Moreover, it is not just the deaths due to air pollution that should be the cause of concern, as chronic diseases and morbidity have also increased due to air pollution. The same study also shows that cases of chronic bronchitis in Delhi has increased by more than 100% during the period of 1995 to 2015 due to $PM_{10}$.

**FIGURE 10: RESTRICTED ACTIVITY DAYS (ADULTS>=20) DUE TO $PM_{10}$ IN DELHI**




Source: Maji et. al. (2016). Environmental Science and Pollution Research

For adults in Delhi, the rising level of $PM_{10}$ has resulted in substantial increase in the number of restricted activity days. The number of restricted activity days has increased by more than 100% during 1995-2015. One must keep in mind that by restricting the activity of people the PM has also resulted in increased economic cost due to forgone labour.

Despite many such studies, there are some who are not as unconvinced. The Former Union Minister for Environment Anil Madhav Dave for instance reportedly questioned international studies[13]. Indeed there may be methodological issues with some studies, but given India's large population and extreme pollution levels, no one can doubt the loss of healthy life and resultant hardship that a very large number of Indians are facing due to pollution.

[11] "Disability-adjusted life years and economic cost assessment of the health effects related to PM2.5 and PM10 pollution in Mumbai, and Delhi, in India from 1991 to 2015," by Kamal Jyoti Maji, A. K. Dikshit, and Ashok Deshpande. Environmental Science and Pollution Research: December 2016

[12] World Bank; Institute for Health Metrics and Evaluation. 2016. The Cost of Air Pollution: Strengthening the Economic Case for Action. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/25013 License: CC BY 3.0 IGO.

[13] "Government not to rely on global studies on pollution deaths." Livemint: February 22, 2017.

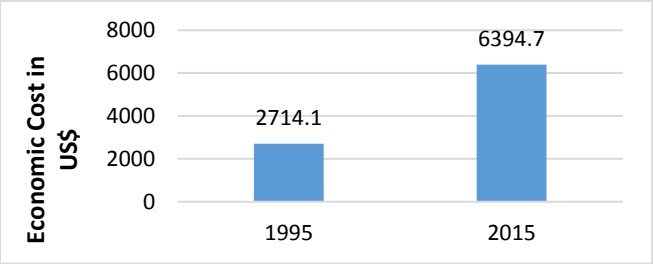
## ECONOMIC AND OTHER IMPACTS

Estimation of economic cost of air pollution in India has been done mainly with regard to the health cost of air pollution. This is one area where there has been little research. No doubt there are studies that analyses how the health cost of air pollution translates into economic cost in the form of labour-days lost and welfare loss as a share of gross domestic product (GDP). However, the economic cost in the form of impact of air pollution on infrastructure like bridges and roads, on machinery in the form of increased corrosion has not received the due importance.

Nevertheless, it is accepted even by United Nations Environment Programme (UNEP)[14] that particulate matter results in accelerated corrosion of metals, as well as damage to paints, sculptures, and soil-exposed surfaces on man-made structures. Soiling of painted surfaces and building materials is one of the most significant detrimental effect of particle matter. Soiling refers to degradation of the surface that can be corrected only through cleaning or washing and depending on the soiled surface, repainting.

However, higher frequency of cleaning is likely to reduce the life and usefulness of the material that has been soiled by the particulate matter. Such losses then translate into financial losses like reduction in service life of a material, decreased utility, substitution of a more expensive material, losses due to an inferior substitute, protection of susceptible materials, and additional required maintenance, including cleaning. The physical and chemical properties of the particulate matter determine the extent of damage caused by it.

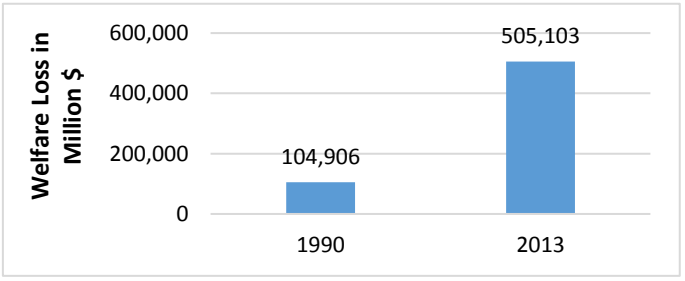
**FIGURE 2: TOTAL ECONOMIC COST OF $PM_{10}$ AT CONSTANT PRICE YEAR 2005 US$ IN DELHI (IN MILLIONS)**




The total economic cost of PM10 in Delhi has increased by more than 100% during the period of 1995 to 2015. For an emerging market economy like India, such a cost only due to pollution can aggravate barriers to further growth.

Source: Maji et. al. (2016). Environmental Science and Pollution Research

**FIGURE 3: TOTAL WELFARE LOSS (MILLION 2011 U.S. DOLLARS, PPP-ADJUSTED) INDIA**



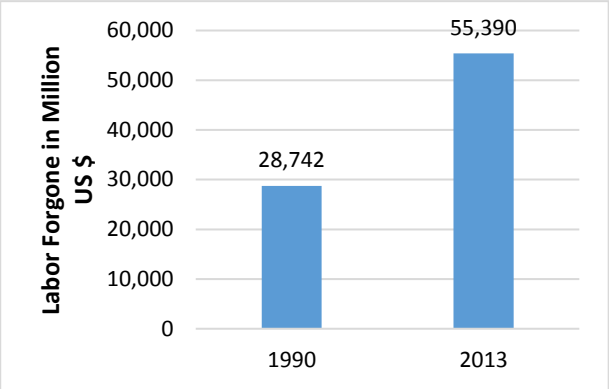

It is not only the economic cost but the welfare loss also that is increasing in India due to rising air pollution. In absolute terms, the total welfare loss has increased by more than 300% during the period of 1990 to 2013. Moreover, welfare loss due to air pollution as a share of gross domestic product has also increased from 6.8% in 1990 to 7.7% in 2013.

Source: World Bank

[14] United Nations Environment Programme (UNEP). http://www.unep.org/tnt-unep/toolkit/pollutants/facts.html

**FIGURE 4: TOTAL FORGONE LABOR OUTPUT (MILLION 2011 U.S. DOLLARS, PPP-ADJUSTED) IN INDIA**

Figure 13 shows that the economic cost in terms of labor output forgone of $PM_{10}$ has more than doubled during the period of 1995 to 2015. This is a cause of a real concern in a country where according to the World Bank largest number of people living below the international poverty line resides.[15]




Source: World Bank

# 4. CLIMATE AND POLLUTION

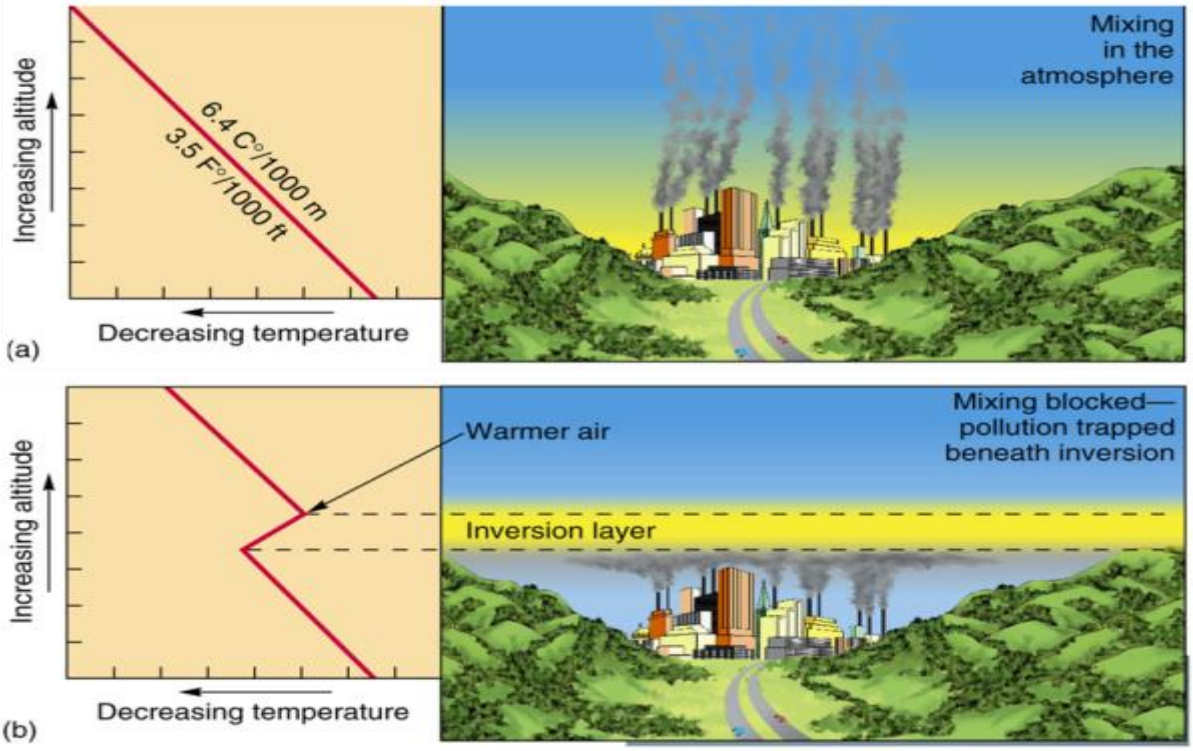
High levels of polluting substances are released in most cities in India and the world. But Delhi is among the most polluted also because climatic and weather conditions trap the air and therefore the pollutants. Typically, air moves both horizontally and vertically. Winds from various directions can move the polluted air horizontally to other less polluted locations and disperse them over a much larger area. Similarly, air movements also occur vertically and this releases polluted air into the upper atmosphere from where it disperses. But during some times of the year, both vertical and horizontal movement of the air gets curtailed and pollution levels rise dramatically. The vertical trap is because of temperature inversion and the lack of horizontal movement is due to lack of strong winds.

## TEMPERATURE INVERSION

Temperature Inversion is a phenomenon under which the air temperature increases with the altitude. Because of this cold air gets trapped below a layer of warm air. Since cold air settles at the bottom, the pollutants are unable to rise up. This mainly occurs in Delhi till the early morning period in the winter months. When heated air containing pollutants emerges from a smokestack or chimney or from any other source, it tends to rise up. However, in the winter months, it cools and rapidly attains the same temperature that exists in the surrounding air. Because of this it stops rising further and the pollutants in the heated air parcel remain trapped below.

[15] "India has highest number of people living below poverty line: World Bank." Business Today: October 3, 2016. http://www.businesstoday.in/current/economy-politics/india-has-highest-number-of-people-living-below-poverty-line-world-bank/story/238085.html

**FIGURE 5: TEMPERATURE INVERSION AND ITS COMPARISON WITH NORMAL CONDITION**




Source: https://is.mendelu.cz/eknihovna/opory/index.pl?cast=56580

There are two types of temperature inversion; low-level temperature inversion, under which temperature near the ground increases with elevation, and high-level temperature inversion under which a high-level layer of warm air exists over a layer of cooler air. The deadly smog which Delhi witnesses during the winter season is due to low-level temperature inversion.

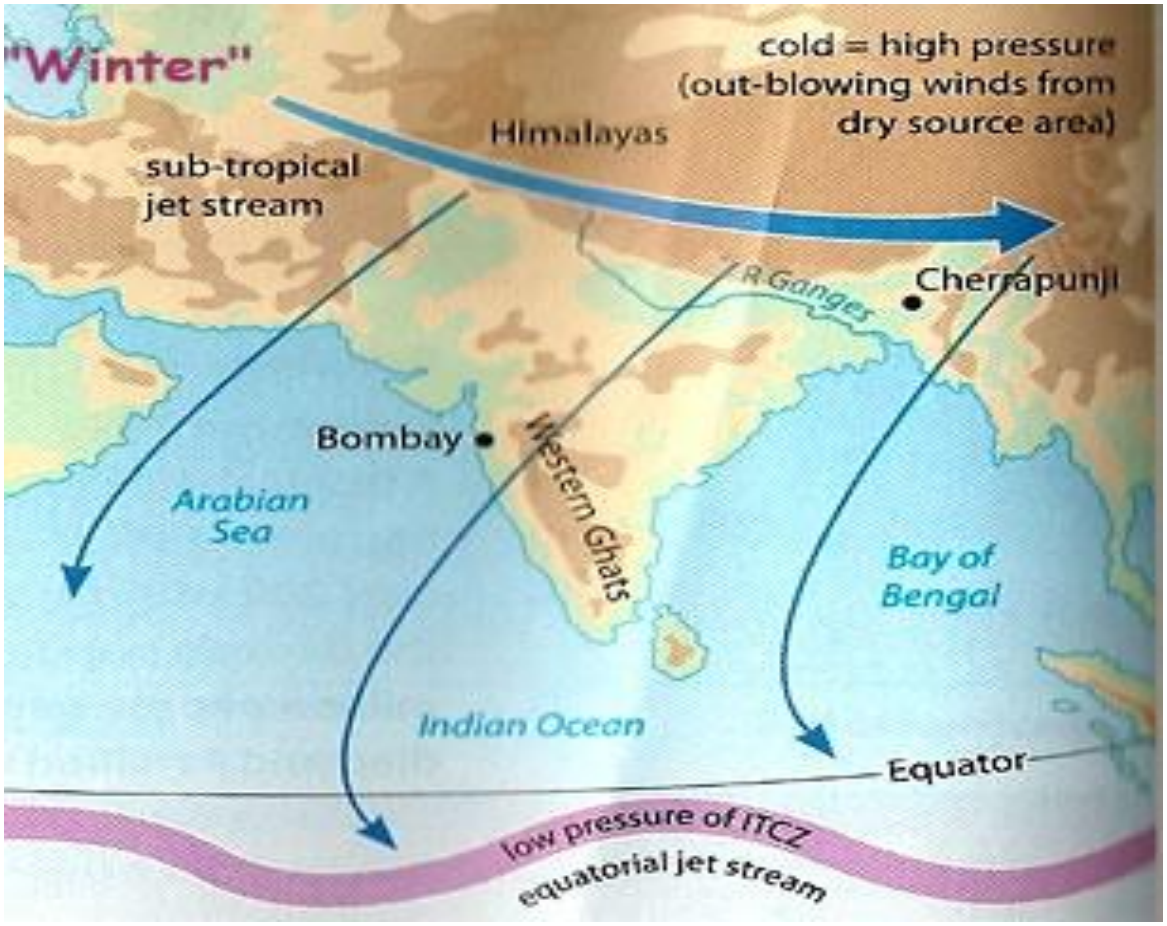
As the sun comes out, it is able to heat up the surface air and the air is able to rise reducing the concentration of pollutants. That is why typically early morning times tend to have the highest pollution levels; not so much because more pollutants are generated at that time, but because of inversion, they are concentrated in a smaller space at the surface.

## MONSOONAL WINDS AND SUB-TROPICAL JET STREAM

The existence of temperature inversion itself is not sufficient for a high concentration of pollutants over a city as one sees in Delhi especially during the winter season. It is the existence of light or calm winds and stable air that ensures the existence of pollution dome over a city. The reason why the air pollution condition in Delhi gets worse during the winter season is the fact that during the winter season the air above the city is much more stable as compared to the summer season due to lack of wind movement. If there is significant wind movement over the city then the air pollution will be dispersed or in other words will be carried downwind to form a pollution plume.

One of the main reasons for high-level of air pollution in Delhi during the winter season is the **retreating monsoon**, in which the pollution generated by crop burning in Punjab, Haryana and Pakistan Punjab reaches Delhi.

**FIGURE 6: RETREATING MONSOON AND SUB-TROPICAL WESTERLY JET STREAM OVER INDIA DURING THE WINTER SEASON**

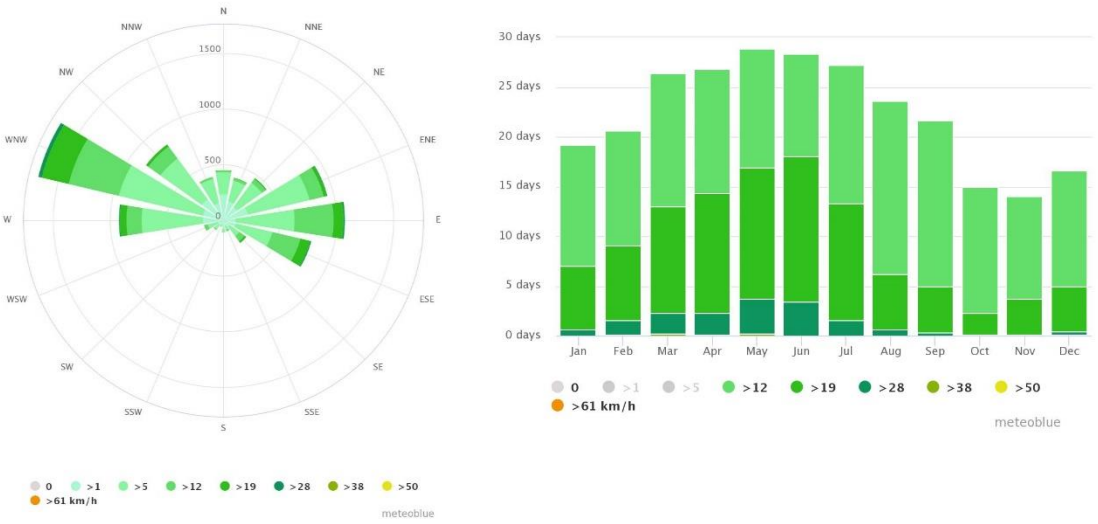



Source: geogonline.org.uk

The figure above shows how the winds from retreating monsoon bring pollution generated by crop burning and other sources to Delhi. In addition to the retreating monsoon, there is another atmospheric phenomenon called **sub-tropical westerly jet stream** that contributes to the increased level of pollution over Delhi during the winter season. Jet streams are a narrow band of very strong air currents that encircle the earth. Jet streams typically run from west to east and are found in the upper-troposphere of the earth.

During the summer season, the **sub-tropical westerly jet stream** flows along the northern edge of Himalayas in early June and in late summer (July-August) along the northern edge of the Tibetan Plateau. However, during the winter season, the jet stream shifts southwards and flows along the southern slopes of the Himalayas. So, along with the retreating monsoon, the jet streams also contribute in bringing the pollution generated in the neighbouring states of Delhi on the western side. Winter season is also that time of the year when there are lots of festivals like Diwali, Dussehra, and others. Burning of firecrackers especially on Diwali and some weeks prior to it also contributes to rising pollution in Delhi as pollution generated by the firecrackers in the neighbouring states reaches Delhi due to wind movement. Moreover, pollution from brick kilns, industries and power plants in the neighbouring states also contributes to deteriorating air quality in Delhi, especially during the winter season.

**FIGURE 16: DIRECTION OF WINDS RECEIVED BY DELHI DURING A YEAR**




Source: https://www.meteoblue.com/en/weather/forecast/modelclimate/new-delhi_india_1261481

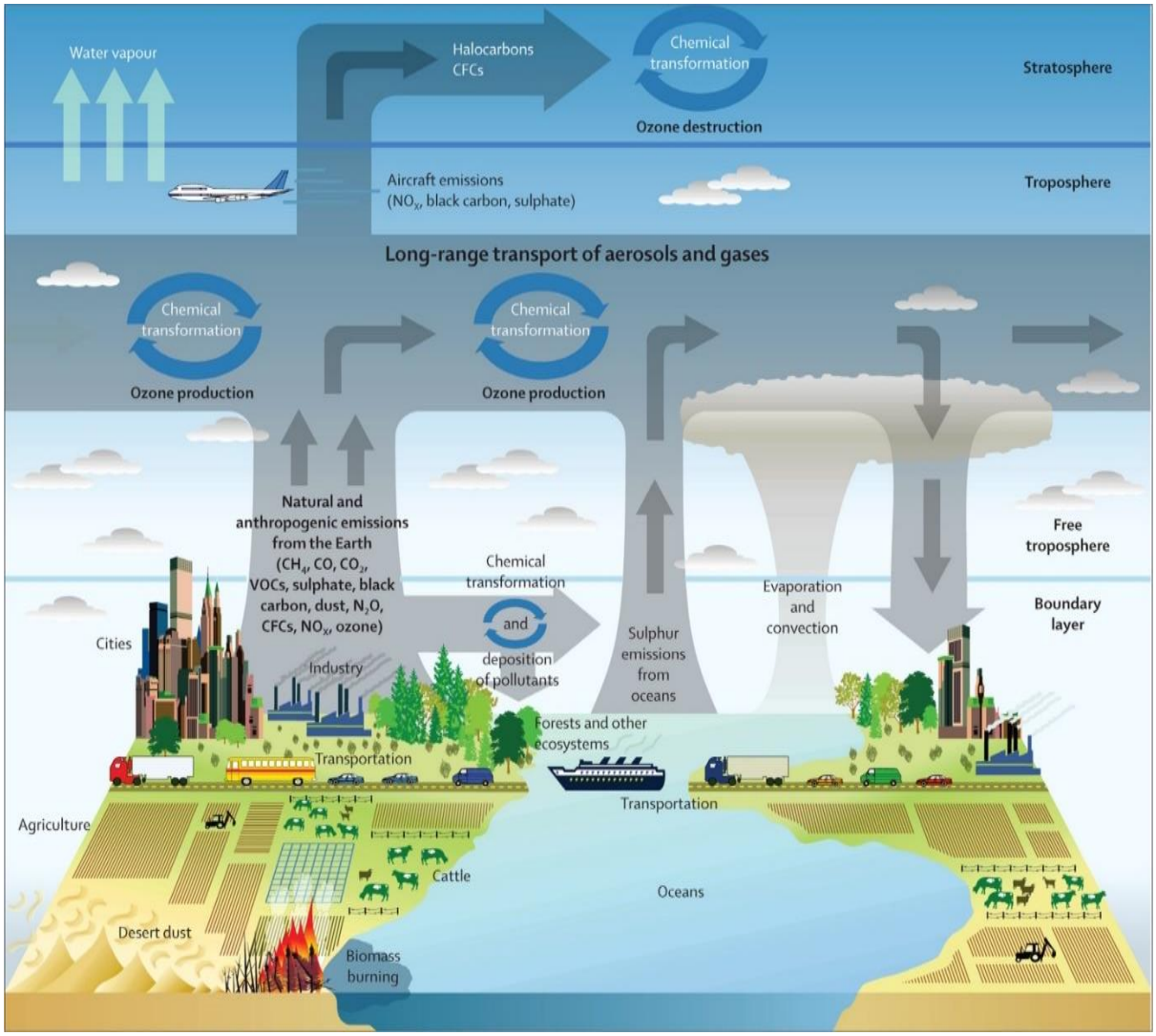
The above graphs show the direction and speed of winds that Delhi receive during a year from different directions through the year. The darker the colour the higher the wind speed, and the longer the bar the greater time do the winds blow for. As can be seen, the winds blow the most from the Western and North-Western direction in Delhi, and as is also apparent they are quite mild for most of the year, but especially so in the winter months. This is significant as the agricultural fields of Punjab and Haryana are to the West and North West of Delhi and crop burning also occurs during the time. The Desert winds from Rajasthan carrying fine sand are also from the west of Delhi.

In other words, winds tend to disperse pollution and dust from Neighbouring states into Delhi. This only goes to indicate that Haryana and Punjab's pollution is not only a problem of those two states but across North India.

# 5. SOURCES OF AIR POLLUTION

There are several sources of air pollutants including, road dust, biomass burning, coal-fired power plants, industries, municipal solid waste burning, and vehicles. The present section deals with each of the sources, provides information on how they are generated and how they can be controlled. However, before going into the analysis it should be kept in mind that any solution to the various sources of air pollutants should be based on cost-benefit analysis that takes into account the economic cost for an emerging economy like India.

**FIGURE 7: VARIOUS SOURCES OF AIR POLLUTION**




Source: The Lancet. Outdoor air pollution and asthma, Michael Guarnieri, John R Balmes, The Lancet, Volume 383, Issue 9928, Pages 1581-1592 (May 2014) , DOI: 10.1016/S0140-6736(14)60617-6

Researchers at the Indian Institute of Technology, Kanpur conducted a comprehensive air pollution study for Delhi. The study looked at pollution samples of Delhi air from various points in Delhi and at different points in time (IITK, 2016).[16] Based on this it estimated the pollution levels and chemical analysis enabled the identification of the probable sources of the particulate matter. This helps us allocate the degree of pollution that various sources are causing. The same study also attempted to estimate the emissions 'load' which attempts to look at the sources and how much they pollute. Due to a range of factors including weather conditions, data availability and ascribing chemical composition to source the figures from the two estimates are different. Nevertheless, both the methods used by the study show that the most important polluting sources are broadly similar and that as seasons and weather change, polluting sources also become less or more important. The policy will, therefore, need to address all major polluting sources.

The table below works with the data published therein. The table below indicates average values of Particulate Matter over Delhi. As mentioned, the researchers analysed both level and the

[16] Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi: Indian Institute of Technology, Kanpur, 2016

composition of the particulate matter. From the composition, they could work backward where the polluting particulate matter was originating from.

To enable a prioritization we also develop an indicative importance allocation to various sources which is reported in the last column. The specific value is not as important as the fact that all major polluting sources are important, and those that are less, have seen successful policy implementation in the past (eg. moving polluting units out of Delhi no doubt helped reduce the level of industrial pollution).

**TABLE 3: SOURCES OF PM2.5 (MICROGRAMS PER CUBIC METRE)**

| | *Micrograms per Cubic Metre* | | | *Percentage Distribution* | | | *Importance Allocation for Delhi* |
|---|---|---|---|---|---|---|---|
| **Sources** | **Summer** | **Winter** | **Average** | **Summer** | **Winter** | **Average** | |
| **Biomass Burning** | 34 | 84 | 59 | 12% | 26% | **20%** | 25 |
| **Vehicles** | 24 | 82 | 53 | 9% | 25% | **18%** | 23 |
| **Coal and Fly Ash** | 73 | 16 | 45 | 26% | 5% | **15%** | 19 |
| **Soil and Road Dust** | 72 | 14 | 43 | 26% | 4% | **14%** | 18 |
| **Solid Waste Burning** | 20 | 25 | 23 | 7% | 8% | **8%** | 10 |
| **Construction Material** | 8 | 5 | 7 | 3% | 2% | **2%** | 3 |
| **Industrial** | 3 | 3 | 3 | 1% | 1% | **1%** | 1 |
| **Secondary Particles** | 42 | 98 | 70 | 15% | 30% | **23%** | |
| **Total** | **276** | **327** | **302** | **100%** | **100%** | **100%** | |

Source: Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi: Indian Institute of Technology Kanpur, 2016, and author estimates. The importance allocation is simply the percentage distribution not including secondary particles.

Biomass burning includes all burning of biological items that include fields, household stoves burning *gobar*, straw, wood etc., other items such as garden waste burning etc. could also be included here, though they are likely to be a small proportion of the total. Of the total SPM content those originating from biomass burning range from 12 percent to 26 percent in the summer and winter respectively.

Vehicle exhaust comes up for much criticism and includes those from old and new, diesel and petrol, 4 wheeled, 2 wheeled, and heavy vehicles such as trucks and buses. The higher winds and temperature in the summer contributes to a lower value in the summer than the winter. However, on the aggregate, this leads to about 18 per cent of the total SPM particles.

Coal and fly-ash include the particles originating in coal plants, industry, and any source where the raw material being used is coal and whose emissions are released. Note that some of the coal emission is in the form of sulphur compounds which convert into particles, these are secondary particles and they are discussed later. In other words, coal burning leads to greater SPM than is reported under the same head.

Soil and road dust includes soil particles and those particles from the exhaust, rubber tyres, and road granules that get pushed up from the road. Road dust can be a very significant share of the total pollution, as other sources are controlled. Also, roads that are kutcha, broken or unprepared typically lead to greater pollution from road dust.

Solid waste burning typically includes plastics and other waste items from households and commercial sources. Pollution from solid waste is a result of waste being burnt in the open or in waste burning plants that do not adequately treat the emissions. The waste includes a multitude of substances including, but not limited to, plastics.

Construction is another large source of suspended particulate matter. Construction sites are characterized by the use of cement, lime, sand, drilling, stone cutting, digging, and use of many construction-related chemicals. The particles and gases escape into the atmosphere and the solutions are generally related to covering and spraying with a fine spray of water.

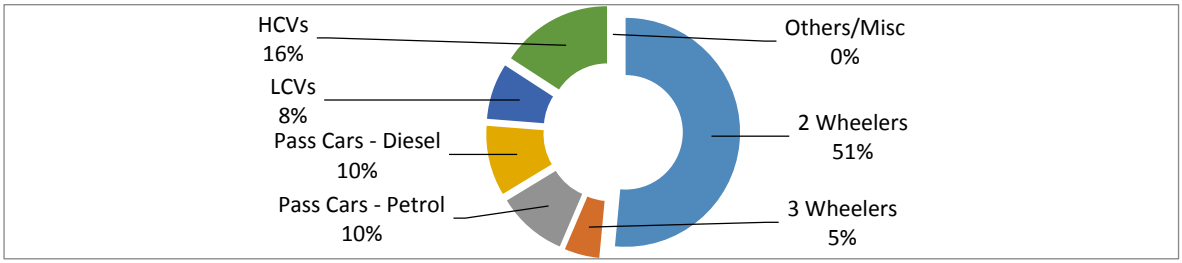
Secondary particles emerge from gases such as SOx originating from some of the above sources. Gases such as SOx convert into fine particles in the presence of moisture and this process is also impacted by ruling atmospheric conditions. Since atmospheric conditions cannot be changed as much, SPM pollution from secondary particles would be addressed if other sources of pollution are addressed.

The following sections go into each of these sources in greater detail.

## 5.1 VEHICULAR EMISSIONS

All vehicles pollute, and naturally, those that are most in number will pollute most in the aggregate as the graph below shows. Focusing on just a subset, whether commercial or SUVs or diesel or 4wheelers etc. while beneficial will not solve the problem. This would require a systemic view as the discussion below focuses on.

**FIGURE 8: SHARE OF DIFFERENT TYPES OF VEHICLES IN PM EMISSION IN DELHI**




Source: Author's calculations based on emission factor data from "Transport fuel quality for year 2005." Central Pollution Control Board, Ministry of Environment and Forests, Government of India. Later data was not available to the author, however the broad allocations would not be any different even a decade later.

The above graph shows that the two-wheelers account for over half of the total emission of particulate matter in Delhi. However, though the table gives an impression that two-wheelers are the biggest culprit, one must keep in mind that two-wheelers also account for close to two-thirds of the total vehicles in Delhi - see Table A3 in Appendix for how these calculations were done. Two wheelers perform a very important economic and social role and cannot simply be banned or taxed away.

At the same time while diesel passenger cars account for about 10% of the total particulate matter emission from vehicles there share in total vehicles in Delhi is 7%. Similarly, while the LCVs and Trucks & Buses account for 8% and 16% respectively of total particulate matter emissions, their share in total vehicles is 2.3% and 1.1% respectively only. Moreover, the PM emission factor in gm/km for two-wheelers of 0.05 is similar to the PM emission factor for diesel passenger cars.

The Ministry of Road Transport and Highways is responsible for framing the emission standards for the vehicles. However, implementation and enforcement are left to individual municipalities. Moreover, the functions of testing emission standards of new vehicles, conformity of production

(COP) testing and inspection and maintenance programs is carried out by other national agencies including, Automotive Research Association of India (ARAI), International Centre for Automotive Technology (ICAT), Vehicle Research and Development Establishment, Ahmednagar (VRDE), Indian Institute of Petroleum, Dehradun (IIP), Central Farm Machinery Testing and Training Institute, Budhni (CFMTTI) and Central Institute of Road Transport, Pune (CIRT). The Motor Vehicles department under the state government in Delhi is responsible for automobile registrations. Despite a multitude of agencies, the powers are well defined.

The Central Government accelerated India's path towards cleaner vehicles when it mandated the introduction of Bharat Stage 6 norms, similar to Euro 6 standards, to apply on all new vehicles by 2020 March. This effectively brought Indian standards at par and in some cases superior to what exists globally. The table below shows that the norms will ensure a reduction in PM to one fifth if the current levels if the norms are followed properly.

**TABLE 4: SULPHUR CONTENT REQUIREMENT UNDER DIFFERENT BHARAT STAGE EMISSION STANDARDS (IN PPM)**

| Fuel Standard | Diesel | Gasoline | Year |
|---|---|---|---|
| **Bharat Stage III** | 350 | 150 | 2005 |
| **Bharat Stage IV** | 50 | 50 | 2010 |
| **Bharat Stage VI** | 10 | 10 | 2020 |

Source: http://transportpolicy.net/index.php?title=India:_Fuels:_Diesel_and_Gasoline
ppm = parts per million

However, given the rapid increase in the number of vehicles in the country, successive reductions in emissions will be rapidly overshadowed by the increase in the number of vehicles. According to an estimate, number of on-road vehicles in India would reach the figure of 315 million by 2030[17]. The Central Government has also recently announced that from 2030 all new vehicles sold in the country would be electric vehicles. Expectedly it has generated significant opposition from the industry as technologies will need to be brought in, production processes overhauled, new training given to convert production lines, all within barely a decade. Nevertheless, vehicular pollution will stop increasing from 2030 onwards and will fall steadily after that.

Then what is the problem if electric vehicles will be introduced? A decade is a long time, past decisions have been known to have been delayed by years and sometimes even decades. Electric vehicles are currently costly and create a different kind of highly toxic pollution via their batteries. Moreover, road dust is a major pollutant and will not go away even with electric vehicles. Meanwhile, lakhs are dying every year in and around Delhi only due to vehicular pollution.

Given this two sets of actions are required: (1) improvement in current emission norms and incentives and its implementation and (2) acceleration of the new low sulphur regime.

*Irregularly applied norms*: During the initial evaluation and of the vehicles in the country low sulphur fuel is normally used. However, the commercially available fuel in the country is different having higher sulphur content which is leading to poor actual emissions estimates. India has elevated levels of sulphur in diesel ranging up to 350 ppm as BS4 was not introduced everywhere, this is important because emission control technologies depend on the content of sulphur in the fuel.

*Taxation regime*: Taxation on vehicles in India is based on the size of engine unlike countries in Europe and even in Asian countries like Japan where taxes are based on vehicle emission standards. This is one of the reasons why the engine size of freight vehicles in India is smaller compared to other countries. However, smaller engines don't mean that the vehicle is also efficient. Therefore,

[17] Position Paper: October 2016. The Energy and Resources Institute (TERI)

taxation regime should be changed from size based to pollution based. This will incentivise mass producers of 4 and 2 wheelers to develop and introduce low emission engines.

*Fuzzy and soft standards*: Government of India has set emission standards of different pollutants according to the types of vehicles including, two wheelers, diesel passenger cars, and petrol passenger cars. In the case of passenger cars, two wheelers and heavy-duty vehicles Bharat Stage IV emission standards are in force. Complete emission standards have been given in Table A1 in Appendix. However, the actual emission by the different type of vehicles has been considerably higher than the standards set by the government. For instance, while according to the Bharat Stage IV standards the emission of particulate matter by diesel passenger car is 0.025 gm/km, the actual emission has been 0.05 gm/km. Similarly, actual particulate matter emission by buses is around 0.24 gm/km, while the standard set by the government is of around 0.03. For more information refer to Table A2 in Appendix.

*Poor certification*: Recently the Environment Protection (Prevent and Control) Authority (EPCA) in its investigation found that only 23% of vehicles in Delhi NCR come for regular PUC tests. This is in addition to the problems of improper testing and lack of qualified PUC operators.[18] In fact, in the adjoining areas of Delhi, the business of pollution checks on push carts has been thriving with the active involvement of local authorities.[19] So, even where there exists PUC certificate it cannot be said with surety that the vehicle meets the emission standards.

As is apparent from above, central, state and even municipal governments ability to implement needs to be strengthened if pollution from vehicles is to be reduced in the near future. Experience has repeatedly shown that announcements need to be followed by good implementation.

## SOLUTIONS

The solutions to vehicular traffic can be divided into those that will pay off immediately, and those that would pay off over the longer term.

*Direct and Immediate Impact*

Supplying low sulphur diesel and petrol at the same price or cheaper than high sulphur fuel will help even the older vehicles emit less sulphur. There is no need to wait till March 2020 for this purpose. Selling only low sulphur fuel in Delhi NCR would be an even more powerful pollution fighting measure. Since cleaner fuel that can be used in older vehicles is possible, it will have an immediate impact on emissions. This could be done in different ways, and all of this is in the domain of the Central Government and would require no change in laws:

a. Converting all the public sector refineries to low suplhur immediately and not wait for the year 2020 for BSVI standards to kick in. It takes a few months to convert a refinery which will anyway have to convert to meet the 2020 deadline.
b. Low Sulphur fuel producing capacity already exists in India and is exported from private refineries.
c. Importing or buying low sulphur petrol and diesel for High pollution areas such as Delhi.

A robust and efficient inspection and maintenance (I&M) system is necessary for reducing pollution from vehicle exhaust. In the absence of such an I&M system, even the introduction of new better-quality fuel and norms will not be able to have the desired impact on the reduction of air pollution.

[18] "India's vehicular pollution tests are a sham," by Anumita Roychowdhury. The Hindustan Times: August 11, 2017.
[19] "On Rajasthan-Haryana border, car pollution checks on push carts," by Sowmiya Ashok. The Indian Express: May 7, 2017.

Various state governments including that of Delhi would need to have the ability to ensure that corruption and laxity do not affect this government responsibility.

*Longer term impact*

There is a need for increased government intervention to make the switch to cleaner fuel viable. The initiative taken by the government of India to encourage the use of LNG in locomotives and barges in the country through more LNG stations of Petronet LNG on the highways is a welcome step. As a result of this effort, truck and bus manufacturers like Tata Motors and Ashok Leyland are now developing LNG versions of their vehicles.[20] A more sanguine taxation regime would incentivise these efforts more.

Taxes on vehicles should be based on emission standards rather than engine size. There should be lower goods and services tax (GST) on BSVI compliant vehicles and electric vehicles. Moreover, the government also need to provide financial assistance for research and development (R&D) activities for 2 wheeled BSVI compliant engines.

Promoting and providing world class public transport system. In Delhi buses and Metro are the two important public transport systems. These need to be expanded in capacity by multiples, but merely their expansion would not help if interconnectivity is not addressed or if footpaths are not walkable.

Promoting the use and purchase of electric and hybrid vehicles. Electric vehicles can reduce pollution, but currently, they are too expensive to be viable on a mass scale in India. At the same time, while the world focuses on 4 wheeled electric vehicles, India could use its expertise in two-wheeler technology to develop strength in electric two-wheelers. Given their light weight, these may be more economically feasible than BS6 compliant 2 wheelers.

Whatever be the specific technology, the taxation, and regulatory regime play a very important role in giving a direction to the automobile sector. The government especially the finance ministry needs to bring out a long-term direction for various stakeholder, given the fact that the government has already committed to the 2030 EV only deadline.

Finally, there will be many different solutions in the long run, and they will all revolve around making public transport more accessible and better and making private transport more expensive and difficult. This is what has been seen globally and will need to be brought into India as well.

## 5.2 SOIL AND ROAD DUST

According to a study by the IIT Kanpur, dust from roads, digging and agriculture accounts for the highest SPM source in Delhi, contributing 38% of $PM_{2.5}$ and 56% of $PM_{10}$ in Delhi. The air concentrations are a bit lower than these figures but that does not take away from the importance of dust as a pollutant.

There can be several sources of dust including, tyre and brake wear, particles of asphalt and other materials that are used for constructing roads, dust from the un-paved roads, dug soil for road or public works construction, etc. Among all the causes of road dust, the presence of un-surfaced roads is the major one. It is surprising that despite being the capital of India more than one-fourth of the roads in Delhi are un-surfaced.

[20] "India's National Highway traffic trucking into gas age with LNG," by Sanjay Dutta. The Economic Times: August 16, 2017.

**TABLE 5: DIFFERENT TYPES OF ROADS IN DELHI, HARYANA AND PUNJAB IN 2014-15 (IN KMS)**

| State | Surfaced | Non-Surfaced | Total | %age Surfaced |
|---|---|---|---|---|
| Delhi | 23,381 | 8,686 | 32,067 | 72.91 |
| Haryana | 41,892 | 4,395 | 46,287 | 90.50 |
| Punjab | 93,820 | 11,548 | 105,368 | 89.04 |

Source: Basic Road Statistics 2014-15, Ministry of Road, Transport and Highways

The presence of un-surfaced roads also contributes to the existence of other causes of road dust such as the particles of tyres which are further impacted due to the high wear and tear of tyres on inferior quality roads. Moreover, the above table only gives information about the un-surfaced roads. The existence of inferior quality surfaced roads is something that has not received due importance in the public debate on road dust. Surfacing inferior quality roads, removing potholes and maintaining them properly will go a long way in reducing this component of pollution. [21]

In addition to the un-surfaced roads, the other major source of dust in Delhi is the agricultural land in Delhi and neighbouring states of Punjab, Haryana, Uttar Pradesh and Rajasthan. The period between the harvesting of crops and planting of new crops is when the dust from the agricultural fields rise the most as the soil is dry.

Dust is not simply from roads or agriculture lands. A substantial part of the city requires digging to maintain or create new infrastructure. However poor contractual practices lead to a situation where many contractors, dig and wait for payment from the government before re-commencing further work. This dug mud can be seen in many parts of the city, as it can be seen all over the country. Moving traffic and winds lead to the suspension of this dust, some of which can stay airborne for many hours.

### SOLUTIONS

Dust that also includes road dust requires a change in practices and some cleaning. However, it should be recognized that as particulate matter pollution falls, lesser road dust will be suspended in the air, hence other actions that reduce vehicular or biomass pollution will also help in reduction of this element to some extent. However, some proactive actions will help reduce this component.

1. Surface additional approximately 8,000 km of roads in Delhi. This will go a long way in reducing road dust. The same should be done in neighboring states of Punjab, Haryana, Uttar Pradesh and Rajasthan. However, Delhi's State Government and its Public Works Department and the local government have the primary responsibility in this.
2. Improved maintenance of all roads in Delhi, especially those in commercial areas and low-income areas, or those away from the public eye. Good quality roads are essential for reducing road dust. Additionally, no amount of vacuuming or washing will have any significant impact if the road is broken or has potholes. Therefore, the State and municipal governments need to resurface or repair all roads where bitumen is lose or there are potholes. This is important as half the roads of Delhi belong to this category conservatively.
3. Vacuum cleaning of roads can reduce road dust to some extent, however, it is extremely expensive to undertake over all of Delhi's 32,000 kilometres of roads. Vacuuming or washing a few hundred kilometres would not help, as road dust is being suspended all over Delhi's vast network of roads. However, ensuring that road sides are free of dust can help significantly.

[21] Government apathy towards the provision of surfaced roads in Delhi NCR has forced many people to take matter in their own hands. For instance, in Gurugram residents were forced to pool money to repair the road. "Residents forego Diwali gifts to repair roads," Shubhra Pant. The Times of India: September 30, 2017.

4. Dust from outside Delhi carried by winds can be trapped by a Green Belt towards the north and western sides. A green belt would have to be broad enough but need not be only forests, orchards and commercial forestry can also help.

## 5.3. POWER PLANTS

Emission from coal-fired power plants in India is one of the major sources of particulate matter emissions in the country in general and in Delhi in specific. Moreover, due to wind movements the particulate matter emitted by coal-fired power plants in the vicinity of Delhi also enters the city, further aggravating the problem. Wind movements can cause the pollution generated by coal-fired power plants to reach as far as 400 Km from the source which means that coal power plants that distant away can pollute Delhi.

Coal-fired power plants are the largest consumer of coal in India. The dependency between coal and power plants in India is mutual since the power sector accounted for 80% of total coal dispatches during the year 2013-14 in addition to supporting a five-fold increase in coal use in electricity generation over the past few decades. [22]

### COAL FIRED POWER PLANTS IN AND AROUND DELHI

There are 27 coal-fired power plants in Delhi, Haryana, Punjab, Rajasthan and Uttar Pradesh. Most of the units in these power plants are small i.e., 210 MW or lower (in fact out of the total 104 units 46 units have capacity lower than 210 MW).[23] This has been deliberately done to take advantage of the emission standards fixed by the government of India. Prior to the year 2015, following were the particulate matter emission standards for the coal-fired power plants in the country:

**TABLE 6: PARTICULATE MATTER EMISSION STANDARDS FOR COAL-FIRED POWER PLANTS BEFORE DECEMBER 2015**

| Power Generation Capacity (Megawatt) | Particulate Matter Emission |
|---|---|
| Less than 210 MW | 350 mg/Nm$^3$ |
| 210 MW or more | 150 mg/Nm$^3$ |

Source: http://www.cpcb.nic.in/divisionsofheadoffice/pci2/ThermalpowerPlants.pdf

The above table shows how smaller units were legally allowed to generate more than twice the particulate matter compared to larger units. The Government of India issued new standards in the year 2015 which are comparatively tough. However, while the new standards don't make a distinction with regard to the size of the individual units, it does make a distinction on the basis of the year of installation. Most of the coal-fired power plants especially with smaller and more polluting units are older than 2003 and therefore these standards do not apply to them. Moreover, such power plants have been given an extension to meet the standards, but most are lagging behind. For more information on the new standards for coal-fired power plants refer to Table A4 in Appendix.

### CHARACTERISTICS OF THE COAL AND ITS ECOSYSTEM

**Low quality Coal:** Indian coal is characterized by low quality. Moreover, only minuscule proportion of total coal in India has coking properties which can help convert it into low sulphur high carbon coking coal. Table A5 in Appendix offers complete information on the coal classification used in India and their definitions.

[22] Coal Directory of India 2013-14. Ministry of Coal, Government of India
[23] http://cbrienvis.nic.in/Thermal%20Power%20Station%20in%20India%202016.pdf

**TABLE 7: PRODUCTION OF RAW COAL IN INDIA IN 2014-15 (MILLION TONNES)**

| Sector | Coking | Non-Coking | Total |
|---|---|---|---|
| | | | |
| *Public* | 51.0 | 516.0 | 567.0 |
| *Private* | 6.4 | 39.0 | 45.4 |
| *All India* | 57.5 | 555.0 | 612.4 |

Source: Provisional Coal Statistics 2014-15. Ministry of Coal, Government of India

As the above table shows only 9% of the total raw coal produced during 2014-15 in the country was of coking grade and also that the bulk of the coal in India is produced in the public sector, Coal India Limited is a large public-sector coal producer.

The levels of silica in the Indian thermal coal is very high that results in ash by-product which further reduces the efficiency of the power plants as the ash by-product is highly corrosive. Consequently, *coals* that are found in India also have a very high ash content in the range of 30% to 50% and very low sulphur. The moisture content in Indian coal is variable with coal produced during the monsoon season having a comparatively higher moisture content.[24] As a result, the export potential of Indian coal is low. Moreover, improved quality coal is imported by India and mixed with the domestic coal to raise the quality and combustion efficiency of coal-fired power plants in the country.

**Poor environmental and efficiency practices:** There is another way to improve the quality of Indian coal, i.e., washing it before its utilization. This not only improves the efficiency of the coal but also helps in reducing emission levels from coal combustion, though it does cause water pollution if not disposed properly. However, despite the awareness and despite the government's stated intentions there is not only very limited coal washing capacity in the country, even the utilization of the existing capacity is low. This can be gauged from the fact that during the same year washed coal accounted for a minuscule 4% (22.1 million tonnes) of the total coal despatches in the country. This raises serious question on the target of thermal coal washing capacity of 175 million tonnes as set by the government in the Twelfth Five Year Plan (FYP) from 2012 to 2017.

Bulk of the coal that is being used by coal-fired power plants in and around Delhi is raw coal with negligible washed coal being used. For instance, during the period of 2013-14 about 5.3 million tonnes of coal was used in Delhi by power utilities, out of which only 0.985 million tonnes of coal was washed. Similarly, in the case of Punjab 100% coal that was used by power utilities was raw un-washed coal. The share of washed coal in the total coal used by power utilities during 2013-14 in Delhi, Rajasthan, Punjab, Haryana, Uttar Pradesh and All India is given in Table A6 in Appendix.

The government is also known to not have followed its own rules and standards. The Ministry of Environment had notified new stricter rules and regulations for thermal power plants in the year 2015. According to the report of Central Pollution Control Board (CPCB) out of the 16 power plants that have come up in India since January 2017, none meets the emission norms set by the environment ministry in 2015.[25]

**High Emissions:** The public-sector companies and power plants have been working to reduce costs at any cost, and this also shows up in the emission levels. The high dependence of the power sector on coal-fired power plants has resulted in power plants becoming major polluters in the country.

[24] "Coal in India: 2015." Office of the Chief Economist: Department of Industry and Science, Government of Australia. https://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/Coal-in-India.pdf

[25] "India allows 16 new thermal power plants that violate stricter air pollution standards to come up," by Kumar Sambhav Shrivastava. Scroll.in: October 2, 2017.

Investments in coal washing, gasification, emission reduction scrubbing, carbon capturing are all possible but are rarely done. Consequently, Indian coal thermal plants are considered to be extremely inefficient and highly polluting globally. The following table shows the amount of emission of different pollutants by coal-fired power plants in and around Delhi.

**TABLE 8: EMISSION OF DIFFERENT POLLUTANTS FROM COAL FIRED POWER PLANTS IN AND AROUND DELHI DURING 2014 (IN KILOTONS)**

| State | $PM_{2.5}$ | $SO_2$ | NOx | CO | $CO_2$ |
|---|---|---|---|---|---|
| Delhi | 12 | 17 | 23 | 13 | 9 |
| Punjab | 11 | 95 | 117 | 71 | 47 |
| Haryana | 15 | 124 | 165 | 92 | 61 |
| Rajasthan | 62 | 148 | 167 | 111 | 73 |
| Uttar Pradesh | 64 | 317 | 423 | 237 | 156 |
| | | | | | |
| **Total** | **164** | **701** | **895** | **524** | **346** |

Source: "Coal Kills: Health Impacts of Air Pollution from India's Coal Power Expansion." Conservation Action Trust (India) and Urban Emissions (India). $PM_{2.5}$ = Particulate Matter 2.5, $SO_2$ = Sulphur Dioxide, NOx = Nitrogen Oxide, CO = Carbon Monoxide, $CO_2$ = Carbon Dioxide

The Ministry of Environment had set December 2017 as the deadline by which toxic emissions from power plants need to be capped. However, the gravity of the problem is reflected in the response from Central Electricity Authority (CEA) to the environment ministry. According to the CEA, the country will at least take 6 years before it can achieve the target.[26] In an era where large units can be put up in less than three years, this response only reflects the orientation of India's electricity ecosystem.

**Increasing Dependence on Coal for Electricity:** The demand for coal in India has been increasing over the years leading to increase in the import of thermal coal by India. This is happening despite the fact that India is the third largest producer of thermal coal in the world. Import of thermal coal increased from 12 million tonnes in 2004 to 142 million tonnes in 2013.[27] These numbers will only go up as more and more large coal plants come up.

Till the recent past, India used to meet the demand for coal through its domestic coal production. However, the import of coal started to increase from 2009 onwards. In fact, the tremendous increase in the import of thermal coal highlights the fact that despite being major polluters coal-fired power plants continue to remain important for the government. While till 2005 India was 90 per cent self-sufficient in coal supply, the self-sufficiency declined to 75% by 2013 due to the tremendous increase in coal imports. The magnitude of increase in thermal coal import by India can be gauged from the fact that in the year 2013 India overtook Japan as the second largest importer of thermal coal despite the increase in thermal coal imports by Japan to help its electricity sector after the Fukushima nuclear disaster of 2011.

**Profitability and Employment:** Coal and power sectors in India are under government control. The Coal India Ltd. and National Thermal Power Corporation (NTPC) Ltd. are both government monopolies in the coal and power sectors respectively.

[26] "India will take at least 6 years to cap toxic emissions from power plants," by Rajesh Kumar Singh. The Economic Times: July 21, 2017.

[27] "Coal in India: 2015." Office of the Chief Economist: Department of Industry and Science, Government of Australia. https://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/Coal-in-India.pdf

**TABLE 9: PROFIT AFTER TAX OF NTPC AND COAL INDIA DURING THE YEAR 2016-17 (IN CRORES)**

| Company | Profit |
|---|---|
| National Thermal Power Corporation (NTPC) Ltd. | 9,385.00 |
| Coal India Ltd. | 9,265.98 |

Source: Annual Report 2016-17. National Thermal Power Corporation (NTPC) Ltd. http://www.ntpc.co.in/annual-reports/7452/download-complete-annual-report-2016-17 Annual Report and Accounts 2016-17. Coal India Ltd. https://www.coalindia.in/DesktopModules/DocumentList/documents/Coal_India_Annual_Report_2016-17_shareholder_version_12.8.2017.pdf

It is not just the profits or the low costs of coal; it is also the employment issue that motivates the government not to act despite knowing that coal is a dirty fuel with severe health and environmental hazards. As of March 31, 2016, the total manpower of Coal India and its subsidiaries stands at 322,404.[28] On the other hand in NTPC the total number of employees as of January 1, 2016, is 23,342.[29] In a country that is struggling to provide adequate employment, it becomes difficult for the government to act against companies that are major employment providers.

## SOLUTIONS

Coal can be made cleaner, but coal can never be clean, the range of measures that the government can take to control the pollution generated by the coal based power plants in the country are discussed below.

*Macro Solutions*

There is a whole range of actions that are required depending upon the allocations that can be made, opportunity costs of various options, and priorities being considered by the government. A broad checklist is given

1. Stop new coal power plants from coming up.
2. Greater investment in other less polluting sources eg. Natural Gas
3. Greater investment in renewable sources: eg. Wind, solar, biomass
4. Increase efficiency of coal plants: investment in boilers etc.
5. Reducing dirtiness of Indian coal: coal washing, gasification, etc.
6. Improving pollution capturing capacity of coal plants: capturing fly ash
7. Capturing and carbon generated: carbon sequestering technologies

Each of these is feasible and has some costs, but each will benefit given our objective to differentiate between long term and immediate impact the following space categorizes the possibilities.

**Immediate**

a. Monitoring data instruments that report *real time data publicly* of each coal power plant, especially emission related data
b. Ensure all operational coal power plants have 24x7 working electrostatic precipitators and filters to remove fly ash from emissions.
c. Increase percentage of coal washed and used in the winter season in all coal power plants
d. Technologies such as flue gas desulfurization higher smokestacks etc., that can be instituted fast
e. Best practices instituted to manage fly ash ponds to prevent blowing of fly ash particles

[28] Annual Report and Accounts 2015-16. Coal India Ltd.

[29] 40th Annual Report 2015-16. National Thermal Power Corporation (NTPC) Ltd.

**Long term**

i. Move coal based power plants from the north and north-west India where wind conditions are not sanguine, replace by other sources including natural gas which needs to be priced lower than coal.
ii. Tax coal and other high pollution fuels for the environmental and health damage caused.
iii. Mandate and closely monitor NTPC to progressively reduce dependence on coal based thermal power
iv. Announce India's long-term strategy for reduction of coal based power (ideally announce complete withdrawal from coal based power over a decade). The costs of this can be met from taxing polluting activities.

There are many other such actions that are possible, but in the long-run if India wants to continue using coal it will have to put up such plants in locations where winds are higher throughout the year. But it is apparent that coal power dependence will harm India in more ways than one.

## 5.4. BIOMASS BURNING

Biomass burning includes the burning of any biological matter – straw in fields, gobar and straw in traditional stoves, etc. Of all the possibilities the IITK study found that crop burning and biomass burning in stoves are responsible for the bulk of the biomass based particulate matter in Delhi's air. These are discussed separately below.

### CROP RESIDUE OR STRAW BURNING

More and more straw is being burnt in northern and western India and this has to do with three forces impacting the crop economy of Punjab and also some parts of West Panjab in Pakistan, UP, Himachal, and Haryana. First, more rice-straw is being generated than before. Second, straw is becoming more difficult to collect than before. And three, straw is becoming less useful than before. The farmer, therefore, is left with the best option of burning his field.

Since the mid-sixties, the area under kharif rice has risen to 3 million hectares from 0.3, and productivity from a ton per hectare to about six tons per hectare. Apart from the availability of HYV seeds, the skewed support prices and procurement practices, abetted by cheap or free electricity, and many other distortions, many farmers are now incentivized to grow a crop that agro-conditions are not inherently suitable for. For short-term gains, they perhaps unknowingly harm their own land, the air over it, and subsurface water.

One way of reducing Delhi's haze is to correct the distortions introduced over time by the Central and State governments. Lower procurement and price distortions will naturally lead farmers to shift to other crops and therefore to reduced paddy cultivation. This will automatically require some farmers to draw less water, and with the reduced burning improve sustainability parameters of Punjab's fertile lands. It will also reduce the haze over Delhi. However, some farmers will continue to produce paddy as they have done from times immemorial.

**TABLE 10: RICE PRODUCTION IN PUNJAB OVER THE YEARS (IN 000 TONNES)**

| State | 1990-91 | 2010-11 | 2014-15 (R) | | 2015-16 (P) | 2016-17 (E) |
|---|---|---|---|---|---|---|
| Punjab | 6,506 | 10,819 | 11,111 | | 11,803 | 12,638 |

Source: Economic Survey of Punjab 2016-17
R = Revised, P = Provisional, E = Estimate

Next, consider straw collection. Changing technology has changed agriculture practices. Where people would manually harvest paddy and take to a common point for threshing, harvester-thresher combines now throw out straw all over the field. While it was easier to bale the straw collected at a single point traditionally, now it needs to be gathered from all over the field. Labour is also now relatively expensive for this to be done manually. Baling machines do exist but they require significant capital, diesel, and other operational costs. Straw being bulky also has significant transport and storage costs. So not only is there more straw, it is also increasingly expensive to collect and use.

The stubble cannot be removed as easily from the ground as straw, and though it is only about 20 percent of what is left over, it is significant nevertheless. A zero-till machine costs about Rs 1.5 lakh and enables the farmer to retain the stubble while he plants the next crop (Rabi – typically wheat). This reduces the seed, fertilizer, water and even tilling costs for the farmer. A profitable service of renting out the use of zero-till machines is feasible and will eliminate the stubble burning problem but will take some time to spread.

But straw is another matter. Traditionally straw was used as cattle-feed, roofing, mixed with dung for plastering, bedding for cattle, etc. When ploughed back into the soil it retains moisture and has some advantages. However, it is low in proteins and so is not the best cattle-feed, thatched roofs and dung plastered walls are no longer in fashion, and many farmers don't keep cattle anymore in these days of 'modern' agriculture. Moreover, the need to quickly ready the land in these days of two to three and sometimes even four crops annually, does not allow the farmer to leave the straw on the land long enough before he can plough it back into the soil. In sum, rural Punjab does not need straw anymore, definitely not in the quantum that is being generated.

Fortunately, straw can be used for power, paper, fiber-board and also as cattle-feed. But unfortunately, in each of these cases there is a better substitute available, and so straw use is not significant enough in India. Paper can be made out of rice-straw, however, it is typically used for low strength paper like napkins. Rice-straw can also be used for power generation however it has high silica and ash content, which has its own complications. Straw-board or fiber-board can be used in construction, however, rice-straw has a wax and silica covering which makes it more difficult to use than, say wood chips. For cattle-feed as well, its hardness and low protein content make it an inferior feed. For each of these uses, there are appropriate solutions that help circumvent the problem, but there is a certain cost associated with each. And therefore currently techno-economic conditions don't allow widespread use of rice-straw commensurate with how much is produced.

The best solution therefore is to find a substitute that can be grown in the erstwhile fertile lands of Punjab that are rapidly degrading thanks to inappropriate rice production and the overdrawing of sub-surface water. Rice on such a massive scale is a new entrant into Punjab and its time that it exited. This can be achieved, if MSP and other incentives are changed to account for greater returns in less polluting crops. And the Food Corporation of India follows a more distributed strategy of paddy purchase from other states. Also, while the concept of MSP was initially devised for all crops, it has been used largely with regard to wheat and rice. There is a need to use MSP in such a way that other crops, like pulses that produces lesser residue are incentivised.

The second solution is to ensure that straw/stubble is not burnt. Of the many options available, zero till machines that don't require destruction of the stubble before replanting are good options around with which rural employment can also be generated. These machines need to be subsidized and provided to rural entrepreneurs and panchayats on a large enough scale.

The third class of solutions are related to the straw collection, and many solutions exist where straw can be used for other purposes. Adding straw or its briquettes to coal power production is a feasible option provided fly ash reduction equipment is working in these plants – straw from rice being high in silica will lead to greater fly ash in these plants. But if the straw can be used and a market created for its use such as in power plants, there will be an increased incentive for the farmer to collect it. And less to burn it. However, there is a possible negative impact as well, in case higher incomes due to straw lead to overproduction of paddy, straw burning may well increase.

The fourth class of solutions are centered around monitoring and enforcement. Satellite or air imagery can help pinpoint farms where fields are being burnt. A 24x7 monitoring mechanism can help identify and enforce the laws if they are directly connected with local police stations. If such enforcement is not possible, such laws and court mandates banning straw burning also should be eliminated.

**TABLE 11A: $PM_{2.5}$ EMISSION GENERATED BY CROP BURNING**

| States | Gross Cropped Area (000 hectare) | $PM_{2.5}$ from Crop Residue Burning (tonnes per year)* |
|---|---|---|
| Delhi | 33.4 | 70 |
| Haryana | 6471.0 | 35,800 |
| Punjab | 7900.0 | 83,150 |
| Uttar Pradesh | 26100.0 | 86,760 |
| Rajasthan | 24235.3 | 10,820 |

Source: "Emission of Air Pollutants from Crop Residue Burning in India," by Niveta Jain, Arti Bhatia, and Himanshu Pathak: Centre for Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute. Economic Survey of Haryana 2016-17. Department of Land Records, Govt. of Haryana. Economic Survey of Punjab 2016-17. Government of Punjab. Economic Survey of Delhi 2016-17. Directorate of Economics and Statistics, Government of NCT of Delhi. *During the year 2008-09. Converted from 1000 tons per year. http://updes.up.nic.in/up%20in%20figures-%202016.pdf and http://plan.rajasthan.gov.in/content/dam/planning-portal/Directorate%20of%20Economics%20and%20Statistics/Publication/Regular%20Publications/Agricultural%20statistics/Agricultural%20statistics-2014-15.pdf

## DOMESTIC FUEL BURNING

Substantial number of households use polluting fuels like coal, wood, and crop residue for various purposes including, cooking and heating in India. While in Delhi close to 90% of the households use LPG/PNG or electricity as a fuel, the proportion declines to less than half (44%) in Haryana while in Punjab barely half of the households (54%) use clean fuel like LPG/PNG or electricity. The data are admittedly not current (later data being unavailable), however, it is apparent that substantial numbers continue to use biomass and coal for energy especially in rural India and slums in urban India.

**TABLE 11B: $PM_{2.5}$ EMISSION GENERATED BY HOUSEHOLDS IN DIFFERENT STATE IN AND AROUND DELHI**

| States | Number of HHs not using LPG/PNG/Electricity | $PM_{2.5}$ from Household Energy Consumption (tonnes per year) |
|---|---|---|
| Delhi | 325,674 | 15,380 |
| Haryana | 2,631,090 | 71,160 |
| Punjab | 2,440,709 | 91,800 |
| Uttar Pradesh | 26,597,732 | 620,480 |
| Rajasthan | 9,676,755 | 230,040 |

Source: http://www.urbanemissions.info/india-emissions-inventory/emissions-in-india-household-cooking-heating/
Census 2011. Registrar General of India, Government of India

As the above table shows, a large amount of $PM_{2.5}$ is generated by the household energy consumption in Delhi and its neighbouring states. Given the wind movement, it is apparent that the major portion of the $PM_{2.5}$ generated in the neighbouring states of Delhi and to its northwest reaches Delhi and from there across to northern plains and contributes toward the deteriorating air quality across North India.

Admittedly recent government initiatives like the expansion of LPG connection under Ujwala Yojana and the launch of Pradhan Mantri Urja Ganga (PMUG) would have significantly increased the number of households using less polluting options than those reported above. However, the figures just bring to focus that if LPG is not accessed adequately, household biomass stoves together can pollute as much as all of the crop burning in Punjab.

The only policy initiative is to ensure 100 percent coverage of households under LPG. Greater access points, even to non-poor households, and regular supply of LPG in north-west India would achieve this. One step could be to mandate each District Commissioner to oversee complete coverage of LPG or electric stoves for cooking.

## 5.5 MUNICIPAL SOLID WASTE (MSW) BURNING

Municipal solid waste (MSW) is generated through several types of consumption and production activities. The amount of MSW generated in Delhi is around 12,000 tonnes per day.[30] MSW consists of organic components, fine earth, paper, plastic, glass, and metals. However, Delhi does not segregate its waste and effectively it becomes one large mix of disparate items. The problem of MSW is therefore aggravated by the absence of any comprehensive system for the collection of garbage from homes. Though garbage is collected fairy regularly from higher income and middle-class neighbourhoods, half of Delhi's households live in low-income areas where garbage collection is fairly weak, in commercial areas and markets as well it is apparent that garbage collection is not being given due attention. Consequently, a substantial number throw their garbage on the road or public spaces or open plots.[31]

Although collection and transportation activities constitute the major part of the total budget for the MSW management, it is very inefficient. Not all the MSW is transported to the landfills, and some of it is simply burned by the garbage collectors and sweepers to make their work easier. According to Singh et al. [32] out of the total MSW generated in Delhi about 87% is collected out of which only 28% is treated. The governance failure in Delhi is apparent given that despite a very large number of cleaners on roll in urban local bodies, garbage is not collected regularly. In June 2017, for instance, the High Court of Delhi observed that despite the East Delhi Municipal Corporation (EDMC) having 50,000 *safai karamcharis,* South Delhi Municipal Corporation (SDMC) having a staff of 23,000 and the North municipal body having 26,000 workers the city is always littered with garbage and sewage.[33] Poor organizational abilities are combined with poor practices which further worsen conditions. Much of MSW, for instance, is transported on open trucks that litter the roads of Delhi during the process of transportation.

[30] "Municipal Solid Waste Management in Delhi – the Capital of India," by Bhavik Gupta and Shakti Kumar Arora. April 2016: International Journal of Innovative Research in Science, Engineering and Technology.
[31] "78% of Delhi dumps garbage on the road, says report." The Hindustan Times: September 22, 2017.
[32] "Greenhouse Gas Emissions from Landfills: A Case of NCT of Delhi, India," by S. K. Singh, Anunay G, Rohit G, Shivangi G and Vipul V. March 2016: Journal of Climatology and Weather Forecasting.
[33] "Enough workforce, yet Delhi remains smothered in garbage, says High Court," by Manish Raj. The Hindustan Times: June 29, 2017.

In addition to the above, lack of MSW disposal facilities at the landfills means the government officials themselves sometimes burn the waste thereby adding to the already polluted environment of Delhi. On September 1, 2017, landfill at Ghazipur collapsed killing two people. Anger among the general public was further increased by the news that the landfill site where every day 3000 tonnes of garbage was being dumped should have been closed 15 years back when it reached its limit. This one tragedy highlights the crisis of the disposal of municipal solid waste in Delhi NCR.

The waste-to-energy plants that were supposed to solve the problem of garbage disposal have been largely operating at sub-optimal levels where they do exist in the country, and also in Delhi. The reason for such a phenomenon is the absence of an efficient system for segregating waste at source. Since the waste-to-energy plants require the absence of wet waste.

Delhi has three 3 landfill sites including, Bhalswa, Ghazipur and Okhla. While Bhalswa landfill site was commissioned in the year 1994, Ghazipur was commissioned in 1984 and Okhla in 1996. However, none of the three meets the criteria mentioned in the schedule 3 of the MSW Rules which came into effect in 2000. Moreover, the DPCC has not granted authorization to all three landfill sites. Despite this, the municipal bodies in Delhi continue to use these landfills. They argue that they are forced to use these landfills as they don't have alternative land for the disposal of MSW.[34]

The net result is that a large proportion of garbage is burnt openly and ends up polluting Delhi on an ongoing basis – the burning of plastics, chemicals, and suchlike releases many highly toxic chemicals. The problem of garbage, however, is a solvable one, as most countries have done.

## Solutions

Municipalities across India are collapsing, being run by managers not concerned with the local population, and being under-resourced both financially and in terms of human capital. Municipal reform may seem like a strange solution to pollution, but much of pollution is because local governments are unable to punish those who break environment laws, and not delivering appropriate services where they are meant to.

Waste Segregation: Focusing on waste segregation at source is important for any long term solution. For this, the optimum option is to promote and support the already existing informal system of *kudewala* at the locality level.

Promoting composting at the locality level so that the wet kitchen garbage can be utilized properly is another corollary to efficient segregation.

A large part of the dry garbage has value and is currently bought and sold by the informal sector. Encouraging the development of this market will enable private entrepreneurs to collect and reuse or recycle this waste. This can be done through a system of low taxes and incentives.

Empowering and rewarding communities and also making them liable, is perhaps the most powerful mechanism dealing with pollution from garbage burning. Communities are aware of what is occurring in their neighbourhood and also have the ability to stop illegal activity from occurring. However, they are currently neither empowered, nor rewarded nor made liable. A combination of the three would be highly potent combination in eliminating garbage burning from neighbourhoods.

Assigning responsibility to office-bearers: Complete ban on burning of waste and garbage in the open needs to be properly enforced. Making local police and municipal officers responsible in case burning is detected will help enforce the laws properly and also check corruption. A centralized cell

[34] http://delhi.gov.in/wps/wcm/connect/7701e3004c7b7a5a84aa94b05f83afbf/Status+of+landfill+Site-1.pdf?MOD=AJPERES&lmod=942394189

for receiving complaints, monitoring investigation, and disciplining those breaking the law can work provided there is adequate NGO and community participation.

## 5.6. INDUSTRIAL AND CONSTRUCTION ACTIVITIES

In March 2016, the Ministry of Environment, Forest, and Climate Change[35] issued a new categorisation of industries in the country based on pollution load. In this section unit level data of the Fourth All India Census of the Micro, Small and Medium (MSME) conducted by the Ministry of Micro, Small and Medium Enterprises has been used. The classification of industries covered under the survey has been done using the categorization issued by the Ministry of Environment, Forest and Climate Change.

**TABLE 12: DISTRIBUTION OF MSME IN DELHI, HARYANA AND PUNJAB**

| Industry Type | Delhi | Punjab | Haryana |
|---|---|---|---|
| *Registered* | | | |
| Non-Polluting | 2009 | 26047 | 15082 |
| Polluting | 1745 | 22063 | 18068 |
| Total (A) | 3754 | 48110 | 33150 |
| *Un-Registered* | | | |
| Non-Polluting | 147016 | 665148 | 353860 |
| Polluting | 27597 | 300462 | 132704 |
| Total (B) | 174613 | 965610 | 486564 |
| **Grand Total (A+B)** | **178367** | **1013720** | **519714** |

Source: Unit Level Data of Fourth All India Census of MSME 2006-07. Ministry of Micro, Small and Medium Enterprises

The level of inaction by some agencies can be gauged from one instance, but there are many such. In October 2017, the Supreme Court of India had to step in and enforce the recommendation of the Environment Pollution Control and Prevention Authority (EPCPA) of banning the use of furnace oil and PET coke in industry in Delhi NCR.[36]

According to the report of the Delhi Pollution Control Committee (DPCC)[37] as of 2016, there are around 25,000 industries in approved industrial areas of Delhi. Major pollution sources include boilers, furnaces, ready-mix concrete plants, brick kilns, metal polishing, grinding and pulverising units, electroplating DG sets, etc. Construction that uses cement

Pollution occurs due to processes related to combustion, chemical processes, cutting and grinding. In most cases, there are no perfect solutions to eliminate polluting substances from being released. However, in all cases, innovative technologies and different substitutes are available that can substantially reduce it.

The critical part in this segment has to do with incentivising businesses, enforcing rules and regulations, and monitoring. Given conditions in India, stringent rules many times lead to greater corruption and lesser enforcement. Merely mandating better processes, practices or inputs, therefore, will rarely work. This is especially so, given the large number of units in Delhi and surrounding areas but limited resources of government departments mandated with overseeing them. And as mentioned poor public monitoring makes enforcement even more difficult.

[35] http://pib.nic.in/newsite/PrintRelease.aspx?relid=137373

[36] "Supreme Court bans use of furnace oil & pet coke in industry in NCR from November 1," by Amit Anand Choudhary. The Times of India: October 24, 2017.

[37] "Measures for Air Pollution Control from Industrial Activities," by D. K. Singh. Delhi Pollution Control Committee

Construction activities include dust generated during demolition, transporting of the debris, dust generated during digging for pillars, basement, etc, open storage of construction materials like sand, cement etc., transportation of construction materials, during construction, grinding and stone cutting at the construction site. In almost all the cases the solution to construction related pollution lies in either covering adequately or spraying with water to keep particulate matter from getting suspended. However, the key issue is that these are expensive and require adequate monitoring, enforcement, and punishment.

Technologies such as infrared spectroscopy do enable such monitoring but have not been tried on a mass scale yet. Three points need to be made related to all such economic activities:

- Given Indian conditions, it is very difficult to ensure monitoring and enforcement without corruption creeping in. When corruption creeps in, even the honest entrepreneur has to conform to demands of functionaries.
- The more stringent the laws, and the less the control over government functionaries, the more is corruption.
- Corruption is best addressed when the polluter's information is made publicly available, and government functionaries are made liable for the pollution they are overseeing. The liability can be of many different types. Currently, the liability is only on the entrepreneur which provides undue power to the functionaries to misuse.
- New technologies have made monitoring far easier and enable real time and public availability at low cost. Without monitoring, and public availability of emission information, disciplining Delhi's large informal and small-scale sector will be difficult.

Where many small businesses, whether in industry or construction are concerned, the solution lies in making public real-time information on emissions. Satellite or airborne balloons can carry various types of pollutant measuring instruments that need to report pollution emission levels on a real-time basis. Along with that the government's enforcement mechanism needs to be open to information passed on by third parties for further investigations – these third parties could include RWAs, or NGOs, or Universities. This responsiveness will encourage many from the community to monitor closely what is occurring in their vicinity.

An even higher level of engagement would be to mandate and make liable RWAs, market associations, and industry associations for pollution in their areas. This would dramatically change the incentive to monitor and enforce. However, the current structure of such agencies (predominantly non-empowered societies) would need to be changed.

BOX: CASE OF BRICK KILNS

India is the second largest brick producer in the world after China employing around 10 million people. However, the 74% of the brick production in the country is done in Bull's Trench Kilns while 21% bricks are manufactured through clamps (which produces the maximum emission). This is in contrast with the trend that exists across the world including China where the more environment friendly Tunnel and Hoffman kilns are used for producing bricks.

Bricks are of two types; fired clay bricks (usually red in colour) and non-fired bricks. While fired clay bricks are made from clay and then fired in kilns, non-fired bricks are made using flyash, sand, lime, gypsum, cement, etc. Close to three-fourth of the bricks manufactured in India are fired clay bricks.

Government of Delhi had closed down all the brick kilns in Delhi during the second half of the 1990s. However, such units are still functional in Haryana, Uttar Pradesh, and Punjab, and after the ban in Delhi, the number of units increased in these neighbouring states as producers shifted their units. Moreover, despite the deteriorating air quality in Delhi NCR governments in neighbouring states instead of closing or regulating brick kilns has encouraged them. In fact, during the year 2016, the state pollution control board of Haryana gave permission for the opening of 46 new brick kilns in Gurgaon alone.[38] The standard type of kiln that is used in these states is Fixed Chimney Bull's Trench Kiln (FCBTK), which though is comparatively cheaper to establish, is highly polluting.

**TABLE BOX: CHARACTERISTICS OF DIFFERENT TYPES OF BRICK KILNS**

| Characteristics | Clamps | Down-Draught Kiln (DDK) | Fixed Chimney Bull's Trench Kiln (FCBTK) | Zigzag (natural) | Zigzag (induced fan) | Vertical Shaft Brick Kiln (VSBK) | Hybrid Hoffman Kiln (HHK) | Tunnel |
|---|---|---|---|---|---|---|---|---|
| *PM generated (gm/kg fired brick)* | NA | 1.56 | 1.18 | 0.22 | 0.24 | 0.15 | 0.29 | 0.24 |
| *%age of good quality product* | 50 | 85 | 60 | 85 | 80 | 90 | 90 | 95 |
| *Cost* (in rupees)* | NA | 13,34,400-20,01,600 | 33,36,000-53,37,600 | 33,36,000-53,37,600 | 33,36,000-53,37,600 | 40,03,200-53,37,600 | 4,00,32,000-4,33,68,000 | 6,67,20,000 |
| *Cost in US dollars* | NA | 20,000-30,000 | 50,000-80,000 | 50,000-80,000 | 50,000-80,000 | 60,000-80,000 | 600,000-650,000 | 1,000,000 |

Source: National Brick Mission: A Scoping Paper. Centre for Science and Environment: http://cseindia.org/userfiles/national-brick-mission.pdf. *Converted from costs in US dollar

As the above table shows productivity wise neither Clamps nor FCBTK are efficient, moreover they produce high level of suspended particulate matter (SPM) compared to other types of brick kilns. FCBTK are signified by high level of emissions and thick smoke which is evident from the fact that these brick kilns generate around 1375 mg/$Nm^3$ of SPM (for coal) and around 400 mg/$Nm^3$ of SPM (for biomass) during the fuel charging period.[39]

The main reason behind the pollution that is generated by brick kilns is the use of very dirty and cheap coal as fuel. The brick manufacturing industry is the third largest industrial user of coal in India after thermal power plants and iron and steel industry. The main reason for such a high use of coal is not only its cheap availability but also the fact that for producing good quality bricks clay needs to be burned at a temperature of around 1,000°C. Moreover, brick manufacturers also use high ash low quality coal, biomass, agricultural waste, heavy fuel oil, wood and tyres as fuels for brick manufacturing. Total annual coal/biomass consumption by brick kilns in India is around 35 to 40 million tonne of coal equivalent as per the study mentioned above.

Pollution from brick kilns can be reduced through substituting the source – natural gas or electricity are possible solutions, to substituting to less polluting technology, to better cleaning equipment. Given that brick kiln is a highly competitive sector, it would be impossible for the industry to spontaneously change its practices. Government intervention – a combination of easy credit and improved returns by using new technologies would enable a smooth changeover. For instance, a

[38] "Amid severe pollution concerns, brick kiln permits double in Gurgaon," by Shilpy Arora. The Times of India: June 10, 2017.

[39] "Brick Kilns in India," by J. S. Kamyotra. Central Pollution Control Board. http://www.cseindia.org/docs/aad2015/11.03.2015%20Brick%20Presentation.pdf

guaranteed 24x7 and 100% supply of electricity would reduce the need for other sources and make efficient brick kilns like Vertical Shaft Brick Kiln (VSBK) more operationally feasible.

Also see "Brick Kilns in India," by J. S. Kamyotra. Central Pollution Control Board.
http://www.cseindia.org/docs/aad2015/11.03.2015%20Brick%20Presentation.pdf

# 6. CONCLUSION - PRINCIPLES OF POLLUTION ABATEMENT

All countries suffer from pollution and many have suffered worst than currently being experienced in urban India and more specifically northern Indian cities. But many countries have been able to address them, so can it be done in urban India, and more specifically Delhi.

Specific issues and some solutions have been discussed throughout this report. There would be many others, we take this space to lay out a broad framework for understanding pollution reduction measures. The objective is to better understand the various forces that get released and collateral damage that some anti-pollution measures can cause. This understanding, it is hoped, would enable better design of pollution reduction measures that India will take.

Pollution reduction can occur mostly due to (a) substitution of an input, technology or a product or (b) eliminating its use altogether, or (c) cleaning up the air. At an extreme, if humanity completely stopped using petroleum fuels, pollution would be dramatically reduced, but it would also cause a massive economic loss, by way of reduced incomes and a large reduction of jobs and consequently negative economic growth. Elimination of a particular activity is among the most harmful to economic well-being and is only done in extreme circumstances.

The recent court ordered stopping of firecracker sales, for instance, led to substantial losses of income and jobs in the firecracker sector, and many businesses who had taken loans to carry those firecracker inventories would have been immensely hurt as well. But their sale was banned given the damage to health they can cause and there were no other feasible alternatives. Cleaning up pollution is typically a very expensive method of addressing the problem, the scales being so high it can be only done in a limited space – vacuuming of roads, air filters in the rooms, air masks, etc. are some cleaning solutions that have an impact though limited.

In other words, there are three types of solutions – Substitute, Stop or Clean, where substitution is possible and the incentives are in sync with the objective, is the most preferred method.

**FIGURE 19: SOME EXAMPLES OF DIFFERENT WAYS OF REDUCING POLLUTION**

| | **Source** | **Technology** | **Lifestyle** |
|---|---|---|---|
| **Substitute** | * Substitute paddy for some other crop<br><br>* Changing from high to low sulphur fuel for vehicles | * Converting vehicles to BS6 Standards from 2020<br><br>* Use LPG stove instead of *gobar* stove (source is also substituted) | * Households shift to segregating garbage<br><br>* Individual substitute to using public transport |
| **Clean** | * Washing coal before it is burnt in power plant<br><br>* Removing more sulphur from petrol and diesel in refineries | * Installing scrubbing machines to clean emissions<br><br>* Catalytic converter in automobile exhausts | * Face Masks and air filters used by households<br><br>* Government uses vacuum cleaners to remove road dust |

| | | | |
|---|---|---|---|
| **Stop** | * Banning of stone crushing<br><br>* Stopping of construction at high pollution times | * Court bans use of diesel generators for a limited time<br><br>* Government announces no sale of petro-cars after 2030 | * Stopping the use of fireworks in Delhi NCR<br><br>* Households stop using plastic bags |

*Lifestyle changes* are the most difficult to institute, as was recently seen in the court ordered ban on firecrackers. But they don't always fail. Lifestyle changes have been known to occur spontaneously through social movements and religion backed mandates – the *swadeshi* movement during pre-independence is one such example. However, few democratic governments find it feasible to *mandate* and implement lifestyle changes. It is always better to *incentivise* lifestyle changes. And incentives always work best when there is a viable substitute available. For example, it would be far easier to achieve success in stopping individuals from bursting firecrackers if an alternative of community fireworks was present.

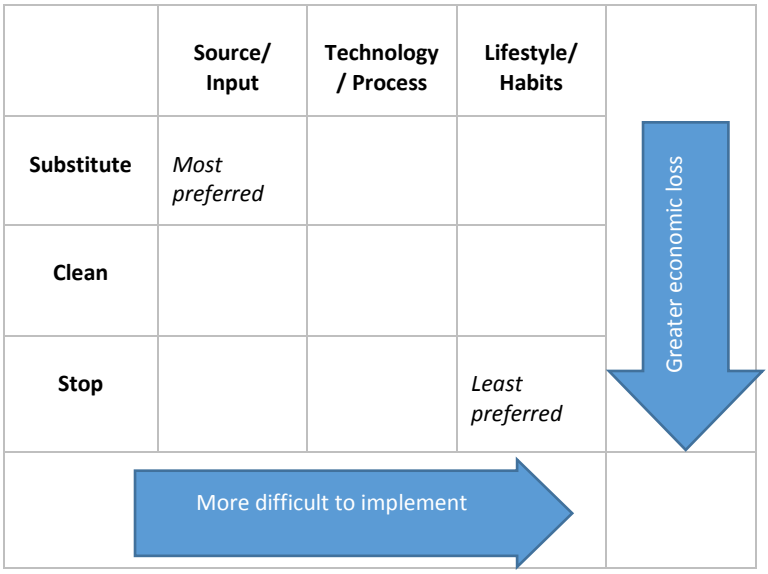
*Technology changes* take some time to implement and require substantial investment by upstream and/or downstream players. Changing the automobile engine standards towards BSVI norms, for instance, will require automakers to coordinate with parts suppliers and even auto repair mechanics. This takes time and is expensive and so there is significant opposition when the government mandates such changes. But here as well, the right incentives will help facilitate the shift and even reduce the opposition. Technology changes are easier to implement than lifestyle changes because of one key advantage – instead of hundreds of millions of consumers, only a few hundred or thousand producers must change their practices.

*Source changes* tend to be easiest to implement because the ability of the government to regulate or regulate a few tends to be the highest. Take for instance vehicular pollution – government refineries and oil companies produce and sell fuel with high sulphur content which results in, among other things, high particulate matter and sulphur compounds in auto emissions. Technology for sulphur reduction has been available for many decades, and governments in the past could have mandated (these are highly profitable government owned companies) to produce and sell, low sulphur fuel. The costs of this, however, would then be borne by the government which could charge a bit extra from consumers.

A different kind of source change has to do with the rice straw and stubble that is burnt in Punjab and Haryana and parts of UP and Rajasthan as well. Even in Pakistan, a substantial number of fields are burnt, though the distance being more from Pakistan and it is less likely to impact Delhi seriously. Rather than attempting to ban straw burning, simply changing the crop mix in Punjab could yield large benefits. Rice requires substantial sub-surface water in Punjab and is known to be responsible for great environmental damage. The Government of India through FCI is a significant buyer of the rice, and also subsidizes its production in many ways. Changing the incentives for the farmer could encourage them to shift to much needed pulses, cotton, or fruits and vegetables, or commercial forestry etc. It will be costly but most likely to be effective if prices are synchronized such that they incentivise the farmers to substitute from one crop to another.

Only in extreme cases where all possibilities of incentives and substitution of source or technology are exhausted, should measures that involve banning be considered. Banning crop burning, for instance, will harm farmers and rural incomes, it is better to incentivise the use of seeding drills. This substitution of technology (from conventional seeding to zero till seed drills) may require some subsidies from the government.

**FIGURE 20: POLICIES TO REDUCE POLLUTION: INDICATIVE FORCES**




The above of course is indicative, there are many idiosyncratic forces that impact each sector or economic activity. But a general thumb rule should be, avoid banning something if it has no substitute, and ensure economic incentives are in line with the objectives.

Pollution is largely a technical phenomenon, that becomes widespread because of certain underlying economic forces. But severe pollution such as what we have in Delhi continues only when there is a serious governance gap. Technology and science need to be understood and the economics appreciated before a good policy can be designed. This is what good governance requires.

## Appendix 1: Selected Data

**TABLE A1: EMISSION STANDARDS APPLICABLE IN INDIA FOR DIFFERENT TYPES OF VEHICLES**

| Vehicle Type | Emission Standard Applicable | CO (gm/km) | HC (gm/km) | HC+NOx (gm/km) | NOx (gm/km) | PM (gm/km) |
|---|---|---|---|---|---|---|
| **Passenger Cars and Light Duty Vehicles (Petrol)** | Bharat Stage IV | 1.00 | 0.1 | … | 0.08 | … |
| **Passenger Cars and Light Duty Vehicles (Diesel)** | Bharat Stage IV | 0.50 | … | 0.3 | 0.25 | 0.025 |
| **2-Wheel Vehicles (Petrol)** | Bharat Stage IV (Class 1 and 2-1) | 1.40 | … | … | 0.39 | … |
| | Bharat Stage IV (Class 2-2) | 1.97 | … | … | 0.34 | … |
| | Bharat Stage IV (Class 3-1 and 3-2) | 1.97 | … | … | 0.20 | … |
| **3-Wheel Vehicles (Petrol)** | Bharat Stage III | 1.25 | … | 1.25 | … | … |
| **2 and 3 Wheel Diesel Vehicles** | Bharat Stage III | 0.50 | … | 0.5 | … | 0.05 |
| **Heavy Duty Trucks and Bus Engines** | Bharat Stage IV (ESC) | 1.50 | 0.46 | … | 3.5 | 0.02 |
| | Bharat Stage IV (ETC) | 4.00 | 0.55 | … | 3.5 | 0.03 |

Source: https://www.dieselnet.com/standards/#asia

Note 1: ESC is European Stationary Cycle under which the engine is tested on an engine dynamometer over a sequence of steady-state modes

Note 2: ETC is European Transient Cycle under which the engine is tested under different driving conditions represented by three parts of the ETC cycle, including urban, rural and motorway driving

Note 3: Classes are based on engine displacement and maximum design speed

Note 4: Class 1 = 50 < engine displacement < 150 cc and maximum design speed ≤ 50 km/h or engine displacement < 150 cc and 50 < maximum design speed < 100 km/h

Class 2-1 = engine displacement < 150 cc and 100 ≤ maximum design speed < 115 km/h or engine displacement ≥ 150 cc and maximum design speed < 115 km/h

Class 2-2 = 115 ≤ maximum design speed < 130 km/h

Class 3-1 = 130 < maximum design speed < 140 km/h

Class 3-2 = maximum design speed ≥ 140 km/h

**TABLE 3: POLLUTANT EMISSION FACTORS FOR DIFFERENT CATEGORIES OF VEHICLES**

| Year | Type | Specified pollutant (gm/km) | | | | | |
|---|---|---|---|---|---|---|---|
| | | CO | HC | $NO_X$ | PM | Benzene | Butadiene |
| 2006-2010 | 2W 2T (a,b) | 1.4 | 1.32 | 0.08 | 0.05 | 0.076/0.025 | 0.003/0.003 |
| 2006-2010 | 2W 4T (a,c) | 1.4 | 0.7 | 0.3 | 0.05 | 0.053/0.031 | 0.007/0.006 |
| 2006-2010 | 3W 2T (a,c) | 2.45 | 0.75 | 0.12 | 0.08 | 0.043/0.014 | 0.002/0.001 |
| 2006-2010 | PCG (f,g) | 1.39 | 0.15 | 0.12 | 0.02 | 0.011/0.006 | 0.001/0.001 |
| 2006-2010 | PCD (h) | 0.58 | 0.05 | 0.45 | 0.05 | 0.003 | 0.001 |
| 2006-2010 | LCV (f) | 0.72 | 0.063 | 0.59 | 0.07 | 0.003 | 0.001 |
| 2006-2010 | Truck (j) | 3.2 | 0.87 | 5.5 | 0.12 | 0.004 | 0.0008 |
| 2006-2010 | Bus (k) | 3.2 | 0.87 | 11 | 0.24 | 0.004 | 0.0008 |

Sources: Transport fuel quality for year 2005. Central pollution control board, Ministry of Environment and Forests, Government of India.
2W: Two Wheelers.
3W: Three Wheelers.
2T: Two Stroke.
4T: Four Stroke.
PCG: Passenger Car (Gasoline)
PCD: Passenger Car (Diesel)

**TABLE A3: PARTICULATE MATTER EMISSION FROM VEHICLES ACCORDING TO FUEL**

| Vehicles | Numbers | PM Emission Factor (gm/km) from CPCB | Assumed distance travelled in a day (in Kms) | Total PM Emission | %Share |
|---|---|---|---|---|---|
| 2 Wheelers | 4113829 | 0.05 | 30 | 6170744 | 51.6 |
| 3 Wheelers* | 155049 | 0.004 -- 0.08 | 100 | 557334 | 4.7 |
| Passenger Cars - Petrol | 1137681 | 0.02 | 50 | 1137681 | 9.5 |
| Passenger Cars - Diesel | 468489 | 0.05 | 50 | 1171223 | 9.8 |
| LCVs^ | 148409 | 0.0035 -- 0.07 | 100 | 931954 | 7.8 |
| Trucks & Buses# | 69972 | 0.012 -- 0.24 | 200 | 1965518 | 16.4 |
| Others/Misc. | 317867 | 0.001 | 50 | 15893 | 0.1 |
| **Total** | **6411296** | | | **11950347** | **100.0** |

Source: Transport fuel quality for year 2005. Central Pollution Control Board, Ministry of Environment and Forests, Government of India
"State of India's Environment: 2017. Down To Earth and Centre for Science and Environment
"Report on strategies to reduce air pollution from trucks entering and leaving Delhi." Environment Pollution (Prevention and Control) Authority for NCR (EPCA) and Centre for Science and Environment
Note 1: Emission Level for 2006-2010
Note 2: Others/Misc. includes LPG, CNG, LPG/Petrol, CNG/Petrol and Electric Passenger Cars
* It includes CNG Auto-rickshaws
# It includes CNG buses of Delhi Transport Corporation
^ It includes CNG/LPG LCVs

**TABLE A4: NEW EMISSION STANDARDS FOR THERMAL POWER PLANTS IN INDIA FROM DECEMBER 2015**

| Parameter | Standards |
|---|---|
| **TPPs ( units) installed before 31st December, 2003*** | |
| Particulate Matter | 100 mg/$Nm^3$ |
| Sulphur Dioxide ( $SO_2$) | 600 mg/$Nm^3$ (Units Smaller than 500MW capacity units) |
| | 200 mg/$Nm^3$ (for units having capacity of 500MW and above) |
| Oxides of Nitrogen ( NOx) | 600 mg/$Nm^3$ |
| Mercury ( Hg) | 0.03 mg/$Nm^3$ (for units having capacity of 500MW and above) |
| | |
| **TPPs ( units) installed after 1st January,2003, up to 31st December, 2016*** | |
| Particulate Matter | 50 mg/$Nm^3$ |
| Sulphur Dioxide ($SO_2$) | 600 mg/$Nm^3$ (Units Smaller than 500MW capacity units) |
| | 200 mg/$Nm^3$ (for units having capacity of 500MW and above) |
| Oxides of Nitrogen ( NOx) | 300 mg/$Nm^3$ |
| Mercury ( Hg) | 0.03 mg/$Nm^3$ |
| | |
| **TPPs (units) to be installed from 1st January, 2017**** | |
| Particulate Matter | 30 mg/$Nm^3$ |
| Sulphur Dioxide ($SO_2$) | 100 mg/$Nm^3$ |
| Oxides of Nitrogen ( NOx) | 100 mg/$Nm^3$ |
| Mercury ( Hg) | 0.03 mg/$Nm^3$ |

Source: Central Pollution Control Board, Government of India:
http://www.cpcb.nic.in/divisionsofheadoffice/pci2/ThermalpowerPlants.pdf
TPP: Thermal Power Plants
*TPPs (units) shall meet the limits within two years from date of publication of this notification.
**Includes all the TPPs (units) which have been accorded environmental clearance and are under construction".

**TABLE A5: COAL CLASSIFICATION IN INDIA**

| Classification | Description | Use |
|---|---|---|
| Coking Coal | When heated in the absence of air coking coal form coherent beads, free from volatiles, with strong and porous mass, called coke. | It has coking properties and it is used in steel making and metallurgical industries. |
| Semi-Coking Coal | When heated in the absence of airs semi-coking coal form coherent beads not strong enough to be directly fed into the blast furnace. Such coal is blended with coking coal in adequate proportion to make coke. | Semi-Coking Coal has comparatively less coking properties than coking coal. It is mainly used as blendable coal in steel making, merchant coke manufacturing and other metallurgical industries. |

| | | |
|---|---|---|
| Non-Coking Coal | Non-Coking Coal does not have coking properties. | It is mainly used for power generation. It is also used for cement, fertilizer, glass, ceramic, paper, chemical and brick manufacturing, and for other heating purposes. |
| Washed Coal | Processing of coal through water separation mechanism to improve the quality of coal by removing denser material (rocks) and high ash produces washed coal which has less ash, higher moisture, better sizing, better consistency, less abrasive, etc. | The washed coking coal is used in manufacturing of hard coke for steel making. Washed non-coking coal is used mainly for power generation but is also used by cement, sponge iron and other industrial plants. |
| Middlings and Rejects | In the process of coal washing, apart from Clean Coal one also gets two by-products, namely, Middlings and Rejects. Clean coal has low density whereas rejects have high density. Middlings have intermediate density. Rejects contain high ash, mineral impurities, fraction of raw coal feed, etc. Middlings are fraction of raw coal feed having values of classificatory parameters between that of clean coals and rejects. | **Middlings** are used for power generation. It is also used by domestic fuel plants, brick manufacturing units, cement plants, industrial plants, etc. On the other hand **Rejects** are used for **Fluidized Bed Combustion (FBC) Boilers** for power generation, road repairs, briquette (domestic fuel) making, land filling, etc. |
| Hard Coke | Solid product obtained from carbonaisation of coal. | It is used mainly in the iron & steel industry. |

Source: Coal Directory of India 2013-14. Ministry of Coal, Government of India

**TABLE A6: SECTOR WISE OFFTAKE OF RAW COAL, WASHED COAL, MIDDLINGS FOR FINAL CONSUMPTION TO DIFFERENT STATES IN INDIA DURING 2013-14 (IN MILLION TONNES)**

| State | Total Power (Utility + Captive) | Total Despatches |
|---|---|---|
| **Delhi** | | |
| Raw Coal | 4.279 | 4.491 |
| Washed Coal | 0.985 | 0.985 |
| Middlings | 0.023 | 0.023 |
| **Total** | **5.287** | **5.499** |
| **Punjab** | 0 | |
| Raw Coal | 11.382 | 12.315 |
| Washed Coal | 0 | 0 |
| Middlings | 0 | 0 |
| **Total** | **11.382** | **12.315** |
| **Haryana** | 0 | 0 |
| Raw Coal | 13.293 | 13.813 |
| Washed Coal | 0.079 | 0.079 |

| | | |
|---|---|---|
| Middlings | 0 | 0 |
| **Total** | **13.372** | **13.892** |
| **Uttar Pradesh** | 0 | 0 |
| Raw Coal | 61.324 | 67.242 |
| Washed Coal | 8.167 | 8.167 |
| Middlings | 0.355 | 0.355 |
| **Total** | **69.846** | **75.764** |
| **Rajasthan** | 0 | |
| Raw Coal | 17.187 | 17.993 |
| Washed Coal | 1.342 | 1.342 |
| Middlings | 0 | 0 |
| **Total** | **18.529** | **19.335** |
| **India** | | |
| Raw Coal | 433.512 | 536.669 |
| Washed Coal | 13.742 | 22.099 |
| Middlings | 8.47 | 8.748 |
| **Total** | **455.724** | **567.516** |

Source: Coal Directory of India 2013-14. Ministry of Coal, Government of India

**TABLE A7: GRADED RESPONSE ACTION PLAN FOR DELHI AND NCR**

| **Severe + or Emergency (ambient PM2.5or PM10concentration values of 300µg/m3or 500 µg/m3 respectively persist for 48 hours or more)** | **Agency responsible/Implementing Agency** |
|---|---|
| Stop entry of truck traffic into Delhi (except essential commodities) | Municipal Corporations and Traffic Police of Delhi and NCR Towns |
| Stop construction activities | Delhi Pollution Control Committee/Municipal Corporations of Delhi and NCR towns |
| Introduce odd and even scheme for private vehicles based on license plate numbers and minimize exemptions | Secretary cum Commissioner of Transport Department, NCT of Delhi, and Transport Commissioners of NCR towns |
| Task Force to take decision on any additional steps including shutting of schools | |
| **Severe (ambient PM2.5or PM10concentration value is more than 250 µg/m3or 430µg/m3 respectively)** | **Agency responsible/Implementing Agency** |
| Close brick kilns, Hot Mix plants, Stone Crushers | Chairpersons Delhi Pollution Control Committee, State Pollution Control Boards of Haryana, Rajasthan, and Uttar Pradesh |
| | Superintendent of Police and Deputy Commissioner of respective districts |
| Shut down Badarpur power plant and maximize generation of power from existing natural gas based plants to reduce operation of coal based power plants in the NCR. | Chairpersons Delhi Pollution Control Committee, State Pollution Control Boards of Haryana, Rajasthan, and Uttar Pradesh |
| Intensify public transport services. Introduce differential rates to encourage off-peak travel. | Secretary cum Commissioner of Transport Department, NCT of Delhi, and Transport Commissioners of NCR towns |

| | |
|---|---|
| | |
| | Chairperson, Delhi Metro Rail Corporation (DMRC) |
| | Chairpersons, State Transport Corporations |
| **Severe (ambient PM2.5 or PM10concentration value is more than 250µg/m3or 430µg/m3 respectively)** | **Agency responsible/Implementing Agency** |
| Increase frequency of mechanized cleaning of road and sprinkling of water on roads. Identify road stretches with high dust generation. | All road owning agencies including Municipal Corporations of NCT of Delhi and NCR towns, Public Works Departments and National Highway Authority of India |
| **Very Poor (ambient PM2.5or PM10concentration value is between 121-250µg/m3or 351-430 µg/m3 respectively)** | **Agency responsible/Implementing Agency** |
| Stop use of diesel generator sets | Chairpersons Delhi Pollution Control Committee, State Pollution Control Boards of Haryana, Rajasthan, Uttar Pradesh |
| Enhance parking fee by 3-4 times | Municipal Commissioner |
| | Municipal Corporations of NCT of Delhi and NCR towns |
| Increase bus and metro services by augmenting contract buses and increasing frequency of service | Principal Secretary, Department of Transport of NCT of Delhi |
| | Delhi Transport Corporation (DTC) |
| | Delhi Integrated Multi-modal Transit System Ltd (DIMTS) |
| | Delhi Metro Rail Corporation (DMRC) |
| | State Transport Corporations in NCR towns |
| Stop use of coal/firewood in hotels and open eateries | Municipal Corporations of NCT of Delhi and NCR towns |
| Residential Welfare Associations and individual house owners to provide electric heaters during winter to security staff to avoid open burning by them | Resident Welfare Associations |
| Alert in newspapers/TV/radio to advise people with respiratory and cardiac patients to avoid polluted areas and restrict outdoor movement. | Chairpersons, Delhi Pollution Control Committee, State Pollution Control Boards of Haryana, Rajasthan, and Uttar Pradesh |

| **Moderate to poor(ambient PM2.5 or PM10 concentration value is between 61-120 µg/m3 or 101-350 µg/m3 respectively)** | **Agency responsible/Implementing Agency** |
|---|---|
| Stringently enforce/stop garbage burning in landfills and other places and impose heavy fines on person responsible | Municipal Commissioner |
| | Municipal corporations of Delhi and NCR towns |
| Close/stringently enforce all pollution control regulations in brick kilns and industries | Chairpersons, Delhi Pollution Control Committee, State Pollution Control Boards of Haryana, Rajasthan, and Uttar Pradesh |
| **Moderate to poor(ambient PM2.5 or PM10 concentration value is between 61-120 µg/m3 or 101-350 µg/m3 respectively)** | **Agency responsible/Implementing Agency** |
| Stringently enforce pollution control in thermal power plants through PCB monitoring | Plant in-charge of power plants in NCR, and Delhi Pollution Control Committee and State Pollution Control Boards of Haryana, Rajasthan and Uttar Pradesh |
| Do periodic mechanized sweeping on roads with heavy traffic and water sprinkling also on unpaved roads every two days | Municipal Commissioner, Municipal Corporations of NCT of Delhi and NCR towns |
| | Commissioners, Traffic Police of Delhi and NCR towns to identify roads with heavy traffic and provide information to respective Municipal Commissioners |
| | Chief Engineers of officers in charge of CPWD, PWD of Delhi and NCR towns to identify unpaved roads with heavy traffic and provide information to respective Municipal Commissioners |
| Strict vigilance and no tolerance for visible emissions – stop plying of visibly polluting vehicles by impounding or heavy fine. | Commissioner or Officer in Charge, Transport Department and Traffic Police of NCT Delhi and NCR towns |
| Strict vigilance and enforcement of PUC norms | |
| Stringently enforce rules for dust control in construction activities and close non-compliant sites | Commissioner or Officers in charge of Police Departments of Delhi and NCR towns |
| Deploy traffic police for smooth traffic flow at identified vulnerable areas | Commissioners Traffic Police of Delhi and NCR Towns |
| Strictly enforce Supreme Court order on diversion of non-destined truck traffic and ensure only trucks registered after 2005 are allowed entry into Delhi | Municipal Corporations of NCT of Delhi and NCR towns |
| | Traffic Police of NCT of Delhi and NCR towns |
| Strictly enforce Supreme Court ban on | Chief Controller of Explosives |

| | |
|---|---|
| firecrackers | |
| | Petroleum and Explosive Safety Organizations (PESO) |
| | Commissioner of Officer in charge of licensing in the police departments of Delhi and NCR |
| Ensure fly ash ponds are watered every alternate day during summer months (March – May). | Plant in charge of Power Plants in Delhi and NCR towns |
| **Moderate to poor(ambient PM2.5 or PM10 concentration value is between 61-120 µg/m3 or 101-350 µg/m3 respectively)** | **Agency responsible/Implementing Agency** |
| Information dissemination Social media, mobile Apps should be used to inform people about the pollution levels, contact details of control room, enable them to report polluting activities/sources to the concerned authorities, and actions that will be taken by government based on the level of pollution. | Chairpersons, Delhi Pollution Control Committee, State Pollution Control Boards of Haryana, Rajasthan, and Uttar Pradesh |

Source: Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, Government of India. http://cpcb.nic.in/final_graded_table.pdf

# APPENDIX 2: ROLE OF STATE IN POLLUTION ABATEMENT

The obligation of state and individuals with regard to protecting the environment is mandated by the Constitution of India.

- Article 48-A puts responsibility on the state to protect environment
- Article 51-A(g) calls upon the citizens to make efforts to protect and improve environment

So, even the framers of the Constitution of India were concerned about the need to protect the environment for the sustainable growth of the country.

Before going into the analysis of the functioning of the regulatory framework with regard to air pollution in India, it is important to understand how the government agencies in the country measure the level of particulate matter in the ambient air.

Government Acts and legal framework

When it comes to acts and regulations related to air pollution in India, the problem is of plenty. Following are the list of some of the government acts and regulations that have direct or indirect bearing on air pollution in the country.

1. Air (Prevention and Control of Pollution) Act, 1981
2. Environment Protection Act, 1986 (EPA)
    a. Ash Content Notification (1997)
    b. Taj Trapezium Notification (1998)
    c. Disposal of Fly Ash Notification (1999)
    d. Rules for the Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms/Genetically Engineered Organisms or Cell (1989)
    e. Recycled Plastics Manufacture and Usage Rules (1999)
    f. Municipal Wastes (Management and Handling) Rules, (2000)
    g. Biomedical Waste (Management and Handling) Rules, 1998
3. Public Liability Insurance Act (PLIA), 1991
4. National Environment Tribunal Act, 1995
5. National Green Tribunal Act, 2010
6. Factories Act, 1948
7. Atomic Energy Act, 1982
8. Motor Vehicles Act, 1988

Notwithstanding the above list of acts and regulations, air quality in the country in general and Delhi in specific has continued to deteriorate. The main reason behind such a phenomenon has been the lack of proper and strict enforcement of the acts and regulations by the regulating authorities.

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