Air pollution in Delhi: biomass energy and suitable environmental policies are sustainable pathways for health safety

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Air pollution causes severe environmental problems and has become a major health risk for livelihood in Delhi. With increase in population, there is an increase in emissions from various utilities as well. The main source of air pollution is crop residue burning followed by vehicular and industrial emission. Crop residue burning during winter produces a thick cloud of smoke and causes major threats to human health by deterioration in air quality. This crucial matter was also discussed in the Indian parliament. The National Green Tribunal and various Courts of India have directed to the Delhi government and various concerned agencies to resolve the air pollution problem. The present study discusses human health safety caused by air pollution, analysis and mitigation of air pollution using suitable environmental policies and application of biomass energy.

Keywords: Air pollution, biomass energy, crop residues, environmental policies.

AIR pollution refers to contamination of the earth's atmosphere with materials that affect the natural functioning of ecosystems, human health and quality of life. Delhi the capital of India, has a population of more than 1.6 crores (ref. 1). Extraordinary growth in population also increases socio-economic and livelihood activities, which ultimately result in the deterioration in air quality; so Delhi is now facing a severe problem of air pollution[2]. WHO has conducted a survey of 1600 cities in the world, and reported that air quality in Delhi is the worst among major cities of the world[3,4]. The main gaseous pollutants are oxides of carbon, oxides of nitrogen, oxides of sulphur, hydrocarbon and suspended particulate matter emitted by different sources, including transport, electricity generation, incineration, burning of domestic and industrial fuel[5–7]. It is observed that due to industrial revolution, CO_2 concentration level has increased by 28% in the atmosphere. This is responsible for change in global average temperature by 0.3°–0.6°C, with increase in ocean level by 10–15 cm during the last century. The emission of greenhouse gases (GHGs) must be reduced with suitable environmental policies; otherwise the global temperature will increase by 1°–3.5°C with increase in ocean level by 15–95 cm in the present century[8]. As a result, several populated areas will submerge in the ocean. The pollution problem becomes severe in Delhi, especially in winter, when the neighbouring states of Haryana, Punjab and Uttar Pradesh start burning large amounts of unused crop residues to quickly clean the fields after harvesting. Due to burning of crop residues, a thick cloud of smoke is formed which causes atmospheric pollution and results in major threats to human health by deterioration in air quality. This calls for suitable environmental policies, and awareness regarding proper utilization and management of crop residues to deal with the problems.

Impact of air pollution on human health

The air quality of Delhi is the worst globally, which is a major health risk for its citizens. The key sources of pollution are air, water, noise and soil contamination. Some less identified forms of pollution like thermal, radiation and radioactive hazards also have an impact. However, air and water pollution are largely responsible for human health risk[1,9]. Table 1 (refs 10–34) provides a summary of air pollution and its impact on human health in Delhi.

Several studies have shown that air contamination is related with respiratory morbidity[12,14,35]. Researchers have also reported a relationship between indoor air contamination and respiratory morbidity[18–20,36–38]. Numerous studies have been conducted on respiratory morbidity in children[18,20,39]. Vehicular air pollution is responsible to increase risk factor for mental growth in children[40], because it decreases serum concentration of vitamin D metabolites as well as lower mean haze score[41]. The pollution level of Delhi is reported to be six times above normal. Breathing the Delhi air is as harmful as smoking 40 cigarettes in a day. $PM_{2.5}$ is more hazardous to human

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Table 1. Summary of impact of air pollution on human health in Delhi

Variable	Finding	Reference
Effects of vehicular air pollution on children	Attention deficit hyperactivity disorder effects on children correlated with PM_{10} level	10
Outdoor air pollution effects	Natural cause of mortality increases by 0.15% with increase of every 10 μg m^{-3} in PM_{10}	11
Outdoor air pollution effects	Pollutant level increase by 10 μg m^{-3} which is considerable relative risks for respiratory morbidity: 1.0040 for NO_2, 1.0330 for O_3, 1.0060 for responsible suspended particulate matter (RSPM)	12
Effects of outdoor air pollution	Respiratory diseases increase the relative risks of hospitalization from relative risks (RR) 1.07 to 2.82	13
Outdoor air pollution effects	OPD cases also increase with increasing particulate matter in air: SPM ($P < 0.01$) and RSPM ($P < 0.05$) show significant effect	14
Outdoor air pollution effects	Air pollution increases cases of hospitalization of humans due to asthma, heart problem and chronic obstructive airways disease (COAD) by 21.30%, 24.30% and 24.90% respectively	15
Outdoor air pollution effects	In Delhi, Mumbai and Ahmedabad, inhalable particulates in atmospheric air have increased due to commercial activities up to 140%, 198% and 406% and due to industrial activities up to 546%, 168% and 320% respectively	16
Outdoor air pollution effects	There are three main sources of particulate matter: vehicular emissions, industrial emission and soil contributing fine PM_{10}: 71.3 ± 15 μg m^{-3} and coarse PM_{10}: 68.3 ± 17 μg m^{-3}	17
Indoor air pollution effects	Indoor air pollution also affects children. SPM, NO_2 and SO_2, family history of smoking have an impact on the respiratory function of children	18
Indoor air pollution effects	During winter, high concentration of indoor air pollutants is associated with respiratory problems in humans	19
Indoor air pollution effects	Children having a history of respiratory illness are affected significantly due to indoor SPM	20
Effects of heavy traffic on indoor air pollution in classrooms situated close to roads	The exhaust emissions from vehicles are significant contributors to SPM	21
Indoor air lead pollution effects	Lead loading for interior and floor projection samples is 19.7 and 75.5 μg ft^{-2} respectively	22
Burning of biomass	Burning of crop residues emits several hazardous gases like CH_4, NO_x, SO_x and NH_3, which cause air pollution and ultimately affect human health risk, and cause eye irritation and chronic bronchitis	23–32
Burning of biomass	Particulate matter emitted from crop residue burning is dangerous from human health point of view due to its high surface area	33
Burning of biomass	Long-term exposure to ambient $PM_{2.5}$ has potential health risks, including premature death	34

health than PM_{10}, because the former penetrates deep into the lungs and may reach the alveolar region and causes asthma, heart problem chronic obstructive airways disease (COAD) and lung cancer, etc.[42,43].

Pollution from different sources

Various sources like industries, vehicles, construction, open biomass burning and dust from roads are responsible for air pollution. Table 2 (ref. 44) presents total emissions from these sources in Delhi.

Pollution from industries

Table 2 reveals that industries are the major contributors of SO_x and NO_x. The fuels used in industries contain high-sulphur materials such as furnace oil, coke and petroleum, which cause industrial pollution. The Supreme Court of India banned the use of these fuels in Delhi, National Capital Region (NCR), Uttar Pradesh and Rajasthan on 24 October 2017 (ref. 45). Thermal power plants that utilize low-grade coal with high sulphur content also contribute to SO_x, NO_x and particulate matter. On 5 February 2018, the Supreme Court directed the Ministry of Environment, Forests and Climate Change (MoEF&CC), Government of India to standardize the process of lime kiln, ceramic, glass, foundries and re-heating furnaces.

The following are required for abatement of air pollution due to industries: (i) Use clean fuel; (ii) The Supreme Court had directed MoF&CC, GoI and the Central Pollution Control Board (CPCB) on 2 May 2017, to standardize the emission level of SO_x and NO_x for industries; (iii) The MoEF&CC, GoI issued a notification on 29 January 2018 for enforcement of emission standards by application of continuous emission monitoring

Table 2. Pollution loads from emission and various sources in Delhi[44]

Source	Emission rate of pollutants (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	HC
Industries	32,479	8781	264,399	360,526	23,771	4765
Vehicles	9750	12,871	720	84,200	217,800	66,700
Road dust	77,275	25,757	–	–	–	–
Open biomass/crop residue burning	27,730	11,115	2608	15,332	132,552	59,968
Total	147,234	58,524	267,727	460,058	374,123	131,433

systems (CEMS); (iv) Optimizing the existing thermal power plants/industries by utilization of natural gas/clean fuel, and (v) Utilization of various catalysts, diesel particulate filter (DPF) and electrostatic precipitator (ESP) for reduction of emissions.

Pollution from vehicles

Vehicular emission mainly contributes carbon monoxide, hydrocarbon, HC and dust particulate matter, which are a threat to human health. On 29 March 2017 the Supreme Court of India banned the sale of BS-III vehicles; now only BS-IV vehicles will be registered by the RTO of India.

The mitigation of vehicular pollution includes the following: (i) Improve pollution control system for vehicles using advance emission control technology, i.e. advance catalytic convertor, diesel particulate filter (DPF) and electrostatics precipitator (ESP), etc.; (ii) Advancement in fuel quality for vehicles and popularization of compressed natural gas (CNG), (iii) Build more bypass roads around Delhi to divert commercial heavy vehicles traffic. Also impose a congestion charge on such vehicles; (iv) Introduce attractive and economic public transport, buses and metro in Delhi for minimizing private vehicles; (v) Scale up electric vehicles production and sale; (vi) Local transit systems should be integrated with regional rapid transit system to provide seamless connectivity between sub-regional and regional centres of Delhi and NCR; (vii) Zonal plans for developing a non-motorized transport (NMT) network should be prepared and implemented, and (viii) Fixing of income tax limit for the purchase of luxury vehicles to discourage black money.

Pollution from dust

Dust is responsible for 30–40% of PM pollution in Delhi and causes health risk. Dust is emitted due to friction of tyres during application of brakes. Construction activities like excavation, block cutting, demolition, road construction, mixing, drilling, loading and unloading of debris, etc. also emit dust particles. In addition, movement of heavy trucks at construction sites increases the amount of particles by crushing and pulverizing them on the surface of roads. During manual road sweeping, leftover dust on the sides of the roads is stored as a heap, which gets re-entrained when traffic movement resumes during the day. Therefore, immediate action should be taken in the case of road dust and particulate matter as follows: (i) Vacuum sweeping; (ii) Mechanical sweeping with water wash; (iii) Use of water sprinkler; (iv) Shoulders carpeting; (v) Standard should be fixed for quality of vehicle tyres and road; (vi) Vertical garden should be established; (vii) Plants, small shrubs, perennial forages, grass cover in open areas, and (viii) Heavy- or light-duty trucks should be equipped with vacuum cleaners to remove road dust.

Pollution from biomass burning

It is observed that around 93 Mt of agriculture residues is burnt in open fields in India[33], of which Punjab produces around 20 Mt of wheat straw and 19–20 Mt of paddy straw. This is due to shortage of time between harvesting and sowing of two crops; about 85–90% of paddy and wheat straw is burnt in open farm areas. The Ministry of New and Renewable Energy, GoI[34] has estimated that every year approximately 500 Mt agriculture residues are produced as by-product – Uttar Pradesh (60 Mt), Punjab (51 Mt) and Maharashtra (46 Mt). Cereals crops produce maximum residues (352 Mt), followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt) and sugarcane (12 Mt). The cereal crops (rice, wheat, maize, millets) contribute about 70%, whereas rice crop alone contributes approximate 53% to crop residues. Presently, around 70–80 Mt of rice residue is burnt in open fields[46–48].

Comparison of pollution levels in winter and summer

In India during winter, wind blows from the north and northwest towards the east. This results in heavy smog formation over Delhi. Figure 1 shows average air quality index (AQI) of Delhi in different months during 2017–18. In winter, it falls in the hazardous range due to biomass burning in the neighbouring agricultural states like Haryana, Uttar Pradesh and Punjab during October and November. In summer, the high value of AQI is because of the augmented concentration of PM_{10} and $PM_{2.5}$, which

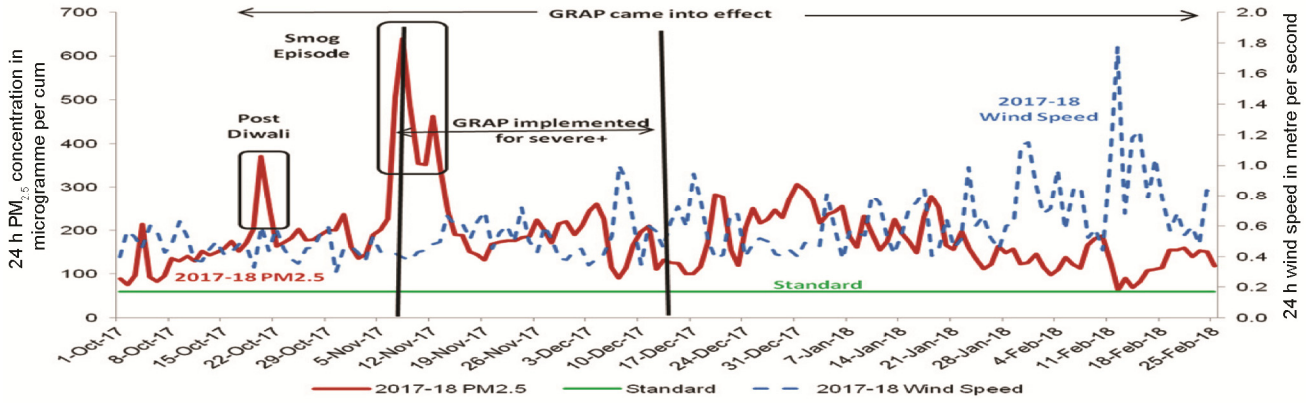

Figure 1. Pollution due to $PM_{2.5}$ from 1 October 2017 to 25 February 2018 at 17 locations in Delhi.

is due to road dust. However, in the rainy season, pollution level goes down due to precipitation of suspended dust, although AQI value is in the sensitive category[49].

Figure 1 shows the pollution level from 1 October 2017 to 25 February 2018.

(i) There is a peak in October followed by smog in November due to bursting of crackers during Diwali, paddy burning in Haryana and Punjab and wind-storms from western Asia. The maximum $PM_{2.5}$ level has been observed on 8 November 2017 at 640 $\mu g\ m^{-3}$, which is 10.7 times more than the standard value.

(ii) Slow wind level may cause an increase in pollution. Wind speed and $PM_{2.5}$ concentration have an inverse relationship.

(iii) It is also observed that average wind speed and temperature remain the same as the previous year; $PM_{2.5}$ level also decreased which is impact of graded response action plan (GRAP), the emergency actions that were taken to reduce pollution.

Approaches to minimize crop residue burning

All state governments especially those of Uttar Pradesh, Haryana and Punjab should take action regarding burning of crop residues and must take steps to educate and advise the farmers through media, Gram Panchayats and NGOs. They should explain the importance of these crop residues that can be used as raw material for power generation, briquette formation, as fuel for vehicles, and contribute to making a green India by reducing pollution and ultimately global warming. The following approaches may be applied by various central and state administrations and regulatory authorities to reduce crop/agriculture residue burning: (i) Ban on crop/agriculture residue burning; (ii) Continuous monitoring of suspected place; (iii) Create public awareness through media and campaigns; (iv) Establishment of a market place for selling crop residues; (v) Collection and transportation of crop residues, and (vi) Provision of subsidy on agri-implements.

Uses of crop residue

Briquettes or pellets formation

Crop residues can be utilized for briquette or pellet formation. Biomass briquettes or pellets can be sold as replacement of coal for an industrial boiler. The crop residues have low bulk density and high volume; therefore, it is difficult and expensive to handle, transport and store them. They also exhibit poor combustion property. These problems can be reduced by densification of loose biomass and formation of briquettes. There are different types of briquetting plants available in India for densification of biomass by which briquettes of density 1.2 g/cm^3 can be produced[50]. The estimated potential of biomass briquetting in India is around 6.1×10^7 kW. The potential of employment generation in the briquetting industry is around 15.52 million. Farmers can earn about Rs 400 per tonne from crop residues[51]. These briquettes may be used for domestic and industrial purposes in both urban and rural areas[52] and burnt efficiently, and therefore are environmentally sustainable. Combustion efficiency of briquetted biomass was around 75% and it burned as good as coal. It is reported that 3 kg of briquetted biomass would replace 1 litre of diesel. Also, briquettes reduced the volume to 1/11th of the original volume of biomass. The production cost of briquettes varied from Rs 2.05 to 2.50/kg based on the use of the briquetting machine from 1800 to 4300 h/annum[53].

Production of bio-fuel

Several types of fuels can be formed from biomass; this includes liquid fuels like biodiesel, ethanol, methanol, bio-oil; solid fuels like bio-char and gaseous fuels like hydrogen and methane. Bio-fuels are primarily used in engines, vehicles and fuel cells for various applications, including generation of electricity[54].

Biodiesel can be prepared through trans-esterification. It can be blended with diesel, and in future will replace

the latter, having the potential to mitigate toxic emissions from vehicles and industries, which are the largest producers of GHGs and particulate matter, thus reducing health risk[55]. A study has reported that if 10% of total production of castor seed oil is trans-esterified into biodiesel, then around 79,782 tonnes of CO_2 emission can be mitigated annually[56]. Ethanol may be formed through fermentation process. Ethanol can be blended with petrol; in future it will replace petrol.

Bio-oil can be formed from crop residues at 400°–500°C by fast pyrolysis process. Around 75% of dry biomass may be transformed into condensable vapours. After condensation a dark brown viscous liquid is formed, known as bio-oil, having calorific value 16–20 MJ/kg (ref. 54).

Hydrogen can be generated from crop residues through thermo-chemical conversion processes such as pyrolysis and gasification. Nowadays hydrogen is a good source of energy which decreases the dependency on fossil sources[57,58]. The Hydrogen Development Board has been established in India to promote technologies for producing, storing, transporting, and distributing hydrogen as well as to explore utilization in fuel cells for efficient end-use of hydrogen[59].

Biogas production

Biogas is the product of anaerobic degradation of organic matter. It contains mainly methane (40–70%), carbon dioxide (30–60%) and other gases (1–5%) having calorific value about 16–20 M/Jm^3 (ref. 60). Biogas is combustible and can be used as a heat source or to generate electricity. About 17,000 MW electricity can be generated using biogas in India, which is around 10% of the total electricity generated in the country[61]. Also, producing heat using biogas is more efficient than producing heat by combustion. Electricity generation from biogas is possible in both duel-fuel mode as well as 100% engine run through biogas. It is helpful to mitigate GHG emissions and abatement of global warming by substituting firewood for cooking, kerosene for lighting.

Biomass gasification

This is the thermo-chemical conversion process in which solid biomass is converted into producer gas. The producer gas consists of CO, H_2, CO_2 and N_2, and has low calorific value (1000–1200 kcal/Nm^3)[62], but it is combustible with good efficiency and can be controlled without emission of smoke. After suitable process, the treated gases can be burned directly for cooking or heat applications, or can be used in secondary conversion devices, i.e. IC engines or gas turbines for producing electricity. One tonne of biomass may generate 300 units (kWh) of electricity. The crop residues may be effectively utilized by gasification technology, after preparation of pellets and briquettes. Therefore, nowadays biomass-based gasification plants have become a good source of electricity supply in rural areas[63].

Establishment of biomass-based power projects

Proper utilization of crop residues is essential and for this a large number of biomass-based power plants should be installed. Presently, Punjab is utilizing only 0.94 Mt of paddy straw against 19–20 Mt of generation. Haryana does not have any operational biomass-based power plant for fruitful utilization of crop residues. All connected states of NCR should develop a plan for fruitful utilization of crop residues. The Central Electricity Regulatory Commission (CERC), notified attractive and favourable tariffs for electricity generated from biomass-based power plants. Punjab has set its electricity tariff @ Rs 8.17/unit, which is more than other sources of renewable energy, such as solar or wind-based power projects.

The Ministry of New and Renewable Energy (MNRE) is promoting biomass gasification technology since the last 20 years. These technologies are being promoted in rural areas of the country in order to utilize biomass resources such as small wood chips, crop stalks, rice husk and other crop residues. The largest biomass-based power projects at Sirohi, Rajasthan, have a capacity of 20 MW. Biomass-based power projects will be installed at 60 rice mills in India this year. Biomass-based power projects of 0.50 MW in Tamil Nadu and 1.20 MW in Gujarat have already been installed[64].

Compost formation

Crop residues are utilized for the preparation of compost. During preparation crop residues are used as animal bedding and then heaped in dung pits. Also, 2–4 kg of urine is absorbed by 1 kg of crop residue, and turn out to be enriches with nitrogen. Paddy obtained from 1 ha area provides about 3 tonnes of manure with good nutrients as farmyard manure (FYM) after composting. The decomposition process take 75–90 days. When the compost is mixed with soil it improves soil health and fertility[54].

Bio-char production

Bio-char is produced during slow pyrolysis. Heating of biomass in the absence of oxygen is known as pyrolysis. It is a high-carbon, fine-grained charcoal and can play a key role in carbon sequestration and mitigation of GHGs. On the other hand, it is not economically feasible and cannot be popularized among Indian farmers. Development of low-cost pyrolysis kiln is required for the generation of bio-char for utilization of surplus crop residues;

otherwise, it will be burnt in-open fields, thus polluting the atmosphere[64].

Profitable use of biomass energy

Conventional use of crop residues was limited to direct burning of biomass for cooking and heating, which causes environmental pollution and health risk. However, the present uses of biomass energy involve more efficient conversion processes and can be profitable in the following manner.

Energy supply in rural areas

Energy from crop residues can help meet the rising demands of electricity and fuel in rural areas. Ultimately, this will increase the living standards and productivity of the rural population.

Rural development

Proper utilization of crop residues will increase the earning power of farmers. The products made from crop residues, i.e. electricity, compost, biogas, ethanol, bio-oil, etc. will provide additional benefits to the farmers as well as improve facilities available in the villages. Electricity generation from crop residue in India has now become an industry that is attracting investments around Rs 6 billion/year, and also generating more than 5 billion units of electricity every year. Biomass energy also creates employment of around 10 million man-days every year in the rural areas[65].

Environmental security

Biomass is a renewable source of energy. It reduces the threats generated from thermal power plants and prevents climate change. The environment could also be saved by avoiding the burning of these residues in the field. Proper utilization of crop residues will save the environment from harmful effects of disposing wastes, which are presently responsible for ruining of soil, water resources and groundwater as well as contributing to emission of GHGs.

Conclusion

The residents of Delhi face serious problem of air pollution during winter due to the burning of crop residues in the neighbouring states. There is an urgent need to manage or completely stop crop residue burning to detect any significant improvement in air quality in Delhi. The problem of air pollution cannot be handled by regulations alone; their strict execution, enforcement and collaboration of general public are also important. Several actions recommended by various authorities/courts/tribunals to control crop residue burning may have some short-term, long-term and permanent solution to save Delhi from air pollution. In addition, there is need to adopt an effective strategy.

Government mechanisms, like MNRE, Indian Council of Agricultural Research, Krishi Vigyan Kendra and Gram Panchayats or other collaborated mechanisms, customized hiring should be available with fully equipped machinery to collect agricultural residues from the farmer's field at the time of harvesting. If advanced machineries are provided to the farmer through government mechanisms, then the problem of crop residue burning will be solved. The government and farmer will get benefit in three ways: (i) Air pollution will be reduced; (ii) Government gets profit by converting crop residues into suitable forms of energy, and (iii) the farmer will benefit by getting the price of crop residues and there will be no loss of soil nutrient, which will increase productivity of the field.

Industries also participate in creating pollution and therefore inspection of industries should be done by competent authority as follows: (i) Compliance of standards, rules and regulation; (ii) Physical inspection of ESP and other emission control devices, (iii) Quality of clean fuel, and (iv) Checking of fuel testing reports and emission monitoring data.

Vehicular emission is another cause of pollution. Improper maintenance of vehicles is responsible to increase emissions; therefore, manufacturer should provide lifetime AMC for vehicles at the time of sale. Standard should be fixed for quality of vehicle tyres and roads to reduce road dust.

Apart from above, Government should motivate the R&D activities for advance pollution control mechanism and development of standards for abatement of pollution.

Human health is precious. The air pollution causes various disease like asthma, heart problem chronic obstructive airways disease (COAD), lung cancer, etc; therefore it is essential to implement suitable environmental policies which are sustainable pathways for health safety as discussed in this article. Children are our future and we are responsible for the present and future of society.

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