Evaluation of mitigation policy scenarios regarding health effects and mortalities due to transport sector air pollution

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Eivind Farstad, Institute of Transport Economics, Oslo
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Introduction

The health effects of air pollution due to transport in India are unquestionably severe. According to the World Bank (1998:20), “the urban population of India bear a high burden of the health costs due to exposure to particulate matter by international comparison that requires immediate actions and targeted environmental policies”. This fact was already recognized by the World Bank nearly thirty years ago, and considering that the air pollution situation in urban India has not changed for the better in the last three decades, this is a matter of foremost importance considering transport and other environmental policies in India’s megacities.

Among the health effects considered in the project, deaths and diseases attributable to air pollution from the transport sector in India are by far the most serious. It is also a type of health effects that can be linked to vehicular emissions in the transport sector, which is also closely linked to climate effects, being the main focus in the project. Therefore, the focus in this paper will be on health effects due to air pollution from the transport sector; and more specifically, tailpipe emissions from vehicular traffic in the case cities, as it will be elaborated on in this text.

Air pollution is a major contributor to premature deaths worldwide. According to a report by the United Nations Children’s Fund (UNICEF, 2016), air pollution was linked with 1 out of every 8 deaths, globally – or around 7 million people in 2012. Around 600,000 those deaths of were among children under 5 years old, globally. For India alone, the estimated number of air pollution-linked deaths was as high as 621 000 in 2012 (WHO, 2016a:67). The World Health Organization (WHO, 2016b) also estimated that, among the 7 million deaths worldwide, 3,700,000 deaths were attributable to ambient air pollution (AAP), and as opposed to household air pollution (WHO, 2016c). The major contributor to AAP is ambient particulate matter pollution (APMP), with ambient ozone pollution being a minor contributor (Ginsberg et al., 2016).

Some vulnerable segments of the population are more at risk in terms of exposure to air pollution. The Lancet Commission on pollution and health points out that disease and death due to pollution is most prevalent in the very young and the very old (The Lancet Commissions, 2017). Deaths due to all forms of pollution show a peak among children younger than 5 years of age, but most pollution-related deaths occur among adults older than 60 (Figure 1). Among all forms of pollution, air pollution is one of the major contributors to premature deaths, particularly for the very young and elderly, as shown by the red line in Figure 1 below.

Pregnant women and their unborn children are also at risk, since air pollution is linked to birth defects and complications, and diseases in the fetus. Air pollution can affect the fetus considerably. Studies have shown stark associations between high levels of PM and foetal loss, preterm delivery, and lower birthweight and fertility (UNICEF, 2016).

The UNICEF-report (UNICEF, 2016) further shows that the most common outdoor air pollutants that affect human health are particulate matter (PM), ozone
(O3), nitrogen oxides (NOx), sulfur dioxide (SO2), carbon monoxide (CO) and chemicals such as polycyclic aromatic hydrocarbons (PAHs).

According to the UNICEF, approximately 89% of deaths due to ambient air pollution occurred in low-income and middle-income countries in 2015. Several cities in India and China record average annual concentrations of PM2.5 pollution of greater than 100 μg/m³, and more than 50% of global deaths due to ambient air pollution in 2015 occurred in India and China (UNICEF, 2016).

Power generation, industry and transportation are large contributors to air pollution. Based on a report by United States Environmental Protection Agency (2016) UNICEF (2016) have found that, “among the air pollutants, PM2.5 is often considered particularly dangerous to human health because of its ultrafine size (about 1/30th the average width of a human hair). Not only can PM2.5 penetrate deep inside the lungs, but it can also enter the bloodstream, causing a variety of health problems including heart disease and other cardiovascular complications. “PM2.5 pollution is often the result of fossil fuel combustion from vehicle exhaust, industrial production and power plants, as well as from natural sources such as windblown dust and volcanic activity” (UNICEF 2016:20).

In Delhi, for instance, the top four contributors to PM2.5 emissions are road dust, vehicles, domestic fuel burning; and industrial point sources, based on annual emissions (Sharma & Dikshit, 2016).
The Lancet Commission (2017:14) further points out that “PM_{2.5} is the best studied form of air pollution, and is linked to a wide range of diseases in several organ systems. The strongest causal associations are seen between PM_{2.5} pollution and cardiovascular and pulmonary disease.” Furthermore, The Lancet Commission states that “Specific causal associations have been established between PM_{2.5} pollution and myocardial infarction, hypertension, congestive heart failure, arrhythmias, and cardiovascular mortality.”

The satellite map below, (Figure 2) adapted from the UNICEF-report (UNICEF, 2016), shows the Satellite derived PM_{2.5} level in Asia, 2012-2014. The darker red coloration over large parts of India shows the areas where PM_{2.5} concentrations are substantially higher than the global annual mean, indicating that the PM_{2.5} concentrations in large parts of India are among the highest in Asia.

An article in The Guardian (2017) further exemplifies the seriousness of the PM_{2.5} air pollution situation in Indian cities. For example, Figure 3 shows Delhi compared to selected other cities in the world, where the pollution in Delhi reached more than 10 times the annual average for Los Angeles in 2016.

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As it becomes clear from the research material presented above, the high number of deaths associated with people being exposed to polluted air is a serious issue in many of India’s megacities, where air pollution is already causing thousands of deaths each year.

This paper summarizes the main findings from the CLIMATRANS project related to health effects in terms of deaths (mortalities) due to PM$_{2.5}$ air pollution attributed to tailpipe emissions from the transport sector.

The health effects of air pollution due to transport in India are unquestionably severe. This is a matter of foremost importance considering transport and other environmental policies in India’s megacities. PM$_{2.5}$ air pollution is the number one pollutant causing an estimated 21,000 deaths in total for in the megacities Delhi, Mumbai and Bangalore altogether in 2011 (Sharma, et al., 2017a). A significant share of the deaths due to PM$_{2.5}$ pollution can be attributed to the transport sector in the case cities, as will be presented in this paper.

In this paper the focus is on the PM$_{2.5}$ component in air pollution generated by the transport sector, and more specifically, the tailpipe emissions from vehicular traffic, excluding PM$_{2.5}$ air pollution from transport-related sources, such as road dust and tire-road friction, etc.

Exposure to PM$_{2.5}$ particles in polluted air is the by far the most important cause of the negative health effects of transport in terms of mortality in the case cities. Exposure to the ultrafine particles PM$_{2.5}$ is particularly associated with respiratory and cerebrovascular diseases, and increased morbidity and mortality levels, as pointed out from the various sources cited earlier (see also Sharma, et al., 2017a for further details on the health effects of PM$_{2.5}$ air pollution).
There are, of course, other important health effects from other pollutants generated by the transport sector than PM$_{2.5}$, such as NOx and HC and other types of vehicular emissions. In addition there are health effects other than those manifested as mortalities, such as non-fatal diseases, physical and mental disabilities, lost work days, and the physical condition and general wellbeing of the population etc.

However, given the resource limitations in the project, we have chosen to focus only on PM$_{2.5}$ emissions from tailpipe emissions in the transport sector. This is excluding other particle matter pollution from road dust and tire-road friction etc., which is difficult to estimate based on the vehicle emission factor data available in the project. The effects considered here are only related to estimated mortalities in the case cities, which we have been able to assess within the resource framework of the project.

The focus here will also be on mitigation policy scenarios, rather than adaptation policies, since adaptation policy scenarios are still under the process of development and evaluation at present for some of the case cities. Mitigation policies are also in general more relevant compared to adaptation policies when considering health effects from air pollution by the transport sector.

**Calculations of mortality**

First, it should be mentioned that the calculations and estimations of mortality in this paper are relatively coarse “back of the envelope” calculations, since it has not been possible to incorporate them directly in the transport and climate models within the resource limitations of the project. However, we believe the calculations are indeed illustrative for the effects on mortality for the evaluated policy bundles developed and evaluated for the case cities in the project.

Figure 4 depicts the estimation procedure, which is elaborated below.

*Figure 4: Mortality estimation procedure*

![Diagram of mortality estimation procedure](image)

First, data on the number of mortalities in the case cities due to PM$_{2.5}$ air pollution in the base year 2011 is established. Then transport’s share of emission has been collected from various reports estimating the share. Annual emissions of PM$_{2.5}$ in tonnes per year has then been calculated for 2011 for the case cities. Assuming transport’s share of emissions is equal to transport’s share of mortalities, the number
of mortalities in each case city was calculated. Assuming a reduction in mortalities is proportional to the reduction in PM2.5 emissions in horizon years 2030 and 2050 in the case cities, finally, the number of annual mortalities was estimated based on the estimated PM emissions under the BAU and policy bundles for each city.

Input from the CLIMATRANS paper produced by The Energy and Resources Institute (TERI) “Health impact assessment of air pollution in India and some of its cities” (see Sharma, et al., 2017a) has been used, where mortalities due to PM2.5 pollution in the air have been estimated for India and for Delhi, Mumbai and Bangalore for the base year 2011. The mortalities for the base year 2011 have been estimated to be 11,707, 6,109, and 3,337 for Delhi, Mumbai and Bangalore, respectively (Sharma, et al., 2017a p.7).

The project paper by Sharma, et al. (2017a) does not, however, specify the share of emissions of PM2.5 that can be attributed to emissions from the transport sector, nor the corresponding mortalities that can be associated to transport sector emissions. To arrive at an estimate for mortalities in the three cities in future related to transport sector emissions of PM2.5, it is therefore necessary to calculate the amount of emissions from the transport sector in the base year and compare that to the number of mortalities in 2011.

In the project paper “Emissions inventory for road transport in 3 cities” prepared by TERI (Sharma, et al., 2017b), daily emissions of PM2.5 in 2011 have been calculated, along with CO2, CO and other types of emissions. Daily emissions from the transport sector can then be converted to annual emissions. In Delhi’s case, daily PM2.5 emissions are estimated to 5.4 tonnes per day, yielding 1,971 tonnes per year (5.40 t/d x 365 days). For Mumbai 5.52 tonnes per day yields 2,015 tonnes per year; while 5.90 tonnes per day is equal to 2,154 tonnes per year in Bangalore.

It is then necessary to establish an estimate of the share of total PM2.5 emissions that can be attributed to transport in the three case cities. An estimate of such can be found for Delhi in Sharma & Dikshit (2016) http://delhi.gov.in/DoIT/Environment/PDFs/Final_Report.pdf. This report estimates a share of 0.170 or 17.0% contribution by the transport sector (vehicles) to PM2.5 concentrations in Delhi.

For Mumbai emission estimates can be found in the report “Air quality monitoring, emission inventory and source apportionment study for Indian cities”, prepared by the Central Pollution Control Board (CPCB), see http://cpcb.nic.in/FinalNationalSummary.pdf

The estimates for Mumbai show that 0.144 or 14.4% of emissions can be attributed to the transport sector.

In Bangalore’s case, the share of PM2.5 emissions is not directly available from the Central Pollution Control Board report, only PM10 emissions. According to TERI’s project researchers, PM2.5 emissions are, as rule-of-thumb, equal to 41% of PM10 emissions.
emissions. Based on the PM$_{2.5}$ to PM$_{10}$ ratio, transports’ share is then found to be equal to 0.47 or 47% of total PM$_{2.5}$ emissions in Bangalore, according to TERI’s researchers.

In the following estimations, we have then assumed that these ratios stay constant over time and apply for the horizon years, since there is as of today no available information to base such future ratios on.

The next step has been to calculate the base year total PM$_{2.5}$ emissions for the case cities based on the share of PM$_{2.5}$ emissions from the transport sector in the three cities.

Total emissions in the cities has then been calculated by dividing transport’s share by transport emissions measured in tonnes per year for each city. For Delhi, 1,971 tonnes per year from transport emissions at 17% yields 11,594 tonnes in total annual PM$_{2.5}$ emissions. The corresponding total emissions are 13,992 tonnes for Mumbai, and 4,582 tonnes for Bangalore, as shown in table 1 below.

<table>
<thead>
<tr>
<th></th>
<th>Delhi</th>
<th>Mumbai</th>
<th>Bangalore</th>
<th>Totals, all cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total PM$_{2.5}$ emissions, tonnes/year</td>
<td>11,594</td>
<td>13,992</td>
<td>4,582</td>
<td>30,168</td>
</tr>
<tr>
<td>PM$_{2.5}$ emissions from transport, tonnes/year</td>
<td>1,971</td>
<td>2,015</td>
<td>2,154</td>
<td>6,139</td>
</tr>
<tr>
<td>Total mortality, persons/year</td>
<td>11,707</td>
<td>6,109</td>
<td>3,337</td>
<td>21,153</td>
</tr>
<tr>
<td>Mortality attributed to transport, persons/year</td>
<td>1,990</td>
<td>1,039</td>
<td>1,568</td>
<td>4,597</td>
</tr>
</tbody>
</table>

Mortality is related to PM$_{2.5}$ concentration in the air (see Sharma et al., 2017a, among other sources cited). The PM$_{2.5}$ concentrations in future years in the case cities have not been calculated for the BAU (Business-As-Usual) scenario and the various policy bundles/scenarios evaluated in the project. In the following estimations, it has therefore been assumed a constant relationship of mortality to PM$_{2.5}$ emissions measured in in tonnes, rather than PM$_{2.5}$ concentrations in the air.

Since PM$_{2.5}$ emissions from the transport sector are estimated at 17.0%, 14.4% and 47.0% of total PM$_{2.5}$ emissions in Delhi, Mumbai and Bangalore, respectively, the assumption has been made that the same ratios apply for transport’s share to total mortalities in the three cities. For instance, based on an estimated number of annual mortalities due to PM$_{2.5}$ pollution in Delhi of 11,707 in 2011, at total of 1,990 (17%) of those mortalities can be estimated to be linked to emissions from the transport sector, as shown in table 1. Likewise, annual mortalities due to transport sector PM$_{2.5}$ emissions are estimated to be 1,039 for Mumbai and 1,568 in Bangalore.
Estimations of mortality in three cities

In the following estimations for the case cities, inputs on PM$_{2.5}$ emissions have been taken from the respective CLIMATRANS mitigation policy bundle evaluation reports for Delhi, Mumbai and Bangalore. Table 2 summarises the PM$_{2.5}$ emissions under the BAU and policy bundles for the three cities.

Table 2: Emissions of PM$_{2.5}$ in tonnes per year, by BAU and policy scenario for case cities.

<table>
<thead>
<tr>
<th></th>
<th>Delhi PM$_{2.5}$ t/y</th>
<th>Mumbai PM$_{2.5}$ t/y</th>
<th>Bangalore PM$_{2.5}$ t/y</th>
</tr>
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<tbody>
<tr>
<td>Base 2011</td>
<td>1971*</td>
<td>Base 2011</td>
<td>2015*</td>
</tr>
<tr>
<td>BAU 2030</td>
<td>316</td>
<td>BAU 2031</td>
<td>341</td>
</tr>
<tr>
<td>BAU 2050</td>
<td>259</td>
<td>BAU 2050</td>
<td>338</td>
</tr>
<tr>
<td>PB1 2030</td>
<td>173</td>
<td>BAU 2031 w/EV</td>
<td>172</td>
</tr>
<tr>
<td>PB1 2050</td>
<td>94</td>
<td>BAU 2050 w/EV</td>
<td>176</td>
</tr>
<tr>
<td>PB2 2030</td>
<td>143</td>
<td>PB1 2031</td>
<td>326</td>
</tr>
<tr>
<td>PB2 2050</td>
<td>106</td>
<td>PB1 2050</td>
<td>324</td>
</tr>
<tr>
<td>PB3 2030</td>
<td>243</td>
<td>PB1 2031 w/EV</td>
<td>165</td>
</tr>
<tr>
<td>PB3 2050</td>
<td>137</td>
<td>PB1 2050 w/EV</td>
<td>178</td>
</tr>
<tr>
<td>Comb. PB1 v/EM 2030</td>
<td>134</td>
<td>PB2 2031</td>
<td>276</td>
</tr>
<tr>
<td>Comb. PB1 v/EM 2050</td>
<td>43</td>
<td>PB2 2050</td>
<td>288</td>
</tr>
<tr>
<td>Comb. PB2 v/EM 2030</td>
<td>110</td>
<td>PB2 2031 w/EV</td>
<td>147</td>
</tr>
<tr>
<td>Comb. PB2 v/EM 2050</td>
<td>33</td>
<td>PB2 2050 w/EV</td>
<td>179</td>
</tr>
</tbody>
</table>

* Base year 2011 emissions are estimated based on daily emissions of PM$_{2.5}$ calculated by TERI (cf. Sharma et al., 2017b) for the case cities. Remaining figures for the horizon years are calculated in the respective case city reports.

To estimate mortalities for the horizon years 2030 and 2050 under the BAU scenarios and policy scenarios, it is assumed that the number of mortalities are proportional to the estimated level of PM$_{2.5}$ emissions measured in tonnes per year under the different scenarios. For instance, if the level of PM$_{2.5}$ emissions is reduced by 50% by a given policy bundle, the number of mortalities is also assumed reduced by 50%, or a reduction in emissions by 70% will result in 70% less mortalities in the horizon years, and so forth.

When considering the following estimations of the mortalities in future years (horizon years 2030 and 2050) one should make note of the “inherent” PM$_{2.5}$ reductions assumed to take place in the future. Fortunately, due to e.g., presumably cleaner fuels, energy efficiency and vehicle technology, and mode shifts to lower emission transport etc., the emissions of PM$_{2.5}$ can be significantly reduced from the base level year, even under the BAU scenarios. For instance, daily emissions of PM$_{2.5}$ for horizon year 2030 are estimated by Sharma et al. (2017b) to drop from 5.4 tonnes per day to only 0.9 tonnes per day in 2030, and 0.8 tonnes per day in 2050, even without policy intervention beyond the BAU. It means that estimated mortalities due
to PM$_{2.5}$ emissions will be much lower than in the base year, even under the BAU scenarios, in all the three case cities.

We refer to the individual case city mitigation policy bundle evaluation reports for more details on the methodical approach, data and assumptions used for the calculations, and a detailed description of the respective policy scenarios for each city (cf. Chandel, et al., 2017; Gupta & Saini, 2017; & Verma, et al., 2017). In addition, details on the various types emissions estimated for the base years, BAU and the policy scenarios can be found in the individual case city reports.

Figure 5 below shows the estimated number of mortalities in Delhi for the base year 2011 compared with the BAU scenario and the policy scenarios evaluated in the project for the horizon years 2030 and 2050.

The estimations show that the number of mortalities will be reduced from 1990 in the base year 2011 to about 447 in 2030 with the BAU scenario in Delhi. With implementation of a policy scenario (Policy bundle 2) focusing on Travel Demand Management (TDM) the number of mortalities can be further reduced to 322 per year in 2030; that is 27 percent less than the estimated mortalities under the BAU scenario. A TDM policy bundle combined with an electric mobility policy can reduce the number further to about 111 mortalities, about one third of that under the BAU.

The estimations show that implementing the BAU scenario for 2050 will reduce the number of mortalities to 295 in 2050. Again, the TDM and electric mobility combination of policies is estimated to reduce the number to only 33 mortalities per year in 2050.

Moving on to the estimations for Mumbai, Figure 6 below shows a similar pattern. The number of mortalities due to transport sector PM$_{2.5}$ emissions are estimated at
1,039 in 2011. Following the BAU path, the annual mortalities can be bought down to 176 in 2030. The BAU scenario combined with an electric vehicle policy can cut the number of mortalities to 89 per year in 2030, whereas Policy bundle 2 in combination with an electric vehicle policy can reduce the number to 76.

Policy bundle 2 combines Policy 2, the Draft Mumbai Metropolitan Regional Plan 2016-36 scenario with Policy 3 Transport Infrastructure Development, and Policy 4 Travel Demand Management in Mumbai (see the Mumbai mitigation report for details).

There are only minor differences in the estimates from 2030 to 2050, where both BAU, Policy bundle 1 and Policy bundle 2 in combination with electric vehicle policy yields about equal estimates, around 90 mortalities per year in Mumbai.

Figure 7 shows the estimation of mortalities for the base year 2011 and the BAU and policy scenarios for horizon years 2030 and 2050 for Bangalore. These is a huge reduction in estimated mortalities even when following the BAU track, bringing mortalities down from 1,568 in 2011 to 103 mortalities in 2030. All policy scenarios are estimated to lead to a further reduction in mortalities. Among the stand-alone bundles, Policy bundle 3 is a comprehensive bundle, combining all of the following policies:

- Increasing network coverage of Public Transit
- Defining car restricted zones
- Congestion Pricing
- Park and Ride
- Cycling and Walking infrastructure
- Encouraging car-pooling and High Occupancy Lanes
- High density mix building use along main transport corridors

Adding an EV policy, Policy bundle 4 (Policy bundle 3 combined with electric vehicles) can be considered the “best” in terms of reductions in mortality. The number of mortalities estimated under Policy bundle 4 is 52, approximately half of the estimated number for the BAU in 2030.

**Figure 7: Estimations of mortality in Bangalore**

For horizon year 2050, implementing Policy bundle 4 can reduce the estimated number of mortalities from 85 to 27 compared to the BAU. The “best” policy bundle, without factoring in electric vehicles, is Policy bundle 3, with an estimated 83 mortalities in 2030 and 69 in 2050.

**Conclusions**

Air pollution represents a serious problem in India’s megacities, and in this paper we have considered the estimated effects of PM$_{2.5}$ emissions by the transport sector (i.e., tailpipe emissions) on mortality numbers in Delhi, Mumbai and Bangalore in the future.
On the positive side, an “natural” reduction in mortality will come as a result of significantly lower emissions of PM$_{2.5}$ per VKT in the future, probably as a result of cleaner fuels, better exhaust cleaning technology, vehicle energy efficiency and mode shifts to lower emission transport, etc. The PM$_{2.5}$ emissions are therefore greatly reduced even when following a BAU pathway for all three cities.

However, implementing policy bundles or scenarios that can bring down PM$_{2.5}$ emissions even more can save additional lives in all the three case cities, according to our estimations. Considering the social and economic loss of premature deaths, all lives saved are immensely important. A significant introduction of electric vehicles will have a very positive impact on all types of vehicular emissions. For instance, implementing the “best” policy bundle combined with electric mobility/vehicles, can bring down the estimated number of mortalities to about one third in Delhi compared to the BAU in 2030. In Mumbai the “best” policy bundle including EVs, can reduce mortalities with more than half the number. The case is similar in Bangalore, where the best policy bundle can cut the amount of mortalities to about one half compared to the BAU in 2030.

In 2050 the best policy bundle in Delhi only represent about 11% of the mortalities estimated under the BAU. In Mumbai, the estimated number of mortalities is only about 52% of the BAU estimates, and in Bangalore the number of deaths are only 32% of the corresponding BAU estimate for 2050.

In conclusion, even though one can expect a great drop in mortality rates attributed to PM$_{2.5}$ emissions due to other factors than implementing the suggested policy bundles, these policy bundles will, however, have a significant effect on reducing mortalities even further. This is particularly the case when including policies that will increase the share of electric mobility/vehicles. In addition to other very positive effects on e.g. GHG emissions, these policy bundles can potentially save many lives per year in the future in Delhi, Mumbai and Bangalore, as shown in this paper.

Public policy and environmental regulations on air quality have proven to be successful, at least to some degree, in India the last few decades. According to a MIT study (Greenstone & Hanna, 2013), the air pollution regulations in India were responsible for substantial improvements in air quality, indicating that environmental regulation can succeed in India.

Future research in this area could focus on even better estimation models for mortality, taking into account both transport and climate modelling to arrive at estimates of PM$_{2.5}$ air concentrations in future years, rather than emissions measured in tonnes.

Moreover, research on the impact of other pollutants from transport than PM$_{2.5}$ on population health is called for, as well as other important health effects apart from mortalities (diseases, wellbeing, liveability, etc.) in the case cities, as well as elsewhere in India and globally. Good estimates of the economic cost of lives lost/saved, morbidity and other social costs for Indian cities will also add to the value of future research.
References

Central Pollution Control Board (2011) “Air quality monitoring, emission inventory and source apportionment study for Indian cities - National Summary Report”


