Short-lived pollutants: Health and climate impacts of diesel black carbon emissions

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Particulate pollution:
Ninth largest killer in the world

Global Burden of Disease
Fifth largest killer in India......

More than 18 million healthy life years lost due to air pollution. Air pollution triggers stroke, cardiovascular and respiratory diseases, cancer.....

Air pollution is the 5th largest killer in India......
Strong link with lung cancer

<table>
<thead>
<tr>
<th>Toxic Air Contaminant</th>
<th>Unit Risk/Million People</th>
<th>Detection limit (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>2.7</td>
<td>0.10</td>
</tr>
<tr>
<td>Benzene</td>
<td>29</td>
<td>0.05</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>170</td>
<td>0.04</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>42</td>
<td>0.02</td>
</tr>
<tr>
<td>Chromium, Hexavalent</td>
<td>150,000</td>
<td>0.06 (in nanogram)</td>
</tr>
<tr>
<td>Para-Dichlorobenzene</td>
<td>11</td>
<td>0.30</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>6</td>
<td>0.10</td>
</tr>
<tr>
<td>Methylene Chloride</td>
<td>1</td>
<td>0.10</td>
</tr>
<tr>
<td>Perchloroethylene</td>
<td>5.9</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Diesel particulate matter</strong></td>
<td><strong>300</strong></td>
<td><strong>N/A</strong></td>
</tr>
</tbody>
</table>

Note: Unit Risk represents the number of excess cancer cases per million people per micromg of TAC concentration over a 70 year lifetime exposure. A diesel particulate matter unit risk value of 300 is used as a reasonable estimate in the “Risk Reduction Plan to reduce Particulate Matter Emissions from Diesel Fuelled Engines an vehicles (ARB, October 2000).”

Source: California Air Resource Board
Also a climate rogue....
Emerging science has implicated black carbon as climate forcer:

**Warming impacts**-- Black carbon absorbs radiative heat from the sun and warms everything around it. UNEP 2011– Reducing short term forcers is likely to slow down the rate of global warming over the next two to four decades -- Long lived CO2 is steadily pushing up global temperature but short lived climate forcers accelerate short spikes.

**Albedo effect – melts snow**-- Black carbon falls onto snow and ice and changes the overall reflectivity of those surfaces, accelerate melting, -- exposes the darker ground or water, causing even faster warming.

**Affects rainfall**-- Black carbon interacts with clouds and affects
PM vs BC?

**Particulate Matter**

- All combustion processes
- All dust generating activities
- Secondary particulates – Nitrates and sulfate
- The condensation of gases into liquid droplets

**Black Carbon**

- Part of PM2.5........
- Low temperature combustion of carbonaceous fuels
- Incomplete combustion....
- These last up to one week or little more in the atmosphere
There are many sources of black carbon….But warming and cooling fraction vary depending on source

- Diesel vehicles (particle filters+)
- Coal briquettes replacing coal in residential stoves
- Pellet stoves & boilers replacing residential wood burning in industrialized countries
- Clean-burning cookstoves in developing countries
- Modern brick kilns
- Modern coke ovens
- Ban of open burning of agricultural waste
Global warming potential of short lived gases: IPCC Report (AR5 WGI)

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Notation</th>
<th>GWP 20-year</th>
<th>GWP 100-year</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
<td>CO₂</td>
<td>1</td>
<td>1</td>
<td>AR5 WG1, Table 8.A.1</td>
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<tr>
<td>Carbon Monoxide</td>
<td>CO</td>
<td>18.6</td>
<td>5</td>
<td>AR5 WG1, Table 8.A.4; from Shindell et al. (2009)</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>SO₂</td>
<td>-268</td>
<td>-71</td>
<td>AR5 WG1, 8SM-23; from Shindell et al. (2009)</td>
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<tr>
<td>Oxides of Nitrogen</td>
<td>NOₓ</td>
<td>-560</td>
<td>-149</td>
<td>AR5 WG1, Table 8.A.3; from Shindell et al. (2009)</td>
</tr>
<tr>
<td>Fossil Methane</td>
<td>CH₄</td>
<td>85</td>
<td>30</td>
<td>AR5 WG1, Table 8.A.1</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>N₂O</td>
<td>264</td>
<td>265</td>
<td>AR5 WG1, Table 8.A.1</td>
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<tr>
<td>Black Carbon</td>
<td>BC</td>
<td>3200</td>
<td>846</td>
<td>AR5 WG1, Table 8.A.6; from Bond et al. (2013)</td>
</tr>
<tr>
<td>Organic Carbon</td>
<td>OC</td>
<td>-160</td>
<td>-43</td>
<td>AR5 WG1, Table 8.A.6; from Bond et al (2011)</td>
</tr>
</tbody>
</table>

There are several and varying sets of values

Bottom line – It affects health and climate.

AR5 WGI for the first time included various available estimates of GWP
Some cool and some warm.....

Global Radiative Forcing Since the Industrial Revolution:
Mix of cooling and warming PM varies in different sources

Ratio of black carbon to organic carbon

Smoke from open burning of biomass or wildfires appears gray because of the high ratio of OC which scatters sunlight and therefore appears light colored.

Soot from diesel combustion appears black because of its high content of black carbon, the light-absorbing component of aerosols.

Note: All sources emit significant quantities of other pollutants that may warm or cool the climate, including CO₂ (warming), NOₓ (ozone and N₂O warming, nitrate cooling), and SO₂ (sulfate cooling).

SOURCE: Non-CO₂ Climate Forcers Report (2010), Bond (2007), GAINS
This science influence the position of regions region-wise quantum of aerosols and their sources

`Bounding the role of black carbon` Report 2013: Residential solid fuels -- 60 to 80% of Asian and African emissions; All diesel engines -- about 70% of emissions in Europe, North America and Latin America.

Net annual BC inventory by region and sector: BC inventory is offset by corresponding OC inventory.

Gross annual BC emission by region and sector: Region of North America excludes Mexico while Pacific region includes Japan. Efforts Emphasize Air Quality Co-Benefits
Black carbon emissions from transport sector.....
Global BC from transportation sector

Source: World Bank 2014
Reflection of increased vehicle activity.....

Figure 1-2: Vehicle Activity Forecast By Region, to 2050. Source: Data from Facanha et al. (2012).

Source: World Bank 2014
Vehicles responsible for ~25% of global black carbon emissions

Source: Bond et al., GBC 2007 + van der Werf, 2006 + updates for IPCC AR5

UNEP: Sectoral emissions of BC in India. In India transport is responsible for 21%

Science is more certain about warming impact of diesel black carbon........
'Bounding the role of black carbon' Report 2013:
-- Globally diesel BC is expected to be 20 per cent of the total BC emissions
-- Total emissions from gasoline are less than 10% of diesel BC emissions, although gasoline vehicles are more numerous.
Challenge of black carbon emissions from vehicles

Black carbon fraction is high in all diesel uses

- Gasoline, all vehicles
- Diesel, railroad
- Diesel and heavy oil, ships
- Diesel, non-farm off-road vehicles
- Diesel, farm vehicles
- Diesel, superemitter
- Diesel, on-road general
- Diesel, on-road general
- Aviat on fuel, aircraft

Share of BC sources vary across regions

- EU emissions remain significant, despite historic reductions
- In regions where agricultural burning is controlled (Europe, North America), diesel higher proportion of total (>50%)

Source: Richard o Sullivan 2012
In US the biggest BC challenge is diesel.
Per capita BC emissions is high in the US

Ref: Ramanathan and Leng, 2008; Data source: Bond et al 2004
Europe has initiated assessment of BC policies
Impact of current and planned legislation on BC emissions in the EU28, kt

Source: IIASA – recent GAINS calculations
Black carbon emissions by transportation by region among top 10 motorised nations 2000-2050

Source: World Bank and ICCT 2014
Impact of emissions standards roadmap .... Air quality and health policy driving stringency of emissions standards
BC reduction technologies become effective only after Euro V standards

Source: Richard o Sullivan 2012
Very high ratio of Black Carbon to Organic Carbon

Black carbon share of PM2.5 emissions for diesel vehicles for European standards (in %)

<table>
<thead>
<tr>
<th></th>
<th>Euro I</th>
<th>Euro II</th>
<th>Euro III</th>
<th>Euro IV</th>
<th>Euro V</th>
<th>Euro VI</th>
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<tbody>
<tr>
<td>LDV</td>
<td>70</td>
<td>80</td>
<td>72</td>
<td>69</td>
<td>25</td>
<td>25</td>
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<tr>
<td>Bus</td>
<td>65</td>
<td>65</td>
<td>61</td>
<td>83</td>
<td>83</td>
<td>7</td>
</tr>
<tr>
<td>LHDT</td>
<td>70</td>
<td>81</td>
<td>72</td>
<td>69</td>
<td>23</td>
<td>25</td>
</tr>
<tr>
<td>MHDT</td>
<td>70</td>
<td>80</td>
<td>72</td>
<td>68</td>
<td>23</td>
<td>25</td>
</tr>
<tr>
<td>HHDT</td>
<td>65</td>
<td>65</td>
<td>61</td>
<td>83</td>
<td>83</td>
<td>8</td>
</tr>
</tbody>
</table>

Source: World Bank 2014
Diesel fuel sulphur levels: global status

Source: UNEP, Partnership for Clean Fuels and Vehicles, Diesel fuel sulphur levels: Global status, April 2014

*Information in parts per million (ppm)
For additional details and comments per country, visit www.unep.org/transport/pcfv/
Emission standard status 2012: most regions in Africa have no policy/ or unknown

Vehicle Emissions Standards

- Above Euro 3
- Euro 3
- Below Euro 3
- No Policy / Unknown

October 2012
www.unep.org/pcfv
Euro IV standards in India

Refineries and Fuel Standards in India

BS-IV standards implemented

Refineries
Capacity (MMTPA)
- 0.1
- 1
- 10

* indicates refineries still under construction

Major roadways

Source: Based on market data

1 The National Capital Region (NCR) comprises four constituent sub-regions: the Haryana sub-region (Faridabad, Gurgaon, Mewat, Rohtak, Sonipat, Rewari, Jhajjar, Panipat and Palwal), the Uttar Pradesh sub-region (Meerut, Ghaziabad, Gautam Budha Nagar, Bulandshahr, and Bijnor), the Rajasthan sub-region (Alwar district), and the National Capital Territory (NCT) of Delhi.
Challenge of dieselization in India...
Dieselised……..

Jump from 4% in 200 to 49% in 2011

In popular car models the share of diesel car is 70-75%

After price deregulation some decline in diesel car sales reported.

Even at a moderate and flat growth rate of 20 per cent a year, the total diesel cars in 2020 will be double the size of the total car sales today.

Source: Based on market data
Price Differential between Petrol and Diesel

Price differential

Price differential (Rs per litre)

Price (Rs/Litre)

Petrol (Rs/litre)

Diesel (Rs/litre)
Cheap diesel is pushing market towards bigger cars that guzzle more fuel

2012 -- Petrol car sales higher in small car segment -- 87% of petrol cars are below 1200 cc. More than 40% of the diesel cars are above 1500 cc

Source: Based on market data
Why diesel makes us climate insecure?

Black carbon emissions from diesel vehicles are several times more heat trapping than CO₂.

CO₂ emissions from the upstream diesel refining process will increase: European Commission has found lifetime pollution costs of Euro IV compliant diesel car is much higher than petrol cars.

Rebound Effect: Diesel fuel has higher carbon content than petrol. If more diesel is burnt encouraged by its cheaper prices and more driving, more heat-trapping CO₂ will escape.

Nullifies marginal greenhouse gas reduction benefit of diesel car …..
Unacceptable time lag
-- Bharat Stage III 12 years behind Europe
-- Bharat stage IV seven years behind

Diesel car emission norm trajectory and India’s position

During 12th plan refinery capacity will expand 1.6 times.

Proposed roadmap:
Euro IV nation-wide in 2017-18
Euro V: 2020-21 (with 10 ppm sulphur fuel)
Euro VI: 2024

Source: based on European Commission, MORTH, India, Diesel Net
Global move towards Clean diesel
It is possible to reduce harmful diesel emissions drastically.
But India is dieselising without clean diesel

We need clean diesel (10 ppm sulphur) along with advanced after treatment system.

Need a fiscal strategy to meet the cost of makeover

Source: ICCT
Much cleaner diesel vehicles are possible, through stricter standards and clean diesel fuel.

- **No retrofit system**
  - Uncontrolled Diesel Exhaust (Level 1)
  - Old technology
  - Little black carbon removal
  - Little ultrafine PM removal
  - Does not remove lube oil ash

- **Retrofitted with Diesel Oxidation Catalyst (DOC)**
  - (Level 1)
  - Old technology
  - Little black carbon removal
  - Little ultrafine PM removal
  - Does not remove lube oil ash

- **Retrofitted with Partial Filter**
  - (Level 2)
  - Little black carbon removal
  - Little ultrafine PM removal
  - Does not remove lube oil ash

- **Retrofitted with Diesel Particulate Filter (DPF)**
  - (Level 3)
  - New Technology
  - Used on all new trucks since 2007
  - >85% black carbon removal
  - >85% ultrafine removal
  - >85% lube oil ash removal

- Cleaire Advanced Emission Controls LLC
Clean fuel and public transport: A win-win....
Delhi CNG programme

New study shows that in comparison with the warming potential of black carbon emissions from the older diesel fleet, CNG has been less warming.....

-- When black carbon from diesel is not considered estimated CO2 (e) increase due to switch

-- When black carbon is taken into account -- switch is carbon neutral
Upto 30% reduction in CO2 (e)

Source: Conor Reynolds and M Kandlikar, British Columbia
2008
Example of BC contribution for one specific vehicle

Euro III double deck bus tested over MLTB on chassis dyno

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 g/km over cycle</td>
<td>1500</td>
</tr>
<tr>
<td>PM g/km over cycle</td>
<td>0.35</td>
</tr>
<tr>
<td>Typical %C in PM</td>
<td>70</td>
</tr>
<tr>
<td>Net BC g/km in PM</td>
<td>0.245</td>
</tr>
<tr>
<td>GWP of BC over 20 years*</td>
<td>2000</td>
</tr>
<tr>
<td>Net effect of PM as CO2 g/km equivalents</td>
<td>490</td>
</tr>
<tr>
<td>GWP as % of CO2 emissions</td>
<td>33%</td>
</tr>
</tbody>
</table>

*Bond estimate for US Senate hearing 2007

Source: Richard o Sullivan 2012
Bus and clean fuel in Chile

Source: Gianni López
Centro Mario Molina Chile
BRT programme based on clean diesel in Mexico city....

Fuel savings and CO2 savings of a BRT corridor in Mexico City

- CO2 Reduction (modeshift from car to bus, bus switch and reduction in parallel traffic)
- Fuel Savings (modeshift from car to bus, bus switch and reduction in parallel traffic)
- Air Pollution/Health Benefits from lower air pollution
- VKt external costs -- reduction in all traffic
- Time Savings of Bus Riders

ADB 2009
Economic benefits with costs associated with ultra-low sulphur fuel production and cleaner vehicles.

Economies of scale stabilize costs in the long-term benefits far outweigh costs.

Benefits continue to rise, as vehicle population increases and lower ambient PM2.5 concentrations reduce premature mortality.

**World Bank study for India (July, 2013):**
Outdoor air pollution is 29% of the total environmental damages
Health cost of PM10 – 3% of GDP
PM10 mitigation cost less than 1% of GDP
Annual savings from health benefits can be more than USD 100 billion
CO2 emissions can be reduced by upto 60%
Action on diesel – ensures both health and climate benefits

Need harmonised national action across regions to accelerate air quality policies and emissions standards roadmap to quickly phase in clean diesel…..

Technical solutions exist. Need effective standards for their quick uptake. Need both stringent PM mass standards as well as PM number standard.

Need stringent programme for in-use fleet especially heavy duty vehicles

Need public transport on clean fuels

Need fiscal policy to enable introduction of clean diesel fuel and vehicles

Alternative fuel strategy

Promote public transport, walk and cycle
Do you think we are not seeing the point?

Thank You.....