A global snapshot of the air pollution-related health impacts of transportation sector emissions in 2010 and 2015

Authors: Susan Anenberg, George Washington University Milken Institute School of Public Health; Joshua Miller, International Council on Clean Transportation; Daven Henze, University of Colorado, Boulder; Ray Minjares, International Council on Clean Transportation


Contact: Joshua Miller (josh@theicct.org)
Author team

Dr. Susan Anenberg, Associate Professor
George Washington University
Washington, DC, USA
Project manager – health modeler

Dr. Daven Henze, Associate Professor
University of Colorado, Boulder
Boulder, CO, USA
Global air quality modeler

Josh Miller, Senior Researcher
International Council on Clean Transportation
San Francisco, CA, USA
Vehicle emissions modeler

Ray Minjares, Clean Air Program Lead
International Council on Clean Transportation
San Francisco, CA, USA
ICCT Project Manager

Review panel members:
• Bianca Bianchi Alves – World Bank
• Michael Brauer – University of British Columbia, member of CCAC Science Advisory Panel
• Thiago Hérick de Sá – World Health Organization, contributor to CCAC Health Initiative
• Reto Thönen – Swiss Agency for Development and Cooperation, contributor to CCAC Heavy Duty Vehicles Initiative
The study evaluated only the impacts of tailpipe emissions and excluded other transportation health impacts. Applying GBD 2017 methods, it considered health impacts from direct exposure to PM\textsubscript{2.5} and ozone, not NO\textsubscript{2}, which is associated with asthma incidence among children and asthma emergency department visits. Estimated PM\textsubscript{2.5} and ozone health impacts are likely undercounted for several reasons; see the paper for discussion.
The study evaluated the health burden attributable to tailpipe emissions of four transportation subsectors.

- **On-road diesel vehicles** include passenger cars, light commercial vehicles, trucks, and buses with diesel engines. In China and India, this category includes three-wheeled freight vehicles used for on-road applications. Diesel is the principal fuel; these activities also include a small share of biodiesel typically blended into diesel fuels.

- **On-road non-diesel vehicles** include passenger cars, light commercial vehicles, two-wheeled vehicles, and three-wheeled vehicles, as well as trucks and buses fueled by gasoline, LPG, CNG, electricity, or other non-diesel fuels.

- **Non-road mobile sources** include rail, agricultural equipment, construction machinery, inland shipping, and other non-road mobile machinery. Most of these activities are fueled by diesel; some are fueled by gasoline, LPG, electricity, or other fuels. Rail is the principal source of electricity consumption.

- **International shipping** includes container ships, bulk carriers, cargo ships, tankers, cruise ships, fishing vessels, ferries, and other service vessels. The main fuels for these activities are residual fuels, which include heavy fuel oil; diesel, also referred to as distillates; and a smaller amount of LNG.

### Table 1. Definition of transportation subsectors evaluated in this study.

<table>
<thead>
<tr>
<th>Transportation Subsector</th>
<th>Main Fuel Types</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-road diesel vehicles</td>
<td>Diesel</td>
<td>ICCT (Miller &amp; Jin, 2018)</td>
</tr>
<tr>
<td>On-road non-diesel vehicles</td>
<td>Gasoline, LPG, CNG</td>
<td>IIASA (ECLIPSE v5a)</td>
</tr>
<tr>
<td>Non-road mobile sources</td>
<td>Diesel, gasoline, LPG, electricity</td>
<td>IIASA (ECLIPSE v5a)</td>
</tr>
<tr>
<td>International shipping</td>
<td>Residual fuels, diesel, LNG</td>
<td>ICCT (Comer et al, 2017)</td>
</tr>
</tbody>
</table>
Six air quality simulations estimate concentrations (1) with all emissions and (2-5) zeroing out each subsector and (6) all transportation emissions.

These simulations allowed the calculation of, for each pollutant (PM$_{2.5}$ and ozone), country, source category, and year:

- **Transportation Attributable Concentration (TAC).** The difference in concentrations from zeroing out a given source category compared with the base case (i.e. the absolute contribution of that source category to ambient air pollution, in units of concentration).

- **Transportation Attributable Fraction (TAF).** The fractional difference in total mortality from the zero-out scenario compared to the baseline (i.e. the percent of total air pollution mortality attributable to transportation tailpipe emissions and each subsector).

Unlike TAC, TAF is influenced by non-transportation emission sources, since the denominator is total PM$_{2.5}$ and ozone mortality, which are affected by many different emission sources.
Gridded transportation health impacts were calculated using gridded total ambient PM$_{2.5}$ and ozone burdens and TAF.

1. Gridded burden of disease from total ambient PM$_{2.5}$ and ozone
   - Mortality, disability adjusted life years (DALYs), years of life lost (YLL)
   - PM$_{2.5}$ health impacts: ischemic heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, lower respiratory infection
   - Ozone health impacts: chronic respiratory disease
   - Baseline disease rates from IHME for 2010 and 2015
   - Gridded impacts (0.1 x 0.1 degree) summed to national and urban boundaries

2. Health impacts from transportation tailpipe emissions
   - Multiply gridded PM$_{2.5}$ and ozone health impacts by TAF for each subsector
   - Avoids dependency of results on order in which emissions were zeroed out
   - Avoids potential biases in air quality modeling, which largely cancel out in TAF
   - TAF could be applied to future estimates as health impact methods advance
The United States also had high TAFs of 25% for PM$_{2.5}$ and 12% for ozone in 2010. As in the EU, one potential factor in a high TAF is a low denominator, indicating successful efforts to control emissions from other sources. The U.S. PM$_{2.5}$ TAF declined 13% from 2010 to 2015 (from 25% in 2010 to 21% in 2015), indicating that the introduction of world-class standards in the United States (e.g., Tier 2 LDV standards and EPA 2010 HDV standards) resulted in the contribution of transportation sources declining faster than other sectors over that period.

Figure 3. National population-weighted transportation-attributable fraction (TAF) for PM$_{2.5}$ and ozone in 2010 and 2015.

Figure 4. Maps showing the change in national population-weighted average transportation-attributable concentrations from 2010 to 2015 (annual average for PM\textsubscript{2.5}, 6-month average of the 8-hour daily maximum for ozone).

Table 3. Global air quality and health impacts of transportation tailpipe emissions in 2010 and 2015. For premature deaths, 95% confidence intervals reflect uncertainty in the relative risk estimate only.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
<th>Metric</th>
<th>2010</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation-attributable concentration (TAC)</td>
<td>How much do tailpipe emissions from transportation sources contribute to global population-weighted air pollutant concentrations? Units: depends on pollutant</td>
<td>annual average PM$_{2.5}$</td>
<td>2.9 µg/m$^3$</td>
<td>3.0 µg/m$^3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-month average of the 8-hour daily maximum ozone</td>
<td>5.5 ppb</td>
<td>5.6 ppb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>annual average BC</td>
<td>0.2 µg/m$^3$</td>
<td>0.2 µg/m$^3$</td>
</tr>
<tr>
<td>Transportation-attributable deaths</td>
<td>How many premature deaths are associated with global transportation-attributable concentrations of PM$_{2.5}$ and ozone? Units: thousands (95% confidence interval)</td>
<td>ambient PM$_{2.5}$ deaths</td>
<td>312 (240–386)</td>
<td>330 (255–408)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ambient ozone deaths</td>
<td>49 (18–76)</td>
<td>55 (20–85)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total ambient PM$_{2.5}$ and ozone deaths</td>
<td>361 (258–462)</td>
<td>385 (274–493)</td>
</tr>
<tr>
<td>Transportation-attributable fraction (TAF)</td>
<td>What fraction of ambient air pollution deaths are attributable to tailpipe emissions from transportation sources? Units: percent</td>
<td>PM$_{2.5}$</td>
<td>11.9%</td>
<td>11.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ozone</td>
<td>10.4%</td>
<td>10.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total PM$_{2.5}$ and ozone</td>
<td>11.7%</td>
<td>11.4%</td>
</tr>
<tr>
<td>Transportation health damages</td>
<td>What is the welfare loss due to global transportation-attributable deaths? Units: 2015 US$</td>
<td>PM$_{2.5}$</td>
<td>$900 billion</td>
<td>$891 billion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ozone</td>
<td>$70 billion</td>
<td>$85 billion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total PM$_{2.5}$ and ozone</td>
<td>$970 billion</td>
<td>$976 billion</td>
</tr>
</tbody>
</table>

Figure 8. Transportation-attributable PM$_{2.5}$ and ozone deaths, associated mortality rates, and population in G20 economies in 2015.

Globally and for each trade bloc, transportation-attributable fractions (TAF) of combined PM$_{2.5}$ and ozone deaths in 2015, broken out by subsector.

AMU = Arab Maghreb Union (North Africa); ASEAN = Association of Southeast Asian Nations; CARICOM = Caribbean Community; CEMAC = Central African Economic and Monetary Community; CIS = Commonwealth of Independent States; EAC = East African Community; ECOWAS = Economic Community of West African States; EU & EFTA = European Union and European Free Trade Association; GCC = Gulf Cooperation Council; MERCOSUR = Southern Common Market (South America); NAFTA = North American Free Trade Agreement; SAARC = South Asian Association for Regional Cooperation; SADC = Southern African Development Community; SICA = Central American Integration System.

Figure 11. National total PM$_{2.5}$ and ozone mortality that is attributable to transportation emissions in 2015 in major trade blocs globally, using central relative risk estimates.

AMU = Arab Maghreb Union (North Africa); ASEAN = Association of Southeast Asian Nations; CARICOM = Caribbean Community; CEMAC = Central African Economic and Monetary Community; CIS = Commonwealth of Independent States; EAC = East African Community; ECOWAS = Economic Community of West African States; EU & EFTA = European Union and European Free Trade Association; GCC = Gulf Cooperation Council; MERCOSUR = Southern Common Market (South America); NAFTA = North American Free Trade Agreement; SAARC = South Asian Association for Regional Cooperation; SADC = Southern African Development Community; SICA = Central American Integration System.
Figure 13. Transportation-attributable PM$_{2.5}$ and ozone deaths, associated mortality rates, and population by trade bloc in 2015.

Figure 14. Total number of transportation-attributable PM$_{2.5}$ and ozone deaths in 2015 by urban area.

Bubble size indicates total number of transportation-attributable PM$_{2.5}$ and ozone deaths using central relative risk estimates. Bubble color indicates transportation-attributable fraction (TAF) of total PM$_{2.5}$ and ozone deaths.

Table A3. Comparison of global results from this study with other estimates in the literature.

<table>
<thead>
<tr>
<th>Study</th>
<th>Analysis year</th>
<th>Sector description</th>
<th>Methods</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>2010</td>
<td>Tailpipe emissions from on-road diesel, other on-road, shipping, non-road mobile sources</td>
<td>PM&lt;sub&gt;2.5&lt;/sub&gt;, RR: GBD 2017 IER Ozone RR: GBD 2017 Resolution: 0.1° x 0.1° Emissions: ICCT (Miller &amp; Jin, 2018), ECLIPSE (Klimont et al., 2017; Stohl et al., 2015)</td>
<td>Deaths: 361,000 (258,000–462,000) TAF: 11.7%</td>
</tr>
<tr>
<td>This study</td>
<td>2015</td>
<td>Tailpipe emissions from on-road diesel, other on-road, shipping, non-road mobile sources</td>
<td>Same as row 1</td>
<td>Deaths: 385,000 (274,000–493,000) TAF: 11.4%</td>
</tr>
<tr>
<td>Chambliss et al. (2014)</td>
<td>2005</td>
<td>all mobile equipment powered by gasoline and diesel engines such as on-road passenger vehicles and commercial trucks, rail transportation, off-road agricultural and construction equipment</td>
<td>PM&lt;sub&gt;2.5&lt;/sub&gt; only: GBD2010 IER Resolution: 0.5° x 0.67° Emissions: Representative Concentration Pathway 8.5 (van Vuuren et al., 2011)</td>
<td>Deaths: 242,000 TAF: 8.5%</td>
</tr>
<tr>
<td>Silva et al. (2016)</td>
<td>2005</td>
<td>Land transportation, shipping, and aviation</td>
<td>PM&lt;sub&gt;2.5&lt;/sub&gt;, RR: GBD2010 Ozone RR: Jerrett et al. (2009) Resolution: 0.5° x 0.67° Emissions: Representative Concentration Pathway 8.5 (van Vuuren et al., 2011)</td>
<td>Deaths: 376,000 TAF: 13.8% of anthropogenic PM&lt;sub&gt;2.5&lt;/sub&gt;- and ozone-related deaths</td>
</tr>
<tr>
<td>Weagle et al. (2018)</td>
<td>2014</td>
<td>Transportation</td>
<td>Concentration only Resolution: 0.1° x 0.1° Emissions: EDGAR v4.3 (Crippa et al., 2016), MIX (Li et al., 2017)</td>
<td>TAF: 8.6%</td>
</tr>
</tbody>
</table>

Note: RR = relative risk; IER = Integrated Exposure Response curve; ICCT = International Council on Clean Transportation; GBD = Global Burden of Disease; TAF = Transportation-attributable fraction.

Total number of transportation-attributable PM$_{2.5}$ and ozone deaths in 2015 for select urban areas in Europe.

Fact Sheet: Health Impacts of Air Pollution from Transportation Sources in Germany

Transportation-attributable deaths from PM$_{2.5}$ and ozone pollution, mortality rates, and population in 100 major urban areas, 2015.

Bubble color indicates the trade bloc in which an urban area is located. Bubble size indicates the transportation-attributable mortality rate per 100,000 population.


Fact Sheet: Health Impacts of Air Pollution from Transportation Sources in Paris