Understanding Urban Carbon Flux Quantification Information Systems

SOCCR2 and beyond

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The Urban Share

- Urban areas in North America are the **primary source** of anthropogenic carbon emissions, with cities responsible for a large proportion of **direct** emissions. These areas are also **indirect sources** of carbon through the emissions embedded in goods and services produced outside city boundaries for consumption by urban dwellers (medium confidence, likely).
Many **societal factors** drive urban carbon emissions, but the **urban built environment** and the regulations and policies shaping **urban form** (e.g., land-use) and **technology** (e.g., modes of transportation) play crucial roles. Such societal drivers can lock in dependence on fossil fuels in the absence of major technological, institutional, and behavioral change. Some fossil fuel–related infrastructure can have lifetimes up to 50 years (high confidence).
Key Findings continued

- Key **challenges** for urban carbon flux studies are **observational design**, **integration**, **uncertainty** quantification, and **reconciliation** of the multiple carbon flux approaches to detect trends and inform emissions mitigation efforts (medium confidence, likely).

- Improvements in **air quality** and **human health** and the reduction of the **urban heat island** are important **co-benefits** of urban carbon emissions mitigation (very likely, high confidence).
Key Findings continued

- Urban methane (CH$_4$) emissions have been poorly characterized, but the combination of improved instrumentation, modeling tools, and heightened interest in the problem is defining the range of emissions rates and source composition as well as highlighting infrastructure characteristics that affect CH$_4$ emissions (medium confidence).

- Urban areas are important sites for policy- and decision making that shape carbon fluxes and mitigation. However, cities also are constrained by other levels of government, variations in their sources of authority and autonomy, capacity, competing local priorities, and available fiscal resources (high confidence).
Ongoing work in many NA cities

<table>
<thead>
<tr>
<th>Domain</th>
<th>Framework, Scope, Boundary</th>
<th>Estimation Techniques</th>
<th>Sectors Estimated</th>
<th>References</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indianapolis, IN</td>
<td>In-boundary</td>
<td>Direct flux, activity-EF, and fuel statistics; airborne eddy flux measurement; isotopic atmospheric measurement; inverse modeling</td>
<td>All FF</td>
<td>Cambel et al. (2016); Gurney et al. (2012, 2017); Lanauz de et al. (2016); Turnbull et al. (2015)</td>
<td>Much of the work is space and time explicit; atmospheric monitoring includes CO₂, CO, and CH₄.</td>
</tr>
<tr>
<td>Toronto, Canada</td>
<td>Life cycle (steps 1, 2)</td>
<td>Activity-EF</td>
<td>Residential</td>
<td>Kennedy et al. (2009); Vasic/Bothe and Kennedy (2007)</td>
<td>Annual and census tract</td>
</tr>
<tr>
<td>Los Angeles, CA</td>
<td>In-boundary, embedded in buildings</td>
<td>Atmospheric measurement, activity-EF</td>
<td>All FF; on-road transportation, buildings</td>
<td>Feng et al. (2016); Kort et al. (2012); Newman et al. (2016); Peccia et al. (2014); Perera et al. (2016); Reynolds and Chester (2015); Weng et al. (2015); Wunch et al. (2010)</td>
<td>Some work in space and time explicit; atmospheric monitoring includes CO₂, CO, and CH₄.</td>
</tr>
<tr>
<td>Salt Lake City, UT</td>
<td>In-boundary, consumption</td>
<td>Atmospheric measurement: direct flux, activity-EF, and fuel statistics; forest growth modeling and eddy flux measurement</td>
<td>All FF; biosphere</td>
<td>Kennedy et al. (2009); McKain et al. (2012); Patashnik et al. (2006, 2009); Patarek et al. (2006)</td>
<td>Some work in space and time explicit</td>
</tr>
<tr>
<td>Baltimore, MD</td>
<td>In-boundary</td>
<td>Eddy flux measurement</td>
<td>All FF; biosphere</td>
<td>Crawford et al. (2011)</td>
<td></td>
</tr>
<tr>
<td>Denver, Boulder, Fort Collins, and Arvada, CO</td>
<td>Hybrid life cycle (steps 1, 2, 3)</td>
<td>Activity-EF</td>
<td>All FF</td>
<td>Hillman and Ramaswami (2000)</td>
<td>Addition of scope 3 emissions increased total footprint by 47%</td>
</tr>
</tbody>
</table>

Table 4.1. Scientifically Based Urban Carbon Estimation Studies in North American Cities

<table>
<thead>
<tr>
<th>Domain</th>
<th>Framework, Scope, Boundary</th>
<th>Estimation Techniques</th>
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<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston, MA, Seattle, New York City, Toronto</td>
<td>Scope 1, 2 (some scope 3 included); scope 3 in lowland area</td>
<td>Activity-EF; fuel statistics and downscaling</td>
<td></td>
<td>Kennedy et al. (2011); Kennedy et al. (2012)</td>
<td></td>
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<tr>
<td>Boston</td>
<td>In-boundary</td>
<td>Activity-EF; atmospheric monitoring, and inversion</td>
<td></td>
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<tr>
<td>Chicago</td>
<td></td>
<td></td>
<td></td>
<td>Gurney et al. (2002)</td>
<td></td>
</tr>
<tr>
<td>Mexico City</td>
<td>In-boundary</td>
<td>Eddy flux measurement; Activity-EF</td>
<td></td>
<td>Chaves-Baena and Shieh-Brum-Parodi (2014); Velasco and Roth (2010); Velasco et al. (2005, 2009)</td>
<td>Footprint of single monitoring location; whole-city inventory</td>
</tr>
<tr>
<td>Halifax, Canada</td>
<td>Scope 1, 2</td>
<td>Activity-EF</td>
<td></td>
<td>Wilson et al. (2013)</td>
<td>Spatially explicit</td>
</tr>
<tr>
<td>Pittsburgh, PA</td>
<td>Scope 1, 2</td>
<td>Activity-EF; fuel statistics, and downscaling</td>
<td></td>
<td>Wilson et al. (2013)</td>
<td>Residential, commercial, and transportation</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>In-boundary</td>
<td>Activity-EP and soil chamber</td>
<td></td>
<td>Hoekstra et al. (2012)</td>
<td></td>
</tr>
<tr>
<td>Vancouver, Canada</td>
<td>In-boundary</td>
<td>Eddy flux measurement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vancouver, Edmonton, Winnipeg, Toronto, Montreal, and Halifax, Canada</td>
<td>Scopes 1, 2</td>
<td>Activity-EP</td>
<td></td>
<td>All energy related</td>
<td>Ramaswami and Chouinard (2013)</td>
</tr>
</tbody>
</table>
Urban emission quantification architecture

1) Verification capability
2) Mitigation guidance
3) Questions on urban metabolism

Aiming for the knowledge gap between whole-city inventories and building-scale energy auditing
Hestia

Nested within Vulcan (conserves mass)

Data mining from city operations (traffic data, tax assessment)

Space, time, process
Multiple cities

Melbourne
Auckland
Paris
Sao Paulo

Boston via BU/Harvard

Measuring the carbon emissions of megacities

Megacities Carbon Project
The Vulcan Project
Fossil Fuel Carbon Dioxide Emissions

Scope 1 AND scope 2 (working on scope...
Urban examples
INFLUX inversion

Notes:

The inversion is NOT estimating the same thing as contained in the prior.

There is no inversion without a prior…..hence, there is no “independent” inversion.
Bottom-up/top-down reconciliation

**RESEARCH ARTICLE**
Reconciling the differences between a bottom-up and inverse-estimated FFCO$_2$ emissions estimates in a large US urban area

Kevin R. Gurney*, Jianming Liang*, Risa Patarasuk†, Darragh O’Keeffe*, Jianhua Huang*, Maya Hutchins*, Thomas Lauvaux†, Jocelyn C. Turnbull†§ and Paul B. Shepson†

Hestia compared to atmospheric CO$_2$ inversion (Lauvaux et al., 2016)

**Biotic respiration** prior to persistent ground freeze explains majority of difference
Reconciliation continued
Comparison to self-reported

The mean signed % difference: +24.0%
The mean absolute % difference: 44.3%

For 44 of the 57 cities, Vulcan estimates larger scope 1 FFCO$_2$ emissions
Thank you

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