Informing urban climate planning with high resolution data: the Hestia fossil fuel CO$_2$ emissions for Baltimore, Maryland

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ABSTRACT

Background
Cities contribute more than 70% of global anthropogenic carbon dioxide (CO₂) emissions and are leading the effort to reduce GHG emissions through sustainable planning and development. However, urban greenhouse gas mitigation often relies on self-reported emissions estimates that may be incomplete and unverifiable via atmospheric monitoring.

We present the Hestia Scope 1 fossil fuel CO₂ emissions for the city of Baltimore, Maryland – a gridded annual and hourly emissions data product for 2010 through 2015.

Results
The emissions in the base year of 2011 totaled 1431.5 kt C, with the largest emissions coming from onroad (35.0% of total city emissions), commercial (18.3%), residential (16.7%), and industrial (12.6%) sectors. Scope 1 electricity production and marine shipping were each generally less than 10% of the city’s total emissions. Baltimore’s self-reported Scope 1 emissions of 1,182.6 kt C were 22.8% lower than Hestia-Baltimore emission in 2014, largely due to the omission of petroleum consumption in buildings and several sectors that largely fall outside the city’s regulatory purview – industrial point sources, marine shipping, nonroad vehicles, rail, and aircraft.

Conclusions
We emphasize the need for comprehensive, Scope 1-only emissions estimates for emissions verification and measuring progress towards greenhouse gas mitigation goals using atmospheric monitoring, but we also acknowledge that city planners may desire a greater mix of scope 1, 2, and 3 emissions with an emphasis on activities under local policy control.

Keywords: fossil fuel; carbon dioxide; emissions; Hestia; Baltimore
1. Background

Cities represent more than half of the global population, 67-76% of global energy use, and 71-76% of the carbon dioxide (CO₂) emissions associated with final energy use (1), highlighting the need for sustainable urban development. Cities around the globe are responding to the inertia of nation-state scale climate change mitigation efforts. Organizations such as the C40 cities program (https://www.c40.org/), ICLEI – Local Governments for Sustainability (https://www.iclei.org/), and the Global Covenant of Mayors for Climate & Energy (GCMCE, https://www.globalcovenantofmayors.org/) have participating member cities across the world (94 cities in C40, more than 1,750 member governments in ICLEI, and more than 10,000 cities in GCMCE). The US epitomizes this trend; more than 82% of the population lives in urban areas as of 2018, a number that is expected to rise to 89% by 2050 (2), and groups like Climate Mayors (http://climatemayors.org/) have rapidly grown following the announcement that the US federal government would be leaving the Paris Agreement.

Many cities have been setting sustainability goals, including greenhouse gas (GHG) emissions reductions, and some cities have even set emissions goals more stringent than the Paris Agreement, which seeks to cap global warming at 1.5°C above preindustrial levels (3). In order to meet their stated goals, cities typically start with an inventory of their baseline emissions following one of a few established protocols and inventory tools that accompany them. These protocols/tools are often developed by non-governmental organizations to assist cities with the baseline inventory process and reflect the entire-city scale within broad sectoral categories (We refer to these inventories as ‘self-reported inventories’ – SRIs.). While these tools are relatively simple and accessible, limitations in data, city staff time, and budget constraints mean that the methods, baseline year, estimation quality and
comprehensiveness/completeness, vary from city to city. Furthermore, these SRIs often lack granular spatiotemporal patterns needed to identify high-emitting activities or infrastructure that can be effectively targeted in climate mitigation policy. Finally, they are often a mixture of the traditional emission scopes – Scope 1 (all emissions within a geographical boundary), 2 (emissions driven by the consumption of electricity), and 3 (emissions driven by the consumption of materials, goods, and services) (4,5). This mixture may accommodate city-specific emissions policies or monitoring requirements, but it limits the ability of the SRIs to be compared to atmospheric monitoring, the only current means to independently evaluate emissions and provide constructive feedback to city planners (6,7).

Within the research community, GHG emissions have been estimated at various scales, often as a component of research into biogeochemical cycling and climate change. Multiple national- and subnational-scale emissions estimates of Scope 1 CO₂ emissions from fossil fuel combustion (FFCO₂), the dominant component of anthropogenic GHG emissions, have been developed in the US at fine spatiotemporal resolution. The Anthropogenic Carbon Emissions System (ACES) dataset (8,9) provides FFCO₂ emissions for the north-eastern US at an hourly, 1km resolution and has been used in an urban CO₂ inverse modeling study in Boston (10). The Database of Road Transportation Emissions (DARTE), which is the onroad component of ACES, has been expanded to the entire US domain (11). Meanwhile, the Vulcan product provides hourly, 1km FFCO₂ emissions for the contiguous US and Alaska for 2010 to 2015 (12,13). Vulcan has been tested against atmospheric ¹⁴CO₂, a particularly good tracer for FFCO₂ (as opposed to CO₂) and was found to be within 1.4% of the estimated national total derived from atmospheric observations (Basu et al., under review, 2020). Both ACES and Vulcan leverage data from the US Environmental Protection Agency’s
National Emissions Inventory (USEPA NEI) for 2011 (14), hereafter referred to as the ‘2011 NEI’, among other data sources. The USEPA NEI is an inventory of emissions of ‘criteria air pollutants’, ‘hazardous air pollutants’, and other important pollutant precursors that is produced once every three years. In both ACES and Vulcan, carbon monoxide (CO) emissions from combustion sources in the 2011 NEI were converted to FFCO$_2$ using ratios of emission factors. Output from Vulcan at the county scale is used as input data for Hestia – a city-specific, highly granular FFCO$_2$ emissions product for urban domains (15,16). Hestia was first developed for Indianapolis, spawning the INFLUX project (6,7,17–19), which has tested the accuracy of a GHG measurement system that integrates bottom-up emissions modelling, atmospheric measurements, and inverse modelling. Recent inverse work shows the Hestia estimate to be within 0.6% of the mean 3-year atmospheric inversion result (Lauvaux in review, 2020). Hestia has since been developed for Salt Lake City (20), the Los Angeles Megacity (21), and Baltimore (22).

This paper summarizes the methods and data sources for the Hestia-Baltimore product and provides an overview of spatiotemporal patterns within the city for various sectors. This analysis provides a comprehensive view of FFCO$_2$ emissions for the city with particular emphasis on sub-city spatial variations. We also present a comparison of the Hestia emissions output with the city’s 2014 SRI (2020 email from L. McNeilly to S. M. Miller and G. S. Roest, unreferenced, see notes) and highlight differences in scoping, assumptions about source sectors, and data sources. The aim is to isolate the critical assumptions or data choices that lead to estimation differences and propose recommendations for generating urban emissions estimation that can satisfy the requirements of atmospheric verification and meet city needs related to specific mitigation policy approaches.
2. Results

Baltimore’s FFCO$_2$ emissions in 2011 totaled 1,431.5 kt C (Mg C), with emissions ranging from a peak of 1,798.3 kt C in 2010 to a minimum of 1,420.0 kt C in 2012. After 2012, the total emission increased each year through 2015. The peak in emissions in 2010 was driven largely by the CMV sector. Annual FFCO$_2$ emissions within each output sector are described below for the Hestia-Baltimore base year of 2011 and are summarized in Figure 1 and Table 1. The largest emitting sectors in each year except for 2010 were onroad, commercial, residential, and industrial, representing 35.0%, 18.3%, 16.7%, and 12.6% of the total emissions in the base year of 2011. In 2010, however, CMV emissions were the second largest emitting sector behind onroad. The electricity production and nonroad sectors each accounted for less than 10% of the total emissions in each year, while rail and aircraft emissions accounted for less than 1%.

2.1. Building sectors

2.1.1. Residential

The residential sector emissions of 238.7 kt C represented 16.7% of the total city emissions in 2011. Natural gas consumption was the source of 85.9% of those emissions while petroleum fuels (liquid fossil fuels, e.g. distillate fuel oil and kerosene) contributed nearly all of the rest. Residential coal consumption was negligible. Figure 2 shows the 200 m gridded annual residential FFCO$_2$ emissions for 2011 and Figure 3 shows the cumulative fraction of emissions in all emitting grid cells. The top 10% of emitting grid cells were responsible for 33.8% of residential FFCO$_2$ in Baltimore, while the top 50% of grid cells accounted for 84.8% of residential emissions.
2.1.2. Commercial

The commercial sector emissions total of 262.6 kt C in 2011 (18.3% of the annual total) made this sector the second largest FFCO$_2$ source in the city, with 77.3% from nonpoint commercial buildings and the remaining 22.7% from commercial point sources. Figure 2 shows the prominence of commercial point sources within high emitting grid cells. The top 10% of emitting grid cells were contained 74.7% of emissions (Figure 3). Natural gas use was associated with 92.5% of commercial FFCO$_2$ emissions with petroleum accounting for 7.5%. Less than 0.1% of commercial FFCO$_2$ was associated with coal.

2.1.3. Industrial

The industrial sector’s emissions of 180.6 kt C in 2011 (12.6% of the city total) were dominated by point sources (80.6% of the industrial total), evident in Figure 2 as relatively few grid cells with high emissions. Nonpoint industrial buildings and processes accounted for the remaining 19.4%. The top 10% of emitting grid cells contained 89.9% of industrial emissions (Figure 3), illustrating the impact of point sources in the industrial sector. Unlike the commercial and residential sectors, petroleum was associated with most of the industrial FFCO$_2$ (77.6%) while natural gas use made up the remaining 22.4%.

2.2. Electricity production

Scope 1 FFCO$_2$ from electricity generation totaled 122.3 kt C in 2011 (8.5% of the city total), making it the fifth largest sector from 2011 to 2015. Petroleum consumption was associated with 74.2% of emissions and the remaining 25.8% was from natural gas. Specifically, Hestia-Baltimore contains ten facilities that reported non-zero FFCO$_2$ emissions within the city of Baltimore. CO$_2$ emissions from biofuel-based energy
generation are not included in Hestia-Baltimore. No emissions from coal use are reported for this sector. Figure 4 shows the point electricity producing point sources, which are clustered near the central core of the city and around the harbor. Baltimore contains two facilities that report hourly emissions to the Clean Air Markets Division (CAMD) which burn natural gas (3.8% of electricity production emissions in 2011). Three facilities that burn natural gas and/or petroleum have emissions estimated from monthly fuel consumption data from the DOE/EIA (96.1% of sector total in 2011). Table 2 shows the FFCO$_2$ emissions of the CAMD and EIA facilities from 2010 to 2015. Additionally, nine electricity producing facilities are reported in the 2011 NEI point sector, though only five of these report non-zero emissions (less than 0.1% of sector total in 2011).

Table 3 shows emissions for these facilities in the base year of 2011. The Wheelabrator Baltimore Refuse facility is the largest producer of FFCO$_2$ from electricity production in the city, with FFCO$_2$ emissions coming from petroleum-based solid waste, which is included in Baltimore-Hestia due to the fossil-fuel origin of the waste. However, the facility’s actual CO$_2$ emissions are much higher due to additional combustion of biogenic solid waste (23).

2.3. Onroad

The onroad sector was the largest individual sector, with 501.1 kt C in 2011 – 35.0% of the city total. Gasoline usage accounted for 81.6% of onroad FFCO$_2$ while diesel fuel represented the remaining 18.4%. Figure 5 shows the 2011 annual onroad emissions for all road segments in the city, normalized to segment length. Emissions along interstates and major arterial roadways were distinct among a backdrop of roadways with generally lower emissions. The downtown core of Baltimore also had higher emissions than the
less densely populated suburban outskirts near in the northern part of the city and along the eastern and western boundaries. The top 10% of emitting grid cells accounted for 43.2% of onroad emissions (Figure 2, Figure 3) while the 10% of road length with the highest emissions per meter were responsible for 54.0% of emissions.

2.4. Commercial marine vessels
For the years 2011 to 2015, commercial marine vessels (CMV) emissions within ports were the sixth largest FFCO$_2$ emission sector in Baltimore, behind Scope 1 electricity generating sources. Note that no underway CMV emissions were included within the city boundary as these emissions were allocated to Baltimore County in the 2011 NEI. FFCO$_2$ emissions totaled 93.2 kt C in the base year of 2011, representing 6.5% of the city total. These emissions were larger than the FFCO$_2$ emissions from the largest electricity producing facility within the city (Wheelabrator Baltimore Refuse, Table 2). However, CMV emissions in 2010 were 431.3 kt C, or 24.0% of the city total, only behind the onroad sector with 511.7 kt C (28.5% of the city total). The maximum in 2010 reflects annual fuel sales data from the EIA ‘vessel bunkering use’ and residual fuel oil sales for transportation (13).

2.5. Aircraft, nonroad, and rail
The nonroad, rail, and aircraft sectors cumulatively represented slightly more than 2% of the city’s total emissions in 2011. Nonroad emissions were the largest sector among the three with 27.6 kt C in 2011 (1.9% of the city total), while rail emissions (3.8 kt C, 0.3% of the city total) and aircraft emissions (1.5 kt C, 0.1% of the city total) were the smallest emitting sectors within the city. The relatively low aircraft emissions reflect the fact that the Baltimore/Washington International Airport (BWI) lies within neighboring
Anne Arundel County and is therefore not included in the Scope 1 Hestia-Baltimore emissions.

3. Discussion

3.1. Hestia-Baltimore results

The total FFCO$_2$ emissions in Baltimore were dominated by onroad vehicles and stationary building/point source emissions (residential, commercial, and industrial sectors) in all years except for 2010, when the CMV sector was the second largest emitting sector after onroad. This departure from other years was the result of state-scale fuel sales data, used to scale emissions from the base year of 2011, exhibiting a large decline from 2010 to 2011. Gasoline emissions dominated the onroad sector, where only 10% of the road surface length contributed to more than half of the onroad emissions. This result underscores the potential emissions reductions associated with traffic patterns on major arterial roadways (Figure 5).

The second and third largest sectors in all years except for 2010 were commercial and residential, respectively. Both of these sectors were dominated by natural gas consumption, though petroleum fuel consumption was associated with non-negligible FFCO$_2$ emissions in both sectors (7.5% of commercial and 14.0% of residential emissions in 2011). Residential emissions were assigned entirely to nonpoint buildings while nonpoint commercial building emissions accounted for 77.3% of the sector total in 2011. This result highlights the importance of building energy efficiency in Baltimore’s FFCO$_2$, as the nonpoint commercial and residential emissions represented 30.9% of the city’s total emissions in 2011 and much of the city’s building stock is several decades old (see supporting information).
The industrial sector deviated from the commercial and residential sectors as 77.6% of FFCO$_2$ emissions in 2011 were from petroleum fuel consumption. Industrial point sources were responsible for 80.6% of total industrial emissions in 2011. This result was markedly different than the nonpoint-dominated commercial sector. Industrial point sources alone represented 10.2% of total FFCO$_2$ emissions in Baltimore in 2011.

Scope 1 power plant emissions summed to less than 10% of city total emissions in all years, with the Wheelabrator facility dominating emissions in this sector (6.2% of city total emissions in 2014), followed by the Domino Sugar facility. The Wheelabrator facility may be shut down in the near future due to concerns of air quality (24), which would reduce the city’s Scope 1 FFCO$_2$ emissions. However, the loss of electricity generation within the city would increase the demand for power to be imported from neighboring counties, thereby increasing the city’s Scope 2 emissions. Emissions from the CMV sector were entirely categorized into the ‘port’ subsector, with no emissions reported for ‘underway’ shipping (shipping lanes along coast or towards open water). This sector was highly variable, accounting for 4.3% (2014) to 24.0% (2010) of the city’s total emissions. Nonetheless, CMV emissions represent a non-negligible source of FFCO$_2$ within Baltimore. Nonroad emissions accounted for less than 2% of the total emissions in each year, while rail emissions were less than 0.3% and aircraft emissions were less than 0.2%. While nonroad, rail, and aircraft emissions are not large relative to the city total, they may intersect with other sustainability priorities within the city.

3.2. Baltimore’s greenhouse gas mitigation efforts

In 2009, the state of Maryland passed the Greenhouse Gas Emissions Reduction Act, requiring the state to reduce greenhouse gas emissions by 25% compared to 2006 baseline by 2020. This goal has since been restated in the Greenhouse Gas Emissions
Reduction Act Plan, updated in 2015 (25). The 2006 baseline greenhouse gas inventory for the state estimated statewide GHG emissions of 107 Mt CO$_2$ equivalents (CO$_2$e) – a unit that allows for direct summation of all GHGs by accounting for their differing radiative/chemical properties – including 10 Mt CO$_2$e associated with imported electricity (Scope 2 CO$_2$e emissions). Of the in-state (Scope 1) emissions, 90 Mt CO$_2$e (93%) was emitted in the form of CO$_2$ (25 Mt C). This fact illustrates the need for Maryland and sub-state actors to focus their GHG mitigation efforts on CO$_2$ emissions. The 2015 plan update reported that the state was on track to meet its goal.

At the municipal level, the Baltimore Office of Sustainability (https://www.baltimoresustainability.org/) periodically releases sustainability plans for the city. The 2009 sustainability plan established a goal to reduce Baltimore’s GHG reductions by 15% by 2015, over a baseline emissions of 7,579,144 t (Mg) CO$_2$eq in 2010. Building energy use accounted for 79% of those emissions. The city then published a Climate Action Plan in 2013 (26), which redefined the reduction target to 15% below 2010 levels by 2020. The plan focuses on energy savings and supply, land use, transportation, and growth.

The most recent and complete emissions data for the city of Baltimore are available from the 2014 SRI (2020 email from L. McNeilly to S. M. Miller and G. S. Roest, unreferenced, see notes). This inventory was made using the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GCP) City Inventory Reporting and Information System (CIRIS) spreadsheet tool. The CO$_2$ emissions reported in the 2014 SRI are reproduced in Table 4 and
Table 5 along with the equivalent emissions estimate from the Hestia-Baltimore results. Emissions in the SRI were disaggregated into individual gases, so the CO₂ emissions in these tables do not include other GHGs. The CO₂ emissions in the SRI, reported as metric tonnes of CO₂, were converted to metric tonnes of carbon (t C). The footnotes in Table 4 and Table 5 describe assumptions made to match SRI and Hestia-Baltimore sources and sectors.

We emphasize that neither the 2014 SRI nor Hestia-Baltimore are considered to be “correct” or “incorrect” – instead, the observed differences represent varying data sources, methodologies, assumptions, and decisions to categorically include or exclude emissions based on the purpose of the emissions estimate. A review of each sector is below, followed by a discussion of important takeaways from this comparison. The differences reported represent the relative mean difference (RMD):

\[
RMD = 100\% \times \frac{H - SRI}{\frac{1}{2} (H + SRI)}
\]

where \( H \) represents the Hestia-Baltimore emissions for the subset of sources based on the sector, fuel type, or other identifier, and \( SRI \) represents the self-reported emissions for the same subset of sources. A positive RMD indicated that Hestia-Baltimore emissions are higher than the SRI. Overall, emissions from Hestia-Baltimore totaled 1,487.3 kt C in 2014. When sources that are not included in the SRI are excluded from Hestia-Baltimore, the totals are very similar – 1,159.4 kt C for Hestia-Baltimore and 1,182.6 kt C for the SRI – a difference of -2.0%. However, these estimates are more than 300 kt C (20%) short of the Hestia-Baltimore total for all sectors.
3.2.1. Residential

Residential FFCO$_2$ emissions were only reported for natural gas consumption in Baltimore’s SRI. The residential natural gas emissions in 2014 were estimated to be 244.6 kt C in Hestia-Baltimore and 204.2 kt C in the SRI, resulting in a relative mean difference of 18.0%. The 2014 SRI documentation states that residential GHG emissions in Baltimore were estimated using Baltimore Gas and Electric (BGE) utility data on natural gas energy consumption for single- and multi-family residences while petroleum consumption was not estimated, likely due to the fact that home heating oil is often purchased through private transactions instead of from a centralized utility. The exclusion of petroleum is to be an important data gap in the SRI as 13.4% of residential FFCO$_2$ was associated with petroleum fuels in 2014. The 2011 NEI includes estimates of nonpoint criteria pollutant emissions associated with petroleum combustion - hence, the data used by Maryland to report emissions to the NEI, if available, may be useful for developing city-scale emissions estimates.

3.2.2. Commercial

Commercial sector FFCO$_2$ emissions were also only reported for natural gas consumption in Baltimore’s SRI, under the title ‘Commercial and Institutional Buildings and Facilities’. Emissions in Hestia-Baltimore were 276.0 kt C for point and nonpoint commercial natural gas consumption while Baltimore’s SRI reported 130.3 kt C based on BGE utility data – a difference of 71.7%. The extent to which large point sources are captured in the BGE data is not clear, and there may be differences in the categorization of commercial and industrial emissions. The sum of commercial and industrial natural gas consumption emissions in the 2014 SRI was 285 kt C – only 6.4% less than Hestia-Baltimore. Again, the lack of emissions associated with petroleum in
Baltimore’s SRI represents a data gap, as petroleum fuel consumption was associated with 6.8% of commercial FFCO₂ in Hestia-Baltimore in 2014.

### 3.2.3. Industrial

The industrial sector was difficult to compare between the SRI and Hestia-Baltimore due to apparent differences data sources and categorization. Again, only natural gas use was reported for ‘Manufacturing Industries and Construction’ emissions in Baltimore’s SRI. Baltimore’s SRI reported 155.6 kt C FFCO₂ for natural gas use in this sector while the industrial natural gas use in Hestia-Baltimore was only 28.8 kt C. Again, this discrepancy is likely due to differences in commercial and industrial building categorization between the SRI and Hestia-Baltimore. However, 83.6% of industrial emissions in Hestia-Baltimore were from petroleum fuel use in 2014 – not natural gas. It is possible that some of the ‘Manufacturing Industries and Construction’ emissions in the 2014 SRI were categorized as (e.g.) commercial sector emissions in Baltimore-Hestia. Furthermore, dominance of industrial point sources in Hestia-Baltimore highlights the need to include major point source facilities. Another category called Industrial Processes and Product Use (IPPU) was not reported in the SRI, which is allowed under the GPC standard.

### 3.2.4. Onroad

Emissions from the onroad sector were relatively close between Hestia-Baltimore and the city’s SRI, with Hestia emissions of 508.9 kt C in 2014 and 589.6 kt C in the SRI – a difference of -14.7%. The 2014 SRI provides estimates of ‘vehicle miles travelled’ (VMT) from the USEPA’s MOVES model, which are combined with vehicle-class-specific emission factors to estimate emissions. Hestia-Baltimore also uses data from the MOVES model, but instead of VMT, the FFCO₂ output from the MOVES model in
the 2011 NEI is used directly. Thus, the difference in the total onroad emissions are likely due to differing estimates of (e.g.) traffic volume and/or emission factors used in versions of the MOVES model. Nonetheless, Hestia-Baltimore’s distribution of onroad emissions to all road segments within the city provides insight into the high-emission onroad corridors that should be considered for sustainable transportation planning.

3.2.5. Electricity production

Baltimore’s SRI contains emissions for several electricity producing facilities, though only six of these facilities were located within the city limits of Baltimore (
Table 5). Electricity consumption for the other facilities should be categorized only as Scope 2 emissions and therefore are not included in Hestia-Baltimore. Of the six facilities in Baltimore’s SRI within the city boundary, five overlapped with Hestia-Baltimore facilities, though the Trigen Leadenhall St facility was categorized as an industrial point source in Hestia-Baltimore with FFCO$_2$ emissions of zero in all six years. The remaining facility (Trigen North Central Ave) was not included in the Hestia-Baltimore data. The reason for the differences in emissions for the remaining facilities is not clear, though it is likely due to different data sources – CAMD CO$_2$ data and EIA fuel consumption in Hestia-Baltimore vs. USEPA Flight Database in the SRI. The difference is especially notable for the Wheelabrator facility, which is the largest electricity producing facility within the city of Baltimore. Furthermore, the second largest facility in Hestia-Baltimore – the Domino Sugar facility – was not included in the SRI under electricity producing facilities, though it may have been included in the industrial or commercial sectors. Overall, Hestia-Baltimore estimated emissions of 129.1 kt C from electricity producing facilities within the city boundary, while the SRI reported 103.0 kt C – a difference of 22.5%.

3.2.6. Categorical differences
A number of sectors in Hestia-Baltimore were categorically omitted from the SRI – a practice which is compliant with the GPC standard. While Scope-2 emissions associated with building electricity consumption and electrified railways as well as Scope 3 emissions associated with waste were included, several Scope 1 emissions categories were not included in the SRI: aircraft within the city, FFCO$_2$ emissions along railways and at rail point sources, and CMV and nonroad emissions. Several of these sources are outside of the regulatory purview of the city, but are Scope 1 FFCO$_2$ emissions nonetheless. Emissions from aircraft and rail both accounted for less than 1% of
emissions in Hestia-Baltimore. However, nonroad emissions account for nearly 2% of 
FFCO₂ in Hestia-Baltimore. Again, the USEPA NEI serves as an indirect source of 
FFCO₂ emissions in the absence of centralized data, e.g. from a utility.

3.3. **Implications for Baltimore’s sustainability planning**

Estimating urban GHG emissions is difficult for several reasons:

1. Inventory development is labor intensive and therefore expensive, and cities that 
   operate with limited financial resources will struggle to build and maintain high-
   quality GHG inventories.

2. Data for FFCO₂ sources are idiosyncratic among cities; varying urban 
   typologies, data availability, and state/local policy can prevent cities from 
   identifying and quantifying all sources of FFCO₂ within their boundaries and 
   beyond.

3. Users of GHG emissions estimates often have different motives. City 
   governments often have limited policy levers and therefore may have a narrow 
   range of emissions sources for which they have regulatory interest. However, 
   carbon cycle science requires all sources to be quantified.

Emissions estimates developed with varying assumptions, methods, and data sources 
lead to large differences in total Scope 1 emissions estimates and even larger differences 
within individual sectors. For nonpoint buildings and point sources, some fossil fuels 
may not be delivered by a central utility, and therefore relying only on utility data 
would lead to an underestimate of GHG emissions from nonpoint buildings. In Hestia-
Baltimore, this problem is especially apparent in the industrial sector, where petroleum 
use was responsible for 83.6% of emissions in 2014. Baltimore’s SRI did not report 
petroleum use for the residential, commercial, or industrial sectors, likely due to a lack 
of data on private-sector transactions. However, state-level air quality reporting
provides indirect estimates of energy usage for these sectors and fuels, often through proxies. Cities may benefit by developing relationships with state-level air quality agencies to exchange data that is relevant to both air quality and GHG mitigation. Furthermore, IPPU emissions were not reported in the SRI, which is allowed under the GPC standard and reflects the city’s lack of policy levers to mitigate emissions from private industry. However, this omission contributes to an underestimate of industrial emissions as point sources accounted for 79.1% of industrial sector emissions in 2014 in Hestia-Baltimore. Likewise, large differences in individual power plant emissions were apparently driven by different input data sources between the SRI and Hestia-Baltimore, highlighting the need to identify best practices for estimating emissions from electricity production.

The difference in assumptions and data sources between Baltimore’s SRI and Hestia-Baltimore also demonstrates conflicting goals of GHG emissions estimates. First, many cities, including Baltimore, develop GHG emissions reduction goals as part of a broader sustainability effort within the city, ultimately culminating in city-led actions to reduce emissions and lessen other environmental and social impacts. Within that context, omitting sectors for which the municipal government has no policy levers – e.g., established point facilities that are compliant with the Clean Air Act, or airports where most travelers do not reside in the city – allows the city to focus on the emitting sources that can by influenced by city-level policy. Furthermore, SRI development allows for the inclusion of Scope 2 and Scope 3 GHG footprinting and mitigation planning through (e.g., decarbonizing the electricity mix brought into the city from power plants in other counties or states).

However, city-level inventories often contain substantial uncertainties and can therefore benefit from independent evaluation. Without this evaluation, errors and
omissions in GHG emissions estimates may result in financial resources being directed towards mitigating GHG sources that are relatively insignificant in the broader context of a city’s GHG footprint while other important sources remain unchecked. Furthermore, ongoing inventory evaluation can ensure that policies are having the intended impact on atmospheric GHG levels and provide a course-correcting feedback to policymakers. The use of atmospheric monitoring within a city combined with models of atmospheric transport and space/time-resolved data products such as Hestia, are considered the state-of-the-art in terms of independent evaluation. For the first time, this approach has been shown to be successful in the city of Indianapolis (Lauvaux in review, 2020). However, this evaluation approach produces estimates of Scope 1, or ‘territorial’, emissions as an outcome. Hence, the generation of a Scope 1 SRI estimate, avoiding conflation with Scope 2 or Scope 3 emissions (which are nonetheless helpful for sustainability planning), is crucial to avail of this evaluation capacity. By omitting large emissions sources – e.g. industrial petroleum use and CMV emissions in Baltimore – emissions estimates cannot be evaluated through atmospheric monitoring, leaving city planners with no choice other than to plan, prioritize, and fund city-led mitigation efforts using potentially erroneous and incomplete GHG emissions estimates. Thus, while certain Scope 1 emission sectors/sources may not be of interest to city planners due to a lack of policy levers, they are still necessary for developing a comprehensive and evaluable estimate of a city’s total GHG footprint.
4. Conclusions
The Hestia-Baltimore v1.6 FFCO₂ emissions data product stems from Vulcan v3.0 – a national-scale FFCO₂ emissions data product with emissions disaggregated by sectors, fuel types, and processes (13). The sectoral emission totals in the City of Baltimore were incorporated into Hestia-Baltimore system and distributed in space and time using local data sources where available. The resulting Hestia-Baltimore v1.6 product is available on a 200 m resolution grid as total annual and hourly emissions for the years 2010 to 2015 (27). Onroad, commercial, residential, and industrial emissions represent the largest emitting sectors in all years except for 2010, when CMV emissions were the second largest sector after nonroad. Aircraft and rail emissions each represented less than 1% of the totals, while electricity production, CMV (except for 2010), and nonroad sources each accounted for less than 10% of emissions.

A comparison of Hestia-Baltimore with the city’s SRI for the year 2014 revealed several differences in data sources, methodology, and included/excluded emission sources. While petroleum fuel consumption accounted for 27.1% of residential, commercial, and industrial emissions in Hestia-Baltimore in 2014, petroleum was not included in the SRI, likely due to data limitations. For the residential sector, natural gas consumption was 18.0% higher in Hestia-Baltimore than the SRI. Likewise, only natural gas consumption was included in the SRI’s commercial and industrial sector, leading to relative mean differences of 71.7% for commercial and -137.5% for industrial. These differences may be due to differences in the categorization of commercial and industrial sources. Additionally, the omission of IPPU sources in the SRI, which is permitted by the GPC standard, represents a significant data gap.

Onroad emissions were the closest match between Hestia-Baltimore and the SRI as both estimates utilized the USEPA MOVES model. The observed difference may be
due to different versions of MOVES output in Hestia-Baltimore and the SRI, though the specific reason could not be determined. Likewise, differences were found between the SRI and Hestia-Baltimore emissions in the electricity production sector due to different data sources. Emissions from the nonroad sector and Scope 1 rail and aircraft emissions were not included in the SRI, though Scope 2 electricity consumption in buildings and along electrified railways, as well as Scope 3 airport emissions, were included. CMV emissions, which were entirely associated with ports, were the sixth largest source in Hestia-Baltimore in 2011 to 2015 and the second largest source in 2010. However, no CMV or port emissions were included in the SRI. Like IPPU sources and other transportation sectors, CMV emissions are not required to be reporting under the GPC standard. Overall, the sums of matching Scope 1 emission sources in Hestia-Baltimore and the 2014 SRI matched within 2%, though some individual sectors showed poor agreement. Furthermore, the sum of Scope 1 SRI emissions was more than 20% lower than all Scope 1 emissions in Hestia-Baltimore.

These differences present challenges to city planners who are developing action plans to reduce GHG emissions. The data sources, assumptions, and categorical inclusions/exclusions used to develop emissions estimates may influence the development of climate action plans and the prioritization of GHG mitigation actions. While city planners may choose to omit certain sectors/sources from their sustainability planning, all Scope 1 emissions within a city’s boundary should be quantified and distributed in time and space for the sake of evaluation using atmospheric monitoring. Without evaluation, erroneous data in GHG emissions estimates may lead to costly efforts to reduce emissions from sources that are actually small, while larger sources remain unidentified and therefore unmitigated. Furthermore, the combination of atmospheric monitoring and complete Scope 1 emissions in time and space allows for
emissions mitigation efforts to be monitored for success. We emphasize that comprehensive, spatiotemporalized, and verifiable Scope 1 emissions estimates that are not conflated with Scope 2 or Scope 3 emissions are a critical tool required for city planners to make informed and effective decision making in their GHG mitigation efforts.

5. Methods

5.1. Study domain
The City of Baltimore (also referred to as Baltimore City or simply Baltimore) is located on the western shore of Chesapeake Bay in the state of Maryland. Baltimore County borders the city on the east, north, west, and southwest sides, though Baltimore City is independent from Baltimore County – thus, the emissions in Hestia-Baltimore represent emissions for Baltimore City and not Baltimore County. The mouth of the Patapsco River – a tidal estuary inlet – lies in the southern half of the city, immediately south of the city’s downtown area, with numerous inlets along the southern part of the city. The southernmost part of the city lies along the southern side of the Patapsco River. The city’s population was 620,961 in the 2010 US Census and has declined from a peak population of ~950,000 in the year 1950 (28).

5.2. Input data
The initial data sources for Hestia-Baltimore v1.6 emissions are sectoral, county-scale FFCO$_2$ output from Vulcan v3.0. Full details on data and methodology for Vulcan, including references and links to datasets, are available in Gurney et al. (13) and are not described in full detail here. Instead, a brief overview of data and methods is provided for Vulcan output. City- and state- specific data for relevant sectors in the Hestia-
Baltimore product are described below, with additional details in the Supporting Information.

Vulcan utilizes CO emissions from the 2011 NEI for several sectors – nonpoint (commercial, industrial, and residential), point (mostly commercial and industrial), airport/helipad, rail, nonroad, commercial marine vessels (CMV), and some electricity production. Most of the electricity production FFCO\(_2\) data come from the Clean Air Markets Division (CAMD), with additional emissions estimated from Department of Energy/Energy Information Administration (DOE/EIA) fuel consumption. The onroad emissions come directly from the MOVES model results in the 2011 NEI. Each of these sectors is distributed in space and time using surrogate spatiotemporal information, where available. While Vulcan includes CO\(_2\) emissions from clinker production at cement plants, no emissions associated with cement fall within the Baltimore city boundary.

Emissions from nonpoint buildings in the commercial, industrial, and residential sectors are spatially distributed to parcel and building footprints obtained from the Maryland Department of Planning (29) and the Baltimore City Government (30). The non-electric energy use intensity (NE-EUI) was calculated for building types and vintages and multiplied by each building’s floor area to estimate the buildings’ relative FFCO\(_2\) footprint within the city. Hourly emission profiles follow the Vulcan v3.0 methodology. Additional details on the spatial distribution are available in Supporting Text S1. Likewise, onroad emissions within the city are distributed in space and time using local traffic data. The spatial distributions of average annual daily traffic (AADT) follow Vulcan v3.0 methodology, while the hourly profiles are distributed using kriging for midweek days (Tuesday through Thursday) and are evenly distributed during the remaining weekdays. The temporal allocation is reviewed in more detail in Supporting.
Text S2. All other sectors are distributed in space and time following the Vulcan v3.0 procedures except for airports/helipads, which are assigned a flat temporal distribution in Hestia-Baltimore.

**List of abbreviations**

| Abbreviation | Description |
|--------------|-------------|
| AADT         | Average Annual Daily Traffic |
| ACES         | Anthropogenic Carbon Emissions System |
| BGE          | Baltimore Gas and Electric |
| CAMD         | Clean Air Markets Division |
| CIRIS        | City Inventory Reporting and Information System |
| CMV          | Commercial marine vessel |
| CO           | Carbon monoxide |
| CO₂          | Carbon dioxide |
| CO₂e         | Greenhouse gas emissions measured as carbon dioxide equivalents |
| DARTE        | Database of Road Transportation Emissions |
| DOE          | US Department of Energy |
| EIA          | Energy Information Administration |
| FFCO₂        | Fossil-fuel carbon dioxide |
| GCMCE        | Global Covenant of Mayors for Climate & Energy |
| GHG          | Greenhouse gas |
| GPC          | The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories |
| ICLEI        | Local Governments for Sustainability |
| INFLUX       | Indianapolis Flux Experiment |
| IPPU         | Industrial Processes and Product Use |
| MOVES        | MOtor Vehicle Emission Simulator |
NE-EUI Non-electric energy use intensity
NEI National Emissions Inventory
ORISPL Office of Regulatory Information Systems Plant Location
RMD Relative mean difference
SRI Self-reported inventory
USEPA US Environmental Protection Agency
VMT Vehicle miles travelled

**Declarations**

**Availability of data and materials**
The data that support the findings of this study are openly available in the National Institute of Standards and Technology (NIST) Public data repository at https://doi.org/10.18434/T4/1503342. Baltimore’s 2014 self-reported greenhouse gas inventory was made available through a personal email communication between Lisa McNeilly at the Baltimore Office of Sustainability (https://www.baltimoresustainability.org/, sustainability@baltimorecity.gov).

**Competing interests**
Scot M. Miller has received funding from Baltimore City to update the city's greenhouse gas emissions inventory.

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Authors’ contributions
GSR was the primary author for written content, figures, and tables, with additional writing and editing from KRG. GSR also performed the comparison between Hestia and self-reported emissions. SMM provided insight into Baltimore’s emissions reporting and contributed to the discussion of Baltimore’s efforts to reduce GHG emissions. JL performed the data mining and GIS work specific to the Hestia-Baltimore output. KRG conceptualized the Hestia-Baltimore results.

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Figures

Figure 1. **Annual timeline of emissions by sector in Baltimore.** The ‘other’ category contains nonroad, rail, and aircraft emissions. Nonroad emissions dominate these three sectors. The drop in annual total emissions from 2010 to 2011 and beyond is driven by a decrease in CMV emissions, which reflects a decrease in fuel sales in EIA data after 2010.

Figure 2. **Gridded emissions for the Hestia-Baltimore.** The sectors shown are commercial (top left), industrial (top right), residential (bottom left), and onroad (bottom right). This map was made in ArcGIS v10.6.1 using the Light Gray Canvas basemap (Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community).

Figure 3. **Cumulative plots of emissions in grid cells for the residential, commercial, industrial, and onroad sectors.** The intersection of the vertical dotted line and the sectoral emissions represents the share of emissions that are contained within the top 10% of non-zero emitting grid cells. The top 10% of grid cells contain 89.9% of industrial emissions, 74.7% of commercial emissions, 43.2% of onroad emissions, and 33.8% of residential emissions.

Figure 4. **Electricity production emissions from NEI, CAMD, and EIA data for the base year of 2011.** The units are metric tonnes of carbon (t C). The labels next to each facility indicate the ORISPL or EIS code (Table 2,
Table 3). Note that the four NEI facilities with no reported FFCO$_2$ emissions are not shown. This map was made using R’s ‘leaflet’ package with the Esri World Gray Canvas basemap (Esri, DeLorme, NAVTEQ).

Figure 5. **Annual onroad emissions on all road segments for 2011, normalized to unit length.** Interstates and major arterial roadways appear in red and orange with more than 1 t C m$^{-1}$ y$^{-1}$, while roads in the downtown core of Baltimore generally had emissions of 0.1 to 1 t C m$^{-1}$ y$^{-1}$. Less densely populated parts of the county in the north and along the eastern and western edges had many roads with less than 0.1 C m$^{-1}$ y$^{-1}$. This map was made in ArcGIS v10.6.1 using the Light Gray Canvas basemap (Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community).
Tables

Table 1. *Hestia-Baltimore annual sectoral emissions and the percentages of the total annual emissions in Baltimore*. Sums of individual sectors may not match totals due to rounding. The units of FFCO$_2$ emissions are kt C (Mg C).

| Source     | Year | 2010    | 2011    | 2012    | 2013    | 2014    | 2015    |
|------------|------|---------|---------|---------|---------|---------|---------|
| Residential| kt C | 260.7   | 238.7   | 214.4   | 255.4   | 282.5   | 262.3   |
|            | %    | 14.5    | 16.7    | 15.1    | 17.7    | 19.0    | 17.6    |
| Commercial | kt C | 262.8   | 262.6   | 252.1   | 277.8   | 296.3   | 292.5   |
|            | %    | 14.6    | 18.3    | 17.8    | 19.3    | 19.9    | 19.6    |
| Industrial | kt C | 182.3   | 180.6   | 165.6   | 155.3   | 175.3   | 172.8   |
|            | %    | 10.1    | 12.6    | 11.7    | 10.8    | 11.8    | 11.6    |
| Electricity production | kt C | 115.8   | 122.3   | 124.7   | 126.3   | 129.1   | 131.5   |
|            | %    | 6.4     | 8.5     | 8.8     | 8.8     | 8.7     | 8.8     |
| Onroad     | kt C | 511.7   | 501.1   | 506.1   | 526.3   | 508.9   | 521.3   |
|            | %    | 28.5    | 35.0    | 35.6    | 36.6    | 34.2    | 34.9    |
| Nonroad    | kt C | 28.6    | 27.6    | 27.5    | 27.7    | 27.2    | 27.9    |
|            | %    | 1.6     | 1.9     | 1.9     | 1.9     | 1.8     | 1.9     |
| Aircraft   | kt C | 1.6     | 1.5     | 1.2     | 1.1     | 0.6     | 0.8     |
|            | %    | 0.1     | 0.1     | 0.1     | 0.1     | 0.0     | 0.1     |
| Rail       | kt C | 3.6     | 3.8     | 2.4     | 3.7     | 4.0     | 1.7     |
|            | %    | 0.2     | 0.3     | 0.2     | 0.3     | 0.3     | 0.1     |
| CMV        | kt C | 431.3   | 93.2    | 126.0   | 66.3    | 63.4    | 83.0    |
|            | %    | 24.0    | 6.5     | 8.9     | 4.6     | 4.3     | 5.6     |
| Total      | kt C | 1798.3  | 1431.5  | 1420.0  | 1439.8  | 1487.3  | 1493.9  |
|            | %    | 100.0   | 100.0   | 100.0   | 100.0   | 100.0   | 100.0   |
Table 2. Electricity producing facilities from CAMD and EIA data within Baltimore City. Emissions are reported in tonnes of carbon (t C).

| ORISPL ID | Facility name          | Latitude  | Longitude | Source | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|-----------|------------------------|-----------|-----------|--------|------|------|------|------|------|------|
| 1553      | Gould Street           | 39.2665   | -76.6042  | CAMD   | 4491.2 | 4579.8 | 7187.6 | 3160.7 | 3243.6 | 3987.7 |
| 1560      | Westport               | 39.2661   | -76.6297  | CAMD   | 1873.1 | 101.5  | 2295.1 | 4931.8 | 1479.1 | 5324.5 |
| 1557      | Philadelphia           | 39.2986   | -76.5636  | EIA    | 1262.0 | 1808.3 | 501.7  | 1299.4 | 4797.7 | 1468.3 |
| 10629     | Wheelabrator Baltimore Refuse | 39.266041 | -76.629653 | EIA | 76009.5 | 88883.6 | 87925.1 | 89984.0 | 91614.4 | 92094.4 |
| 54795     | Domino Sugar Baltimore | 39.2744   | -76.5956  | EIA    | 31498.4 | 26862.1 | 26800.7 | 26862.3 | 27841.2 | 28627.3 |

a. The Office of Regulatory Information Systems Plant Location (ORISPL) IDs were used to identify unique electricity producing facilities in the EIA and CAMD data.

Table 3. Electricity producing facilities from the 2011 NEI point reporting.

Emissions are reported in metric tonnes of carbon (t C).

| Facility ID (EIS)a | Facility name                        | Latitude  | Longitude | FFCO₂ (t C) |
|--------------------|--------------------------------------|-----------|-----------|-------------|
| 14534211           | University of Maryland - Baltimore   | 39.287562 | -76.626678 | 22.7        |
| 7974211            | Complementary Coatings Corp.         | 39.279614 | -76.555723 | 22.1        |
| 14662611           | Johns Hopkins Univ. - Madison St     | 39.298954 | -76.592817 | 1.1         |
| 7765011            | Sasol North America Inc              | 39.238333 | -76.565556 | 0.8         |
| 16005911           | Trigen Energy - Inner Harbor East    | 39.283766 | -76.599694 | 0.4         |
| 7946811            | GAF Materials Corporation            | 39.276062 | -76.554512 | 0           |
| 7946911            | Grace - Davison Chemical             | 39.214167 | -76.570556 | 0           |
| 14534311           | Baltimore Sun - East Cromwell Street | 39.2625   | -76.577778 | 0           |
| 16004611           | Verizon Communications               | 39.293022 | -76.615368 | 0           |

a. The facility IDs used for NEI electricity production sources were associated with the USEPA’s Emissions Inventory System (EIS, https://www.epa.gov/air-emissions-inventories/emissions-inventory-system-eis-gateway).
Table 4. **Sectoral comparison of emissions in Baltimore’s SRI for 2014 and matching emissions from Hestia-Baltimore.**

| Source                        | Baltimore SRI for 2014 (CO₂ in t C)a | Hestia-Baltimore for 2014 (t C)b | Relative Mean Difference (%)c |
|-------------------------------|-------------------------------------|----------------------------------|-------------------------------|
| Residential natural gas⁴     | 204152                              | 244624                           | 18.0                          |
| Commercial natural gas⁵      | 130299                              | 275977                           | 71.7                          |
| Industrial natural gas⁶      | 155557                              | 28789                            | -137.5                        |
| Onroad⁷                       | 589595                              | 508917                           | -14.7                         |
| Total                         | 1079603                             | 1058307                          | -2.0                          |

a. Total GHG emissions from Baltimore’s 2014 SRI are reported for individual GHGs – CO₂, methane (CH₄), and nitrous oxide (N₂O) – as metric tonnes (t). CO₂ emissions were converted from t CO₂ to t C in this table.

b. Point and nonpoint petroleum/coal emissions, rail, aircraft, nonroad, and electricity production emissions are not included in this comparison.

c. The differences reported here represent the relative mean difference (Eq. 1). Positive values indicate that the Baltimore Hestia emissions are larger than Baltimore’s SRI.

d. Baltimore SRI data based on metered natural gas consumption at single- and multi-family homes.

e. Baltimore SRI data based on ‘Small Commercial Natural Gas’, ‘General Service Large Natural Gas’, and ‘General Serv – Daily Natural Gas’ for ‘Commercial and institutional buildings and facilities’.

f. Baltimore SRI data based on ‘Interruptible Service Natural Gas’, ‘Patapsco and Back River Natural Gas Consumption’, and ‘Montebello and Ashburton Natural Gas Consumption’ for ‘Manufacturing industries and construction’.

g. Onroad emissions in Baltimore’s SRI were disaggregated by vehicle class, not fuel type. Both Baltimore’s SRI and Hestia-Baltimore onroad emissions are
based on the sum of vehicle class emissions and fuel type emissions, respectively.
Table 5. A comparison of electricity emissions between Baltimore’s SRI and Hestia-Baltimore. Electricity producing facilities in Baltimore’s self-reported inventory (SRI) emissions for the year 2014 were matched to emissions from Hestia-Baltimore v1.6 from 2014. Note that some facilities that were included in the Hestia-Baltimore emissions (Table 2 and Table 3), such as the Domino Sugar facility, are not included in this table.

| Electricity producing facility | Baltimore SRI for 2014 (CO₂ in t C) | Hestia-Baltimore for 2014 (t C) | Relative Mean Difference (%) |
|-------------------------------|-----------------------------------|--------------------------------|-------------------------------|
| Gould Street                  | 3,609.8                           | 3,243.6                        | -10.7                         |
| Philadelphia                  | 5,216.9                           | 4,797.7                        | -8.4                          |
| Westport                      | 1,449.3                           | 1,479.1                        | 2.0                           |
| Wheelabrator Baltimore        | 75,773.5                          | 91,614.4                       | 18.9                          |
| Trigen Leadenhall St          | 11,723.5                          | 0                              | -200                          |
| Trigen North Central Ave      | 5,194.0                           | N/A                            | -200                          |
| Total                         | 102,967.0                         | 101,134.8                      | -1.8%                         |

a. The electricity producing facilities in this table are the facilities reported in Baltimore’s 2014 SRI that fall within the city limits of Baltimore. Electricity consumption from facilities outside of the city’s limits should only be considered Scope 2 (4,5) and therefore are not included in Hestia-Baltimore.

b. Total GHG emissions from Baltimore’s 2014 SRI are reported for individual GHGs – CO₂, methane (CH₄), and nitrous oxide (N₂O) – as metric tonnes (t). CO₂ emissions were converted from t CO₂ to t C in this table.

c. Electricity producing facility emissions in Baltimore’s 2014 SRI were collected from the USEPA Flight Database.

d. The differences reported here represent the relative mean difference (Eq. 1). Positive values indicate that the Hestia-Baltimore emissions are larger than Baltimore’s SRI.

e. Reported as a CAMD facility in Hestia-Baltimore.

f. Reported as an EIA facility in Hestia-Baltimore.

g. The CO₂ emissions in Baltimore’s SRI for the Wheelabrator facility are based on non-biogenic CO₂ emissions reported in the USEPA Flight Database.
h. Reported as an industrial point facility in Hestia-Baltimore, not an electricity producing facility, named ‘Veolia Energy Baltimore Heating, LLP-Spring Gardens’. No carbon monoxide emissions were reported for this facility in the 2011 NEI so there are no FFCO$_2$ emissions in any year. Emissions for Baltimore’s SRI in this table were summed for natural gas and distillate fuel oil use.

i. No matching facility was included in the Hestia-Baltimore data. Emissions for Baltimore’s SRI in this table were summed for natural gas and distillate fuel oil use.