GAP FUND TECHNICAL NOTES

GLOBAL URBAN CARBON EMISSIONS: DATA SOURCES

DECEMBER 2022

Global Urban Carbon Emissions: Data Sources

Gap Fund Technical Note[1]

Introduction

City-level greenhouse gas (GHG) emissions data is necessary as an input into identifying, planning, and monitoring urban climate change mitigation actions. Until recently, the availability of emissions data at the city level required the existence of a local emissions inventory, produced through painstaking local data collection. These inventories use different methodologies and urban boundary definitions, and are available for different years, making comparison or trend analysis across cities difficult. However, academic researchers and international organizations have used modeling techniques and proxy data from various sources to estimate city-level emissions globally. As a result, data sets are now available that estimate emissions, by sector, for thousands of cities worldwide.

This knowledge note aims to provide a guide to global data sources on greenhouse gas emissions in urban areas, and compare global trends in urban emissions between these data sets. Urban planners and policymakers at local and national governments and at international organizations require data on city-level emissions for planning and decision-making, but most may not be aware of these data sets, how to access them, what the differences between them are, and what precautions are necessary in interpreting their data. These data sets also allow the identification of global emissions trends across thousands of urban areas, which helps generate a deeper understanding of the relationships between urbanization and emissions, which in turn can inform urban climate change mitigation actions.

Data sources

1. City inventories

Methodology in brief

Cities prepare inventories by collecting data on activities in the city that result in GHG emissions and multiplying the magnitude of these activities by standard 'emissions factors' which estimate the quantity of GHG emissions produced per unit of a given activity. Emissions factors may vary by context, due to differences in technologies, fuel types, and other variables. The Global Protocol for

[1] Authored by Chandan Deuskar for the City Climate Finance Gap Fund. Axel Baeumler, Asmita Tiwari, and Augustin Maria provided valuable feedback on an earlier draft of this note. Philippe Ciais reviewed and provided inputs for the box on satellite data. Da Huo, Zhu Liu, and Zhu Deng (Tsinghua University) and Philippe Ciais (Laboratoire des Sciences du Climat et de l'Environnement) kindly provided the Carbon Monitor data used in this analysis.

Community-Scale Greenhouse Gas Inventories (GPC)[2] provides detailed guidelines on the production of emissions inventories for cities.[3]

Cities often create city-level inventories in partnership with global city networks, like ICLEI, C40, or the Global Covenant of Mayors for Climate & Energy (GCOM), as part of a larger climate action planning process.

Coverage

Cities can produce their own inventories independently or with various consulting firms or partner organizations, which means that the exact number of cities with up-to-date emissions inventories is difficult to determine. GCOM has inventory data for 444 cities worldwide.

Strengths

- Inventories are produced for individual cities, usually through local data collection, which means the quality of local data in these inventories may be better than in globally standardized data sets.
- As local governments are involved in producing emissions inventories, they may be more willing to accept and work with this data source than with global data sets produced by others.

Limitations

- Producing a city-level inventory through local data collection is time-consuming and requires specialized expertise which may not be available locally.
- Local data may not be easily available for all sectors. Certain sectors may resist disclosing data.
- It can be difficult to combine or compare data from multiple city emissions inventories, as they may be produced in different years, define their spatial boundaries differently, define sectors differently, and include different 'scopes' of emissions.[4] For example, of the 444 cities for which GCOM provides downloadable inventory data, most consider only Scope 1, but 83 also include Scope 2.

---

[2] https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

[3] See also the Gap Fund's knowledge note on urban emissions inventories: https://www.citygapfund.org/sites/default/files/2021-10/Gap%20Fund%20Technical%20Note%201_GHG%20Inventory%20v2.pdf

[4] Scope 1: GHG emissions from sources located within the city boundary. Scope 2: GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary. Scope 3: All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary. (Source: GPC, p. 35)

How to access the data

C40 and GCOM collect and make city-level GHG inventory data available on their websites.[5] City inventory data may also be available in Climate Action Plans or other documents published by individual cities.

2. Emissions Database for Global Atmospheric Research (EDGAR)

Methodology in brief

EDGAR, produced by the European Commission (EC), is a series of global gridded maps of GHG and air pollutant emissions from 1970 onwards. The current version as of 2022 (v6.0) has data for the period 1970 to 2018. The data set divides the earth's surface into grid-cells with dimensions of 0.1 degree latitude x 0.1 degree longitude (roughly 10 km x 10 km). For each grid-cell, EDGAR provides estimates for each greenhouse gas or other air pollutant separately (carbon dioxide, methane, particulate matter, etc.), for each year between 1970 and 2018, for each anthropogenic emitting sector (with the exception of Land Use, Land Use Change and Forestry.)

The EDGAR model estimates national emissions based on activity data and emissions factors mainly from international data sources (e.g., activity data from the International Energy Agency, Food and Agriculture Organization, and others, and emissions factors from the Intergovernmental Panel on Climate Change and elsewhere). This involves detailed sectoral disaggregation, with information on around 60 fuel types, hundreds of technologies, and abatement measures. (National estimates of emissions in EDGAR may differ from those in official national inventories, due to differences in data sources, methodologies and approaches.[6]) It then spatially disaggregates these national emissions for each sub-sector and fuel type to the grid-cell level, based on around 300 spatial proxy data sources including land cover, population, power plant locations, and road networks.[7]

EDGAR was not created specifically for analysis of *urban* emissions, but the creators of EDGAR and others have produced outputs using the data set which facilitate its use for analysis of the relationship between urbanization and emissions:

A. The EC has summarized emissions from EDGAR by settlement type within each country, based on the Global Human Settlement typology (urban centers, towns, suburbs, etc.), for each GHG and pollutant, for the years 1970, 1990, 2005, and 2015.[8] This summary uses

---

[5] C40: https://www.c40knowledgehub.org/s/article/C40-cities-greenhouse-gas-emissions-interactive-dashboard?language=en_US; GCOM: https://www.globalcovenantofmayors.org/our-cities/

[6] Crippa, M., Guizzardi, D., Solazzo, E., Muntean, M., Schaaf, E., Monforti-Ferrario, F., Banja, M., Olivier, J.G.J., Grassi, G., Rossi, S., Vignati, E. (2021). *GHG emissions of all world countries - 2021 Report.*

[7] Crippa, M., Guizzardi, D., Pisoni, E., Solazzo, E., Guion, A., Muntean, M., Florczyk, A., Schiavina, M., Melchiorri, M., & Hutfilter, A. F. (2021). Global anthropogenic emissions in urban areas: Patterns, trends, and challenges. *Environmental Research Letters, 16*(7), 074033. https://doi.org/10.1088/1748-9326/ac00e2

[8] Ibid.

aggregated sector groups (agriculture, energy-industry, residential, transport, waste, and other).[9]

B. The EC's Urban Centers Database (UCDB) includes estimates of CO_2 and PM 2.5 emissions for all 13,135 urban centers (UCs) in the database, for the years 1975, 1990, 2000, and 2015, using a slightly different sector grouping (agriculture, energy, industry, residential, transport)[10], also based on EDGAR data. The urban centers here are the same as those mentioned above. In order to produce outputs at the level of individual urban centers, many of which are smaller than one EDGAR grid-cell, the EDGAR team subdivided each grid-cell into 100 smaller grid-cells and distributed the emissions equally within them, before overlaying the UC boundaries.

C. The World Bank Gap Fund team has also calculated 2018 CO_2 emissions from EDGAR for all Functional Urban Areas (FUAs) that have at least one grid-cell center within them. FUAs are defined by the European Commission and include urban centers (as used in the UCDB) plus a commuting zone around them. (Figure 1 compares UC and FUA boundaries for a sample of cities.) For the purpose of this calculation, all emissions in the grid-cells whose centers fall within a given FUA boundary are counted towards that FUA, regardless of whether the rest of the grid-cell was within the FUA boundary.[11] Of the 9,032 original FUAs defined by the EC, 3,747 FUAs were eliminated for having no grid-cell centers within them, leaving 5,285. This was done for each sector separately, but for ease of interpretation and comparison with other data sources, grouped into sectors similar to those used by the EDGAR team in 'A' above (agriculture, energy-industry, residential, road transport, non-road transport, waste, and other).[12]

Coverage

- Original EDGAR data: Global maps with a spatial resolution of 0.1 degree, for each year from 1970 to 2018.
- National summaries by settlement type: all countries, for the years 1970, 1990, 2005, and 2015.
- Urban center emissions in UCDB: all 13,135 UCs globally, for the years 1975, 1990, 2000, and 2015.
- Functional Urban Area emissions: 5,285 FUAs, for 2018 only.

[9] See Appendix for a list of IPCC sectors in each of these sector groups.
[10] See Appendix for a list of IPCC sectors in each of these sector groups.
[11] Unlike for the analysis performed by the EDGAR team for the UCDB, the World Bank analysis did not divide each grid-cell into one hundred smaller ones before summarizing them at the FUA level.
[12] See Appendix for a list of IPCC sectors in each of these sector groups.

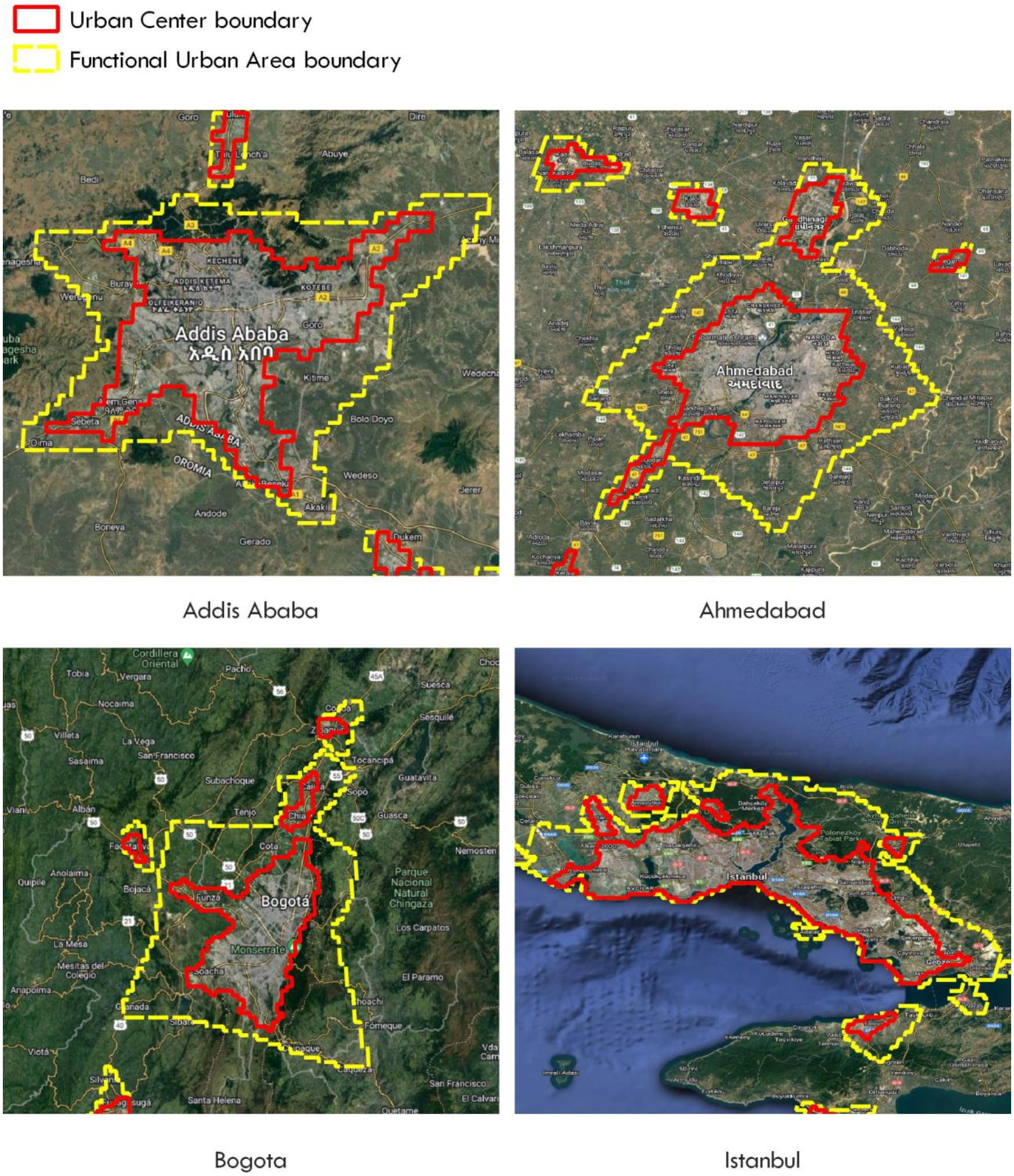

Figure 1: Urban Center and Functional Urban Area boundaries overlaid on satellite imagery for selected cities (Source: Author, using boundaries from the European Commission and satellite imagery and map data from Google)

Strengths

- Global coverage (see above)
- Long annual time series: 1970-2018 (see above)
- Disaggregated by sector, using IPCC sector classifications
- Disaggregated by substance (GHGs and other pollutants)
- Freely available for download
- Well-established data set, produced and maintained by the European Commission

Limitations

- EDGAR maps Scope 1 (territorial) emissions, which means it allocates emissions to where they are released. For example, power sector emissions are counted at power plant locations, not where the energy generated is used. This could dramatically underestimate the emissions for which a city is responsible if it imports electricity, or overestimate it if has power plants within it which export electricity to a larger region. Also, for this reason, the building sector in EDGAR only includes emissions from fuel combustion occurring in buildings (e.g., for gas heating), but not energy used in buildings from the electricity grid (e.g., for cooling using air conditioning), which is counted as part of the power sector.
- The original spatial resolution of the EDGAR model is low for analysis at the level of individual cities. One grid-cell near the equator is larger than 100 sq. km. in area, which means that most urban areas in the world are smaller than a single EDGAR grid-cell. (Even though the UC-level analysis performed by the EDGAR team subdivides these original grid-cells into smaller ones with equal emissions before overlaying UC boundaries, this does not add any meaningful resolution to the data.)
- A limitation in using EDGAR for analysis of the relationship between urbanization and emissions is that the model already uses urbanization and population distribution data, among many other types of data, as spatial proxies to distribute emissions. This means that, to some extent, any relationship observed in EDGAR data between population density and emissions within a country is partly by construction, i.e., a result of some of the assumptions in the model itself.
- EDGAR does not include emissions related to land use, land use change, and forestry, which means it excludes some of the emissions resulting from urban expansion.
- The lack of empirical measurements of emissions means that the model is difficult to validate.

How to access the data

- Original EDGAR data: spatial data can be downloaded in text or NetCDF format from the EDGAR website.

- National summaries by settlement type: Excel spreadsheets can be downloaded from the EDGAR website.
- Urban center emissions: EDGAR data are part of the Urban Center Database, available here.
- Functional Urban Area (FUA) emissions: contact the World Bank Gap Fund team.

3. Carbon Monitor Cities

Methodology in brief

Carbon Monitor Cities is a data set developed by researchers at universities in France, China, and the United States which produces high frequency, 'near-real-time' estimates of CO_2 emissions.[13] The Carbon Monitor (CM) Cities model disaggregates national emissions data spatially to a 0.1-degree grid and temporally to a daily frequency, resulting in daily CO_2 estimates for 1,110 cities in 46 countries. The cities in this data set are defined according to the European Commission's Functional Urban Area boundaries (see Figure 1). Carbon Monitor Cities uses EDGAR data and other data sources for spatial disaggregation, and satellite data on NO_2 emissions and other data where available (e.g., TomTom traffic data for some cities) for temporal disaggregation. Emissions are also disaggregated by sector into power generation, residential (buildings), industry, ground transportation, and aviation.[14]

Coverage

The data set currently includes 1,110 cities (FUAs), mostly in Europe, East Asia, North America, and Latin America, with a small share of cities in South Asia, Middle East and North Africa, and Sub-Saharan Africa. Only 71 cities are in lower-middle-income countries, with the remaining cities roughly divided between upper-middle-income and high-income countries, and no cities in low-income countries. The data set has daily CO_2 emissions estimates from the beginning of 2019 to the end of 2021.

Strengths

- Near-real-time data with a high frequency can aid decision-makers in analyzing the relationship between urban activities and emissions and evaluating the impacts of their actions.
- Depending on the data available for a given city, the spatial disaggregation may be better than in EDGAR. E.g., where available, traffic data from TomTom can result in better spatial disaggregation of transport road emissions than data on length of roads, which is used in EDGAR.

---

[13] Huo, D., Huang, X., Dou, X., Ciais, P., Li, Y., Deng, Z., Wang, Y., Cui, D., Benkhelifa, F., Sun, T., Zhu, B., Roest, G., Gurney, K. R., Ke, P., Guo, R., Lu, C., Lin, X., Lovell, A., Appleby, K., … Liu, Z. (2022). Carbon Monitor Cities, near-real-time daily estimates of CO_2 emissions from 1500 cities worldwide. *Physics.* http://arxiv.org/abs/2204.07836

[14] See Appendix for a list of IPCC sectors in each of these sector groups.

Limitations

- The spatial data needed for realistic disaggregation down to the grid-cell level is not readily available for cities in low- and middle-income countries. Data on local traffic congestion patterns, building types, urban structure, and household parameters would improve the spatial disaggregation of emissions in the model. Similarly, for temporal disaggregation, the model would benefit from city-specific data on traffic congestion, commuting patterns, seasonal unemployment, seasonal migration, etc. Carbon Monitor and the World Bank are currently incorporating such data into daily emissions estimates for 12 pilot cities in Turkey, Egypt, and South Africa. This exercise is expected to be completed in 2023, at which point at can be scaled up to include more global cities.
- Data is only available from 2019 onwards.
- The lack of empirical measurements of emissions means that the model is difficult to validate.
- Carbon Monitor does not include emissions related to land use, land use change, and forestry, which means it excludes some of the emissions resulting from urban expansion.

How to access the data

Contact the Carbon Monitor team.

4. Global Gridded Model of Carbon Footprints (GGMCF)

Methodology in brief

While most of the other data sources discussed above count emissions where they are emitted (Scope 1 emissions), a study by Moran et al. estimates the CO_2 emissions associated with consumption by urban residents (their 'carbon footprints'), regardless of where in the world those emissions are actually released into the atmosphere (Scope 3 emissions). These emissions estimates are based on the incomes and expenditures of residents of a city rather than the emissions sources located within the city. The authors start with national carbon footprints for 2015 from an existing model (Eora multi-region input-output database), as well as subnational carbon footprint data where available (EU, UK, USA, Japan, and China). They then further disaggregate the carbon footprints of urban and rural residents based on urban vs. rural expenditure patterns, for the 113 countries which have such data. They calculate the carbon footprints of grid-cells (250 x 250 m) using gridded population and income data. Finally, they overlay the Global Human Settlement urban center boundaries to calculate the carbon footprints of all 13,135 urban centers globally.[15]

---

[15] Moran, D., Kanemoto, K., Jiborn, M., Wood, R., Többen, J., & Seto, K. C. (2018). Carbon footprints of 13 000 cities. *Environmental Research Letters*, *13*(6), 064041. https://doi.org/10.1088/1748-9326/aac72a

Coverage

The study produced a gridded map of the entire globe (not only urban areas) and calculated the carbon footprints of all 13,135 urban centers. Tabular data published as part of the study in the form of a downloadable spreadsheet only includes city-level data for the top 500 cities by total carbon footprint and the top 500 cities by carbon footprint per capita, and country-level data for all countries. The estimates are for the year 2013 only.

Strengths

Estimates based on territorial boundaries can underrepresent the emissions of cities which import energy, goods, and services from beyond their boundaries and overrepresent the emissions of cities which import them. By contrast, consumption-based estimates represent the emissions caused by final consumption occurring in the city, regardless of where the emissions take place, and therefore help understand how the behavior of urban residents relates to carbon emissions.

Limitations

The lack of empirical measurements of emissions means that the model is difficult to validate.

How to access the data

The study's webpage has downloadable spatial data (global raster files of total and per capita carbon footprints, also viewable as online maps) and tabular data (city-level data for the top 500 cities by total carbon footprint and the top 500 cities by carbon footprint per capita, and country-level data for all countries).

The World Bank Gap Fund has also used the raster data to calculate the emissions for all UCs and FUAs.

Measuring CO_2 emissions directly using satellites

The data sources discussed in this note are based on modeling of greenhouse gas emissions using data on emitting activities and assumptions about the quantity of emissions associated with those activities, rather than direct measurement of greenhouse gases in the atmosphere. A growing number of earth observation instruments aboard satellites are able to directly measure concentrations of CO_2 in the atmosphere, suggesting that satellite observation of GHGs may play a more prominent role in spatial analysis of emissions in coming years. However, while experts in the field of earth observation and atmospheric sciences are optimistic about the future potential of satellite data for measuring urban emissions, they also urge caution in using currently available data for this purpose.

There are a few main reasons for this caution. First, satellites observe CO_2 *concentrations* rather than CO_2 *emissions*. Once emitted, CO_2 quickly mixes in the atmosphere. Over time it is transported by winds and channeled by topographic barriers. For these reasons, tracing concentrations of CO_2 that are observed at a given moment in time back to the location and magnitude of their original emission requires accurate atmospheric transport modeling which takes into account winds, humidity, dust, and other factors. This adds to the complexity and uncertainty associated with these estimates. Second, currently available satellite data does not have high enough spatial resolution to allow accurate and frequent estimation of emissions at the scale of an individual city. This is critical because in order to understand emissions arising from human activity in cities, the urban 'signal' in the concentration data must be distinguished from natural fluxes, which may be of equal or greater magnitude. Third, currently available satellite data is not dense enough in time and space to allow monitoring of emissions from a location over time, instead providing only a series of snapshots at a time of satellite overpass, which relates to emissions few hours before. Many such snapshots are unusable due to cloud cover or insufficient sunlight. For example, a study of satellite imagery for southern China found only 60 usable snapshots over a 5-year period, making it impossible to estimate annual emissions using satellite data. Scientists remain optimistic that the launch of recent and future satellites as well as advances in modeling techniques can help overcome these barriers in coming years.

Source: Based on Philippe Ciais, "Monitoring CO2 emissions of cities with satellites." Presentation to the World Bank, February 2022.

Comparing emissions estimates across data sources

This section compares estimates of emissions between various city-level sources discussed above: inventories from the GCOM database, EDGAR data at the UC level from the UCDB, EDGAR data at the FUA level based on World Bank calculations, Carbon Monitor Cities, and UC- and FUA-level data from the GGMCF.

Emissions in sample cities

Comparing emissions data from these sources for a sample of cities from different regions reveals that the sources can vary significantly in their estimates, with no clear pattern in the variation. This may be due to differences in methodologies, years for which data is available, urban boundary definitions, or other reasons.

Figure 2 compares total per capita emissions for ten cities, the sum of all sectors included in each data set. Figure 3 compares total transportation emissions per capita and Figure 4 compares building or residential emissions per capita. (Ahmedabad, Cairo, Ho Chi Minh City, and Jakarta do not have inventories in the GCOM data set. Addis Ababa is not included in Carbon Monitor Cities. GGMCF does include Addis Ababa, but its carbon footprint is so small that it is not visible in the figure.)

The emissions estimates in GCOM inventory data are for all greenhouse gases, expressed in CO_2 equivalents, while the other sources are for CO_2 only. This may explain why the inventories show higher emissions than most of the other data sources. The inventories only include Scope 1 emissions for most of these cities, as do EDGAR and CM Cities, so this would not explain differences between inventories and these data sources.

Consumption-based carbon footprints are much higher than estimates of territorial emissions for Bogota, Cape Town, and Istanbul, suggesting that they import goods, services, and/or energy associated with emissions more than they export them. The GGMCF does not include a sectoral breakdown and thus is not included in Figure 3 and Figure 4.

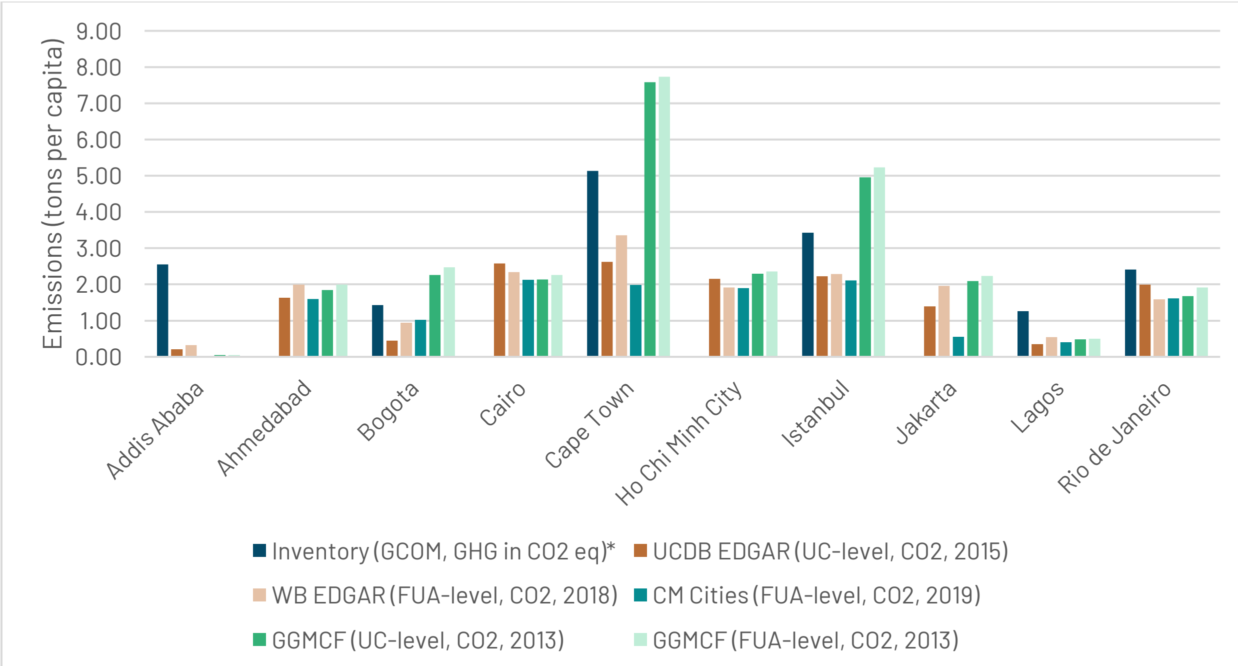

Figure 2: Emissions per capita in sample cities
** All inventories shown here include only Scope 1 emissions, except Lagos which also includes Scope 2.*

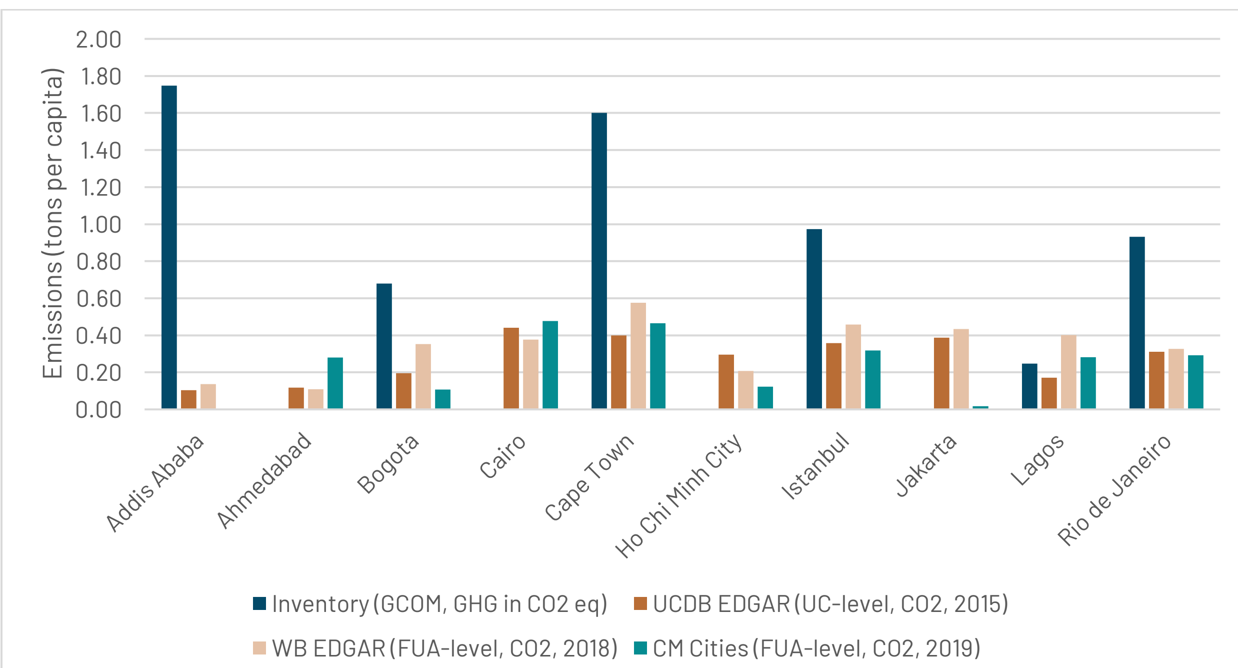

Figure 3: Urban emissions per capita from the transportation sector in sample cities

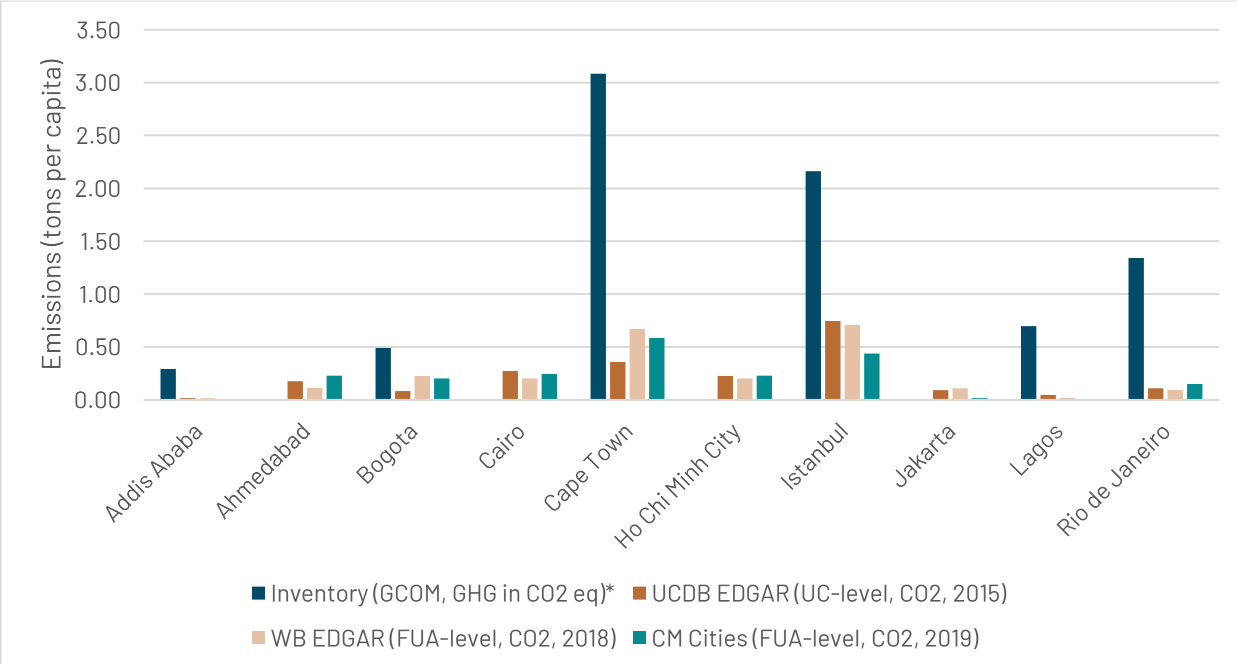

Figure 4: Urban emissions per capita from the buildings/residential sector in sample cities
** All inventories shown here include only Scope 1 emissions, except Lagos which also includes Scope 2.*

Global urban emissions

Urban emissions per capita[16]

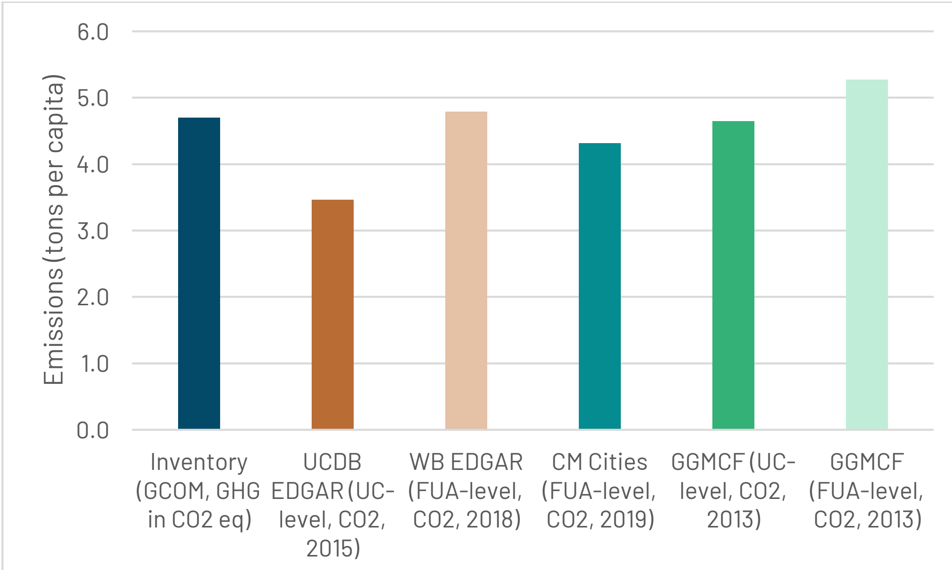

Figure 5: Urban emissions per capita, by data set

Despite the differences in emission scopes, spatial scales, and observation years, the global average estimates of per capita emissions in urban areas are similar across the six data sets analyzed here (Figure 5). The data set which counts only territorial emissions and has the smallest spatial scale (EDGAR at the UC level) has the lowest estimate (3.5 tons of CO_2 per capita in 2015), while the one which considers consumption-based emissions at a larger scale (GGMCF at the FUA level) has the highest estimate (5.3 tons of CO_2 per capita in 2013). The remaining data sets all have per capita estimates between 4 and 5 tons (GCOM inventories[17]: 4.7 tons of GHGs in CO_2 equivalents, EDGAR FUA 2018: 4.8 tons of CO_2, CM Cities FUA 2019: 4.3 tons of CO_2, GGMCF FUA 2013: 4.6 tons of CO_2).

[16] Per capita emissions figures cited here for any category are per capita emissions for the entire category together, i.e., the sum of all emissions from that category divided by the total population within that category, rather than the average of per capita emissions for all urban areas within that category. The approach used here weights all people equally, and therefore weights larger urban areas more heavily, rather than weighting each urban area equally regardless of size.

[17] GCOM inventory data here is for the 359 cities which include only Scope 1 emissions in their inventories.

Urban share of global emissions

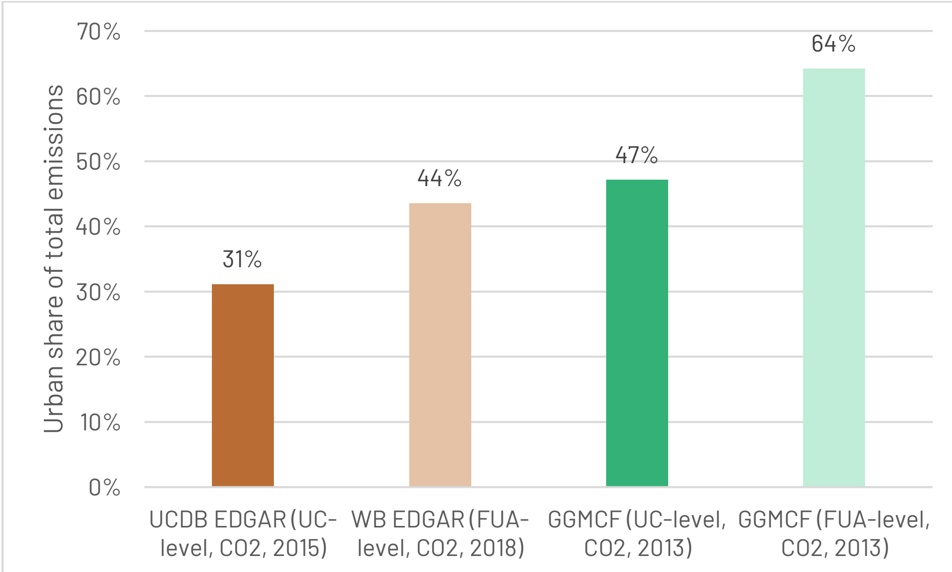

Figure 6: Urban share of emissions, by data set

Figure 6 shows the share of global CO_2 emissions occurring in urban areas according to the different data sets. (GCOM inventories and Carbon Monitor Cities do not have global coverage, so it is not possible to estimate the urban share of global emissions from these data sets.) Based on territorial accounting of emissions in the EDGAR database, approximately one-third of global CO_2 emissions (31% in 2015) take place in urban centers (UCs)[18], while 44% of global CO_2 emissions in 2018 were in the slightly larger spatial unit of functional urban areas (FUAs). Consumption-based data from the GGMCF indicate that around half of the global carbon footprint (47% in 2013) is a result of consumption within UCs, while approximately two-thirds (64% in 2013) is a result of consumption within FUAs.

[18] The analysis of the EDGAR UC-level data presented throughout includes only the 10,303 UCs in the UCDB which the database's own quality control process coded as "true positives" (QA2_1V=1).

Emissions by region

Shares of global urban emissions by region

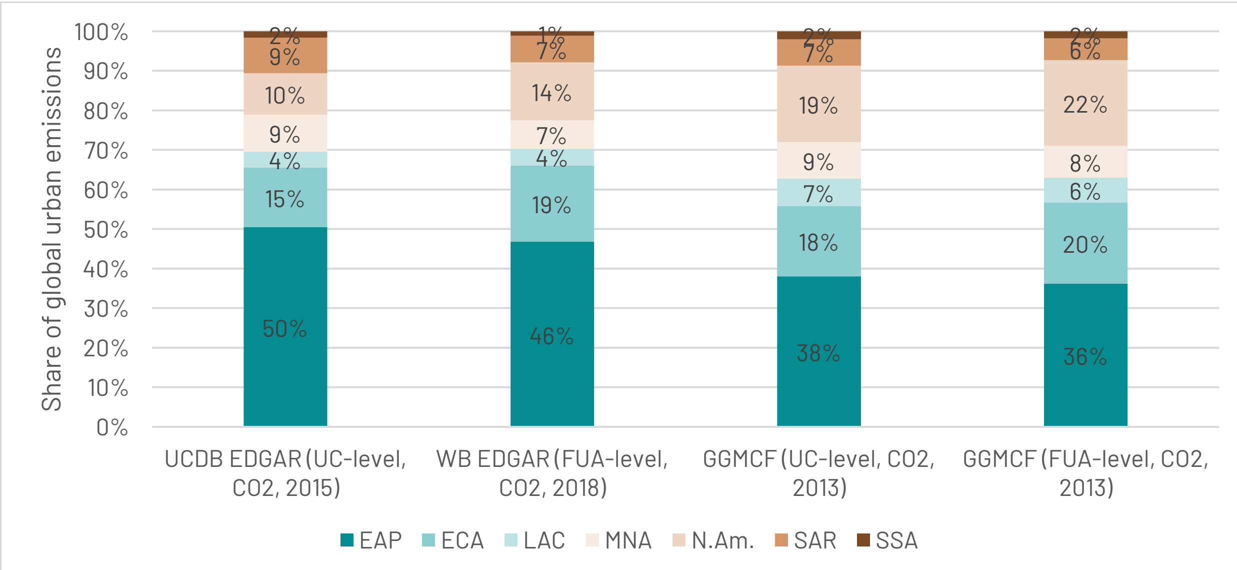

Figure 7: Shares of global urban emissions, by region

As EDGAR and GGMCF are global data sets, they allow us to estimate the share of global urban CO_2 emissions occurring in each region, defining urban areas either as UCs or FUAs (Figure 7). All four of the data sets show the East Asia and Pacific (EAP) region as having the largest share of urban CO_2 emissions. EDGAR data shows that emissions in UCs in EAP represented half of all UC-level emissions in the world, and a slightly smaller share of FUA-level emissions (46%). Despite the large number and size of urban areas in the South Asia region (SAR), UCs and FUAs in the region account for only 9% and 7% of global UC- and FUA-level emissions respectively, according to EDGAR.

GGMCF, which estimates emissions based on consumption locations, reduces EAP's share of urban emissions away and increases the shares in other regions, primarily North America. On its own, this fact could be interpreted to mean that goods are imported by urban areas in North America and other regions from urban areas in EAP. However, if this were the case, emissions in EAP urban areas would be much lower in GGMCF than in EDGAR, which is not the case, as the analysis below discusses. Instead, it may be because urban areas in North America, Europe and Central Asia (ECA), and other regions import goods and energy from non-urban areas within their own region.

Urban emissions per capita by region

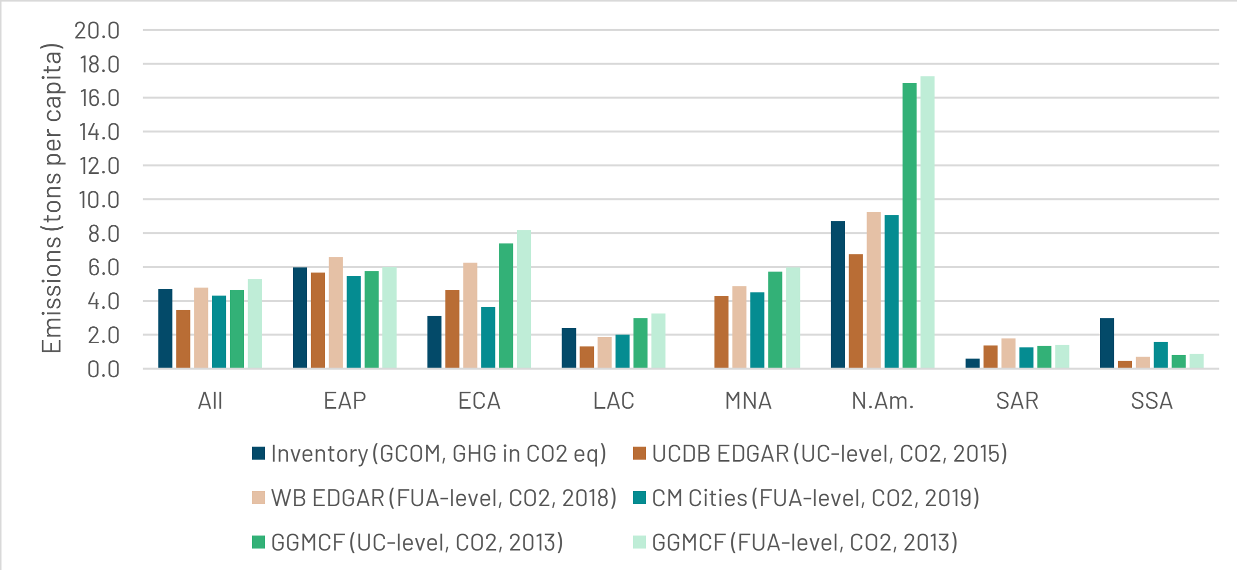

Figure 8: Urban emissions per capita by region[19]

All six data sets show North American urban areas as having the highest CO_2 emissions per capita, followed by EAP in EDGAR and by ECA in GGMCF. The GGMCF's consumption-based accounting of emissions nearly doubles North America's per capita urban emissions, slightly increases per capita emissions in Latin America and the Caribbean (LAC), Middle East and North Africa (MNA), and ECA, while not increasing them significantly in Sub-Saharan Africa (SSA), EAP, and SAR.

In all regions, in both EDGAR and GGMCF, per capita emissions are higher when considering FUAs, the larger spatial unit, than high-density UCs only. This is the case not only for total emissions per capita but also transportation and residential emissions per capita, shown in Figure 9 and Figure 10. This may be because of low-density suburban development or industrial areas on the outskirts of cities, both of which would have high emissions per capita, among other reasons.

Inventory data from GCOM shows much higher transportation emissions per capita than other data sets in almost all regions. This may be due to the inclusion of other GHGs besides CO_2. Residential emissions per capita are also much higher in the inventory data. This may be if inventories categorize emissions from residential energy use under the residential sector rather than the energy sector.

[19] GCOM data includes only one Scope 1-only inventory in MNA (Dubai) so it is excluded for MNA.

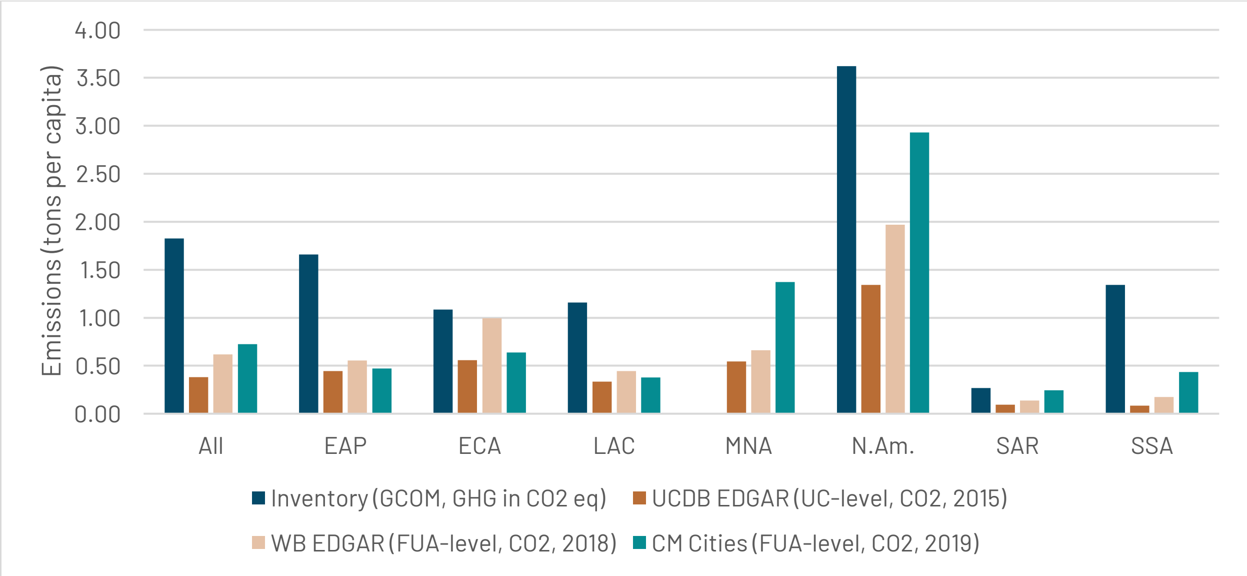

Figure 9: Urban emissions per capita from the transportation sector, by region

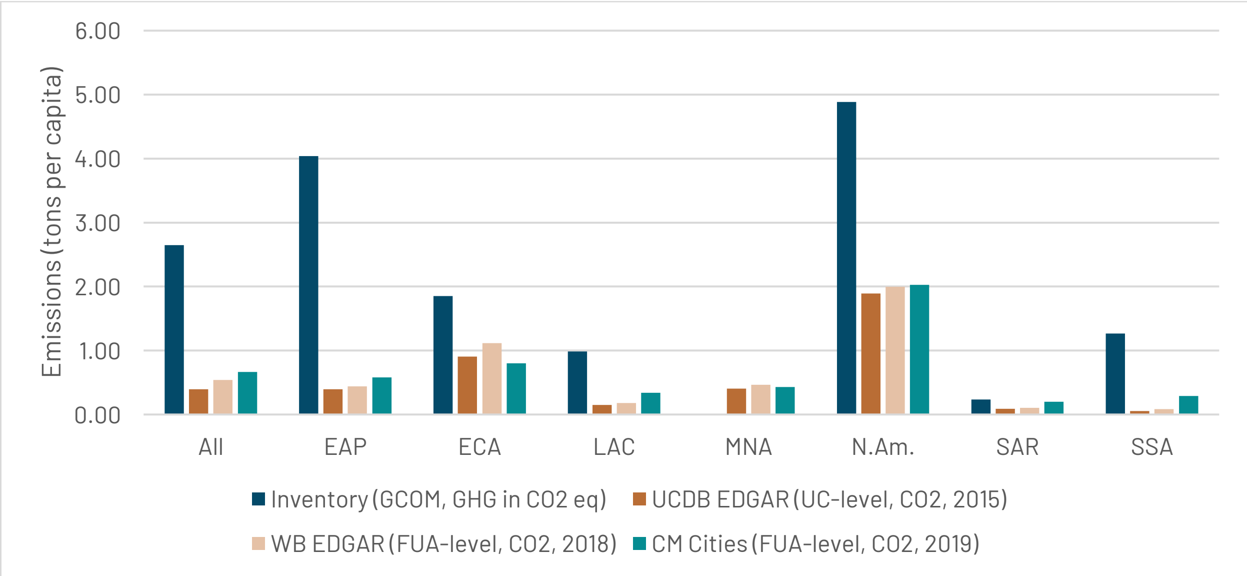

Figure 10: Urban emissions per capita from the buildings/residential sector, by region

Urban share of emissions by region

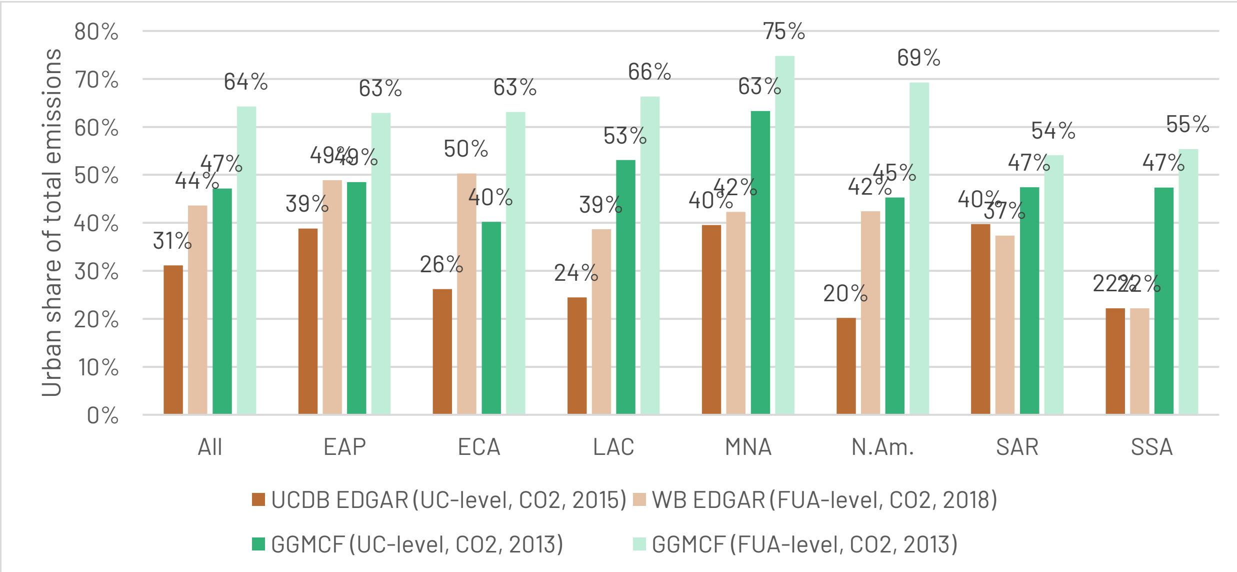

Figure 11: Urban share of emissions by region

The share of total emissions that are associated with urban areas differs by region as well as by data set and spatial scale (Figure 11). The share of territorial emissions in UCs according to EDGAR ranges from 20% in North America to around 40% in EAP, MNA, and SAR. The share when looking at FUAs is 22% in SSA, and between 37% and 50% in all other regions. The UC share of consumption-based emissions is lowest in ECA (40%) and highest in MNA (63%), with the share in all other regions being between 45% and 53%. The equivalent share at the FUA level is lowest in SAR (54%) and SSA (55%) and highest in MNA (75%), with the share in other regions being between 63% and 69%.

Emissions and income

Share of global urban emissions by income group

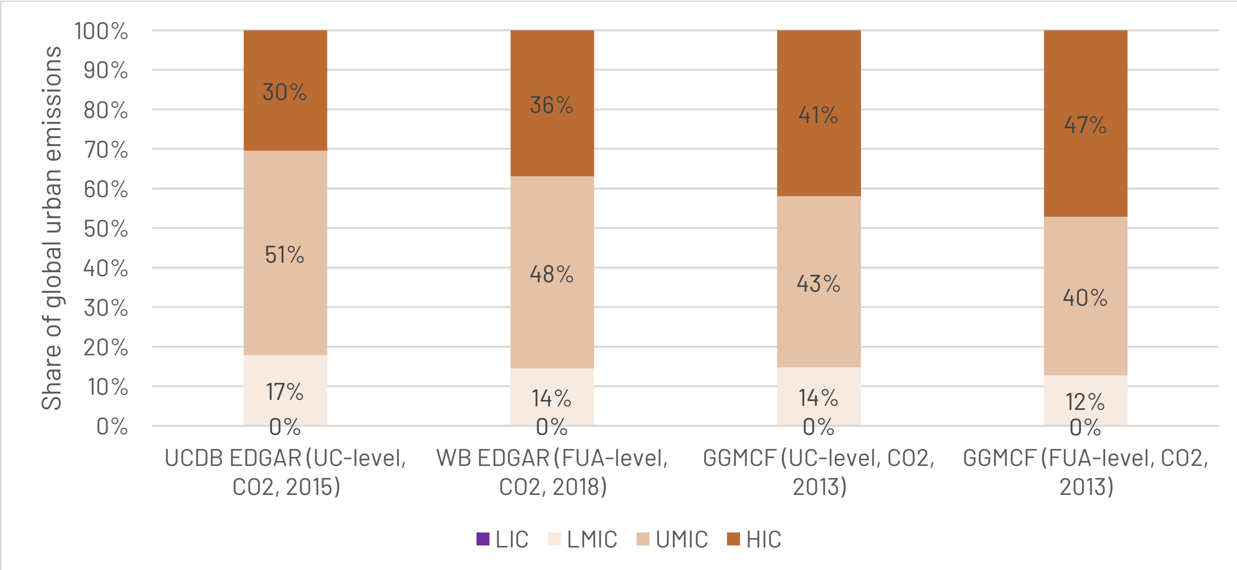

Figure 12: Shares of global urban emissions, by income group

Figure 12 illustrates the disproportionate share of the world's global urban emissions that come from urban areas in high- and upper-middle-income countries (HICs and UMICs), which together account for more than 80% of the world's urban CO_2 emissions. Emissions from urban areas in low-income countries (LICs) are so low that they round to 0% of global urban CO_2 emissions. Moving from the UC scale to the FUA scale to include suburban areas shifts the share of emissions towards HICs, as does shifting from EDGAR's territorial approach to GGMCF's consumption-based approach.

Urban emissions per capita by income group

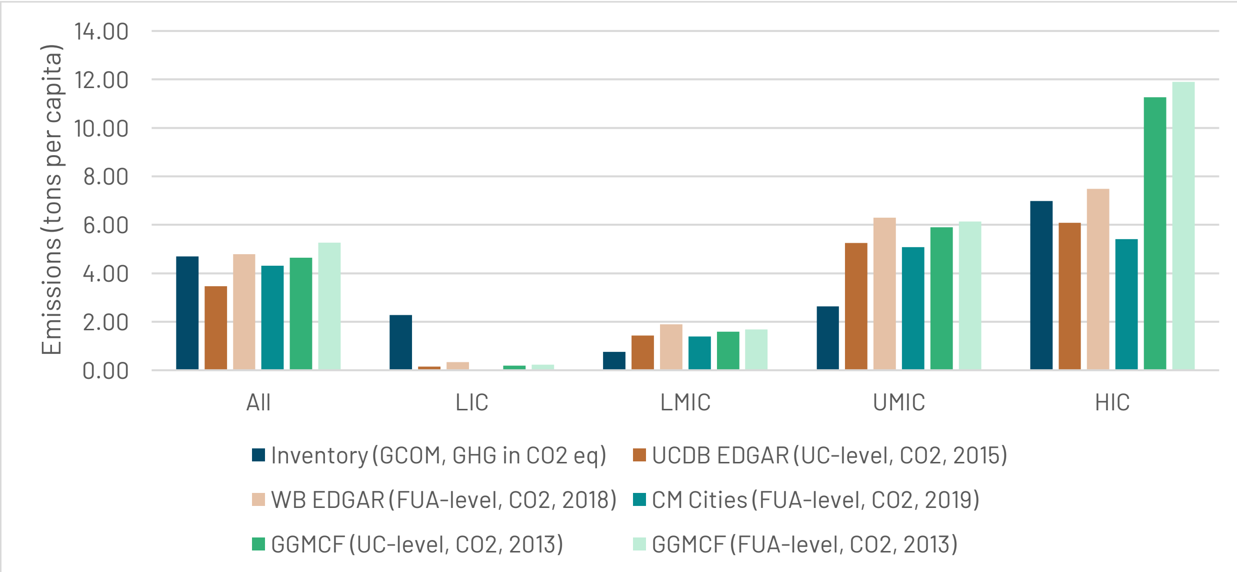

Figure 13: Urban emissions per capita by income group

In EDGAR and GGMCF, urban CO_2 emissions per capita in LICs are negligible: between 0.15 and 0.34 tons per capita, compared to the world average of 3.46 to 5.27. GCOM inventory data has a higher per capita average, but is only available for three LIC cities, and CM Cities includes no LIC cities. All estimates of urban emissions per capita in lower-middle-income countries (LMICs) are below 2 tons. There is a big gap in per capita emissions between LMICs and UMICs. In EDGAR and CM Cities, there is only a slight increase between UMICs and HICs. However, in inventory data and consumption-based data from GGMCF, there is a large gap between the two groups.

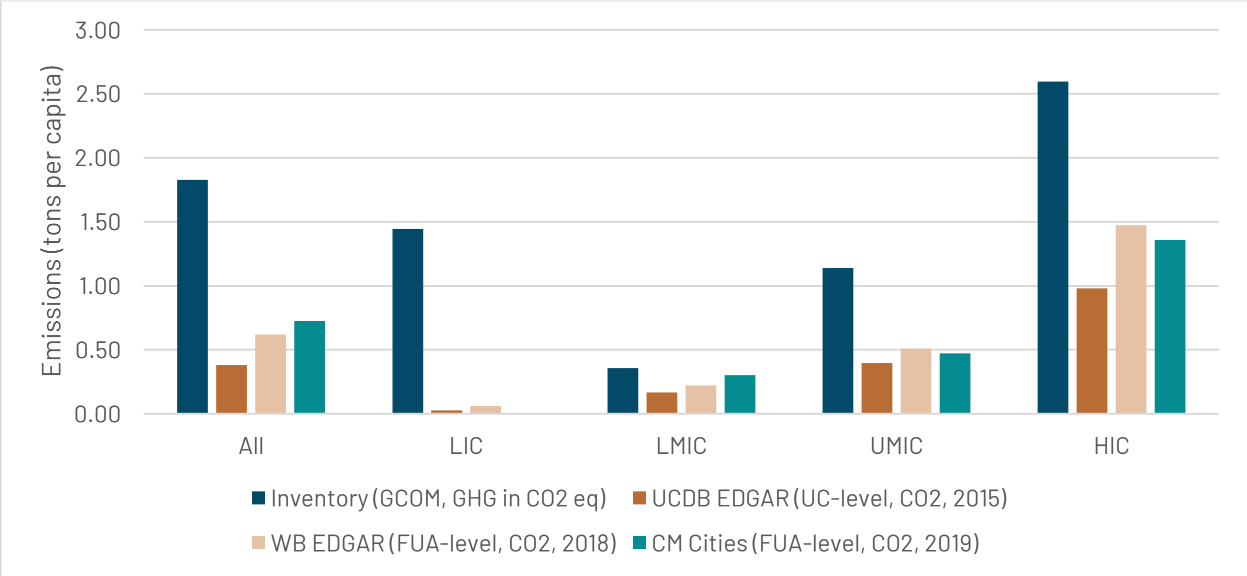

Figure 14: Urban emissions per capita from the transportation sector, by income group

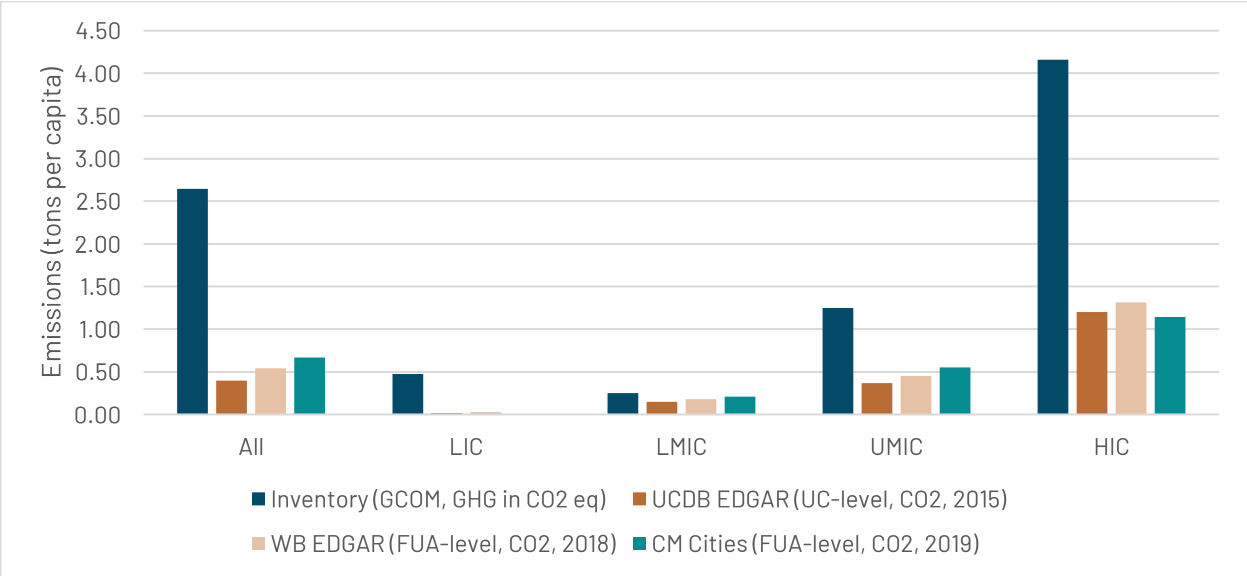

Figure 15: Urban emissions per capita from the buildings/residential sector, by region

Urban share of emissions by income group

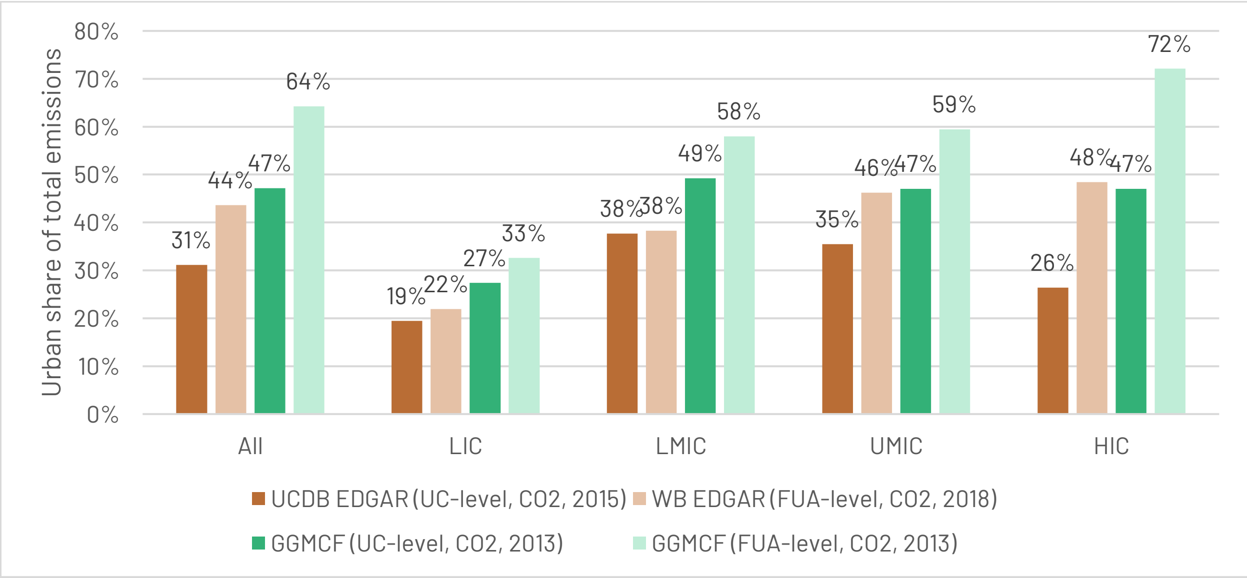

Figure 16: Urban share of emissions by income group

Figure 16 shows the share of emissions that are associated with urban areas, by income group. The distribution demonstrates the sensitivity of this data to the definition of cities. When considering UCs only, LMICs have the highest urban share of emissions, higher than UMICs and HICs, in both EDGAR and GGMCF data. However, when broadening the urban definition to the FUA level in both data sets, UMICs and HICs have higher shares of emissions in urban areas.

Emissions and city population size

Share of global urban emissions by population size class

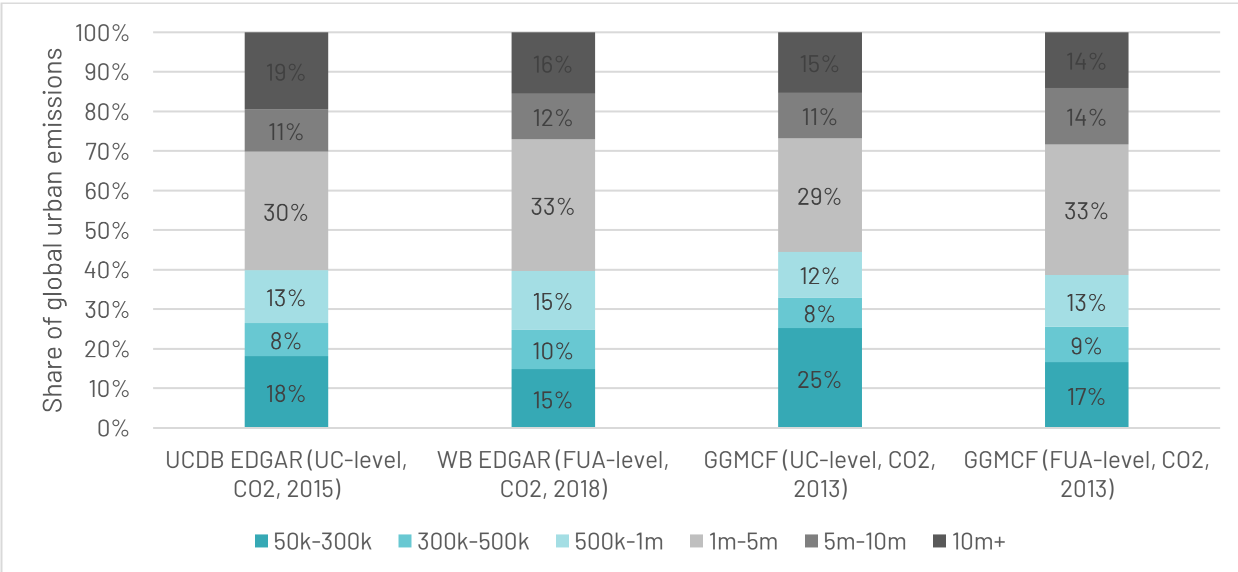

Figure 17: Share of global urban emissions by population size class

The distribution of global urban CO_2 emissions across city population size classes is similar in the different data sets (Figure 17). EDGAR and GGMCF both show that the largest share, close to one-third, comes from urban areas with populations of 1-5 million people. Megacities with over 10 million people as well as small cities of under 300,000 inhabitants are responsible for a roughly similar share of global urban emissions.

Urban emissions per capita by population size class

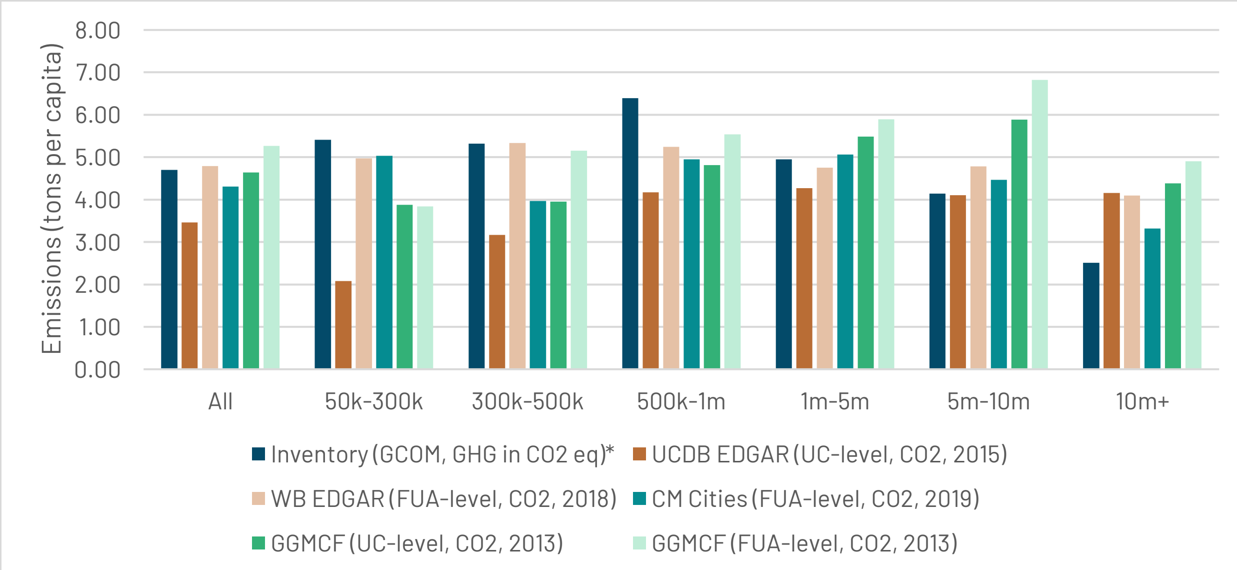

Figure 18: Urban emissions per capita by population size class

There is no clear pattern across data sets in terms of whether larger urban areas have higher CO_2 emissions per capita (Figure 18). According to inventory data, cities with populations of 500,000 to 1 million have the highest per capita emissions, and the largest cities, those with over 10 million people, have the lowest. According to EDGAR, the smallest UCs have the lowest per capita emissions, but the largest FUAs have the lowest per capita emissions. According to CM Cities too, the largest FUAs have the lowest per capita emissions. However, according to GGMCF, the smallest cities have the lowest per capita emissions. Plotting emissions per capita against population size (not shown here) does not suggest any clear relationship between the two in any of the data sets. The lack of a clear pattern is also true in the case of transportation emissions (Figure 19) and residential emissions (Figure 20).

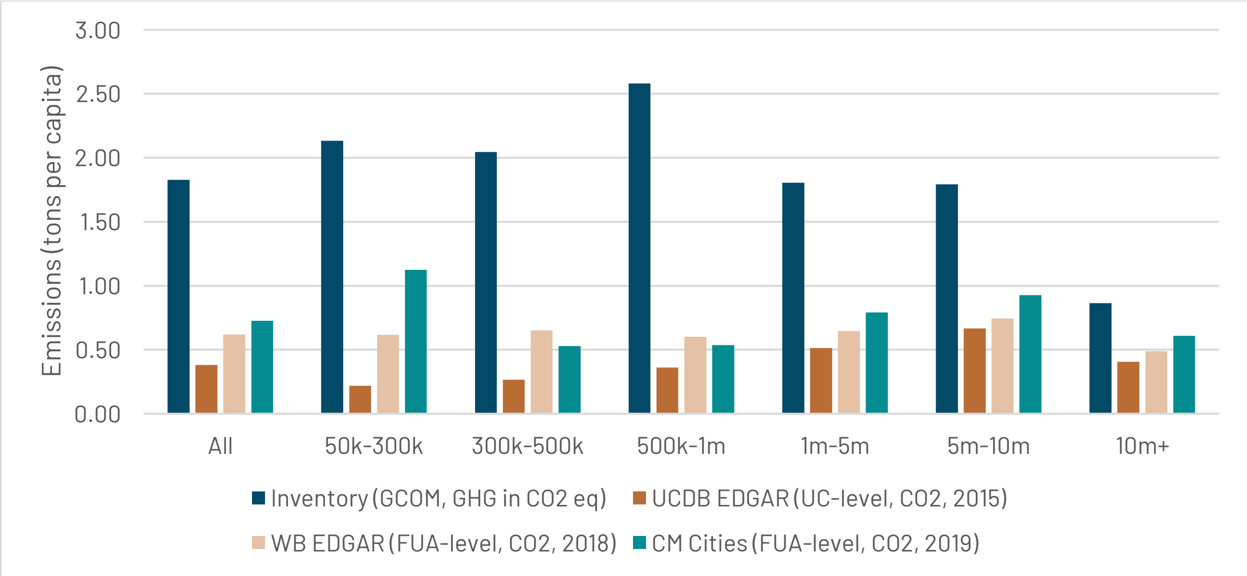

Figure 19: Urban emissions per capita from the transportation sector, by population size class

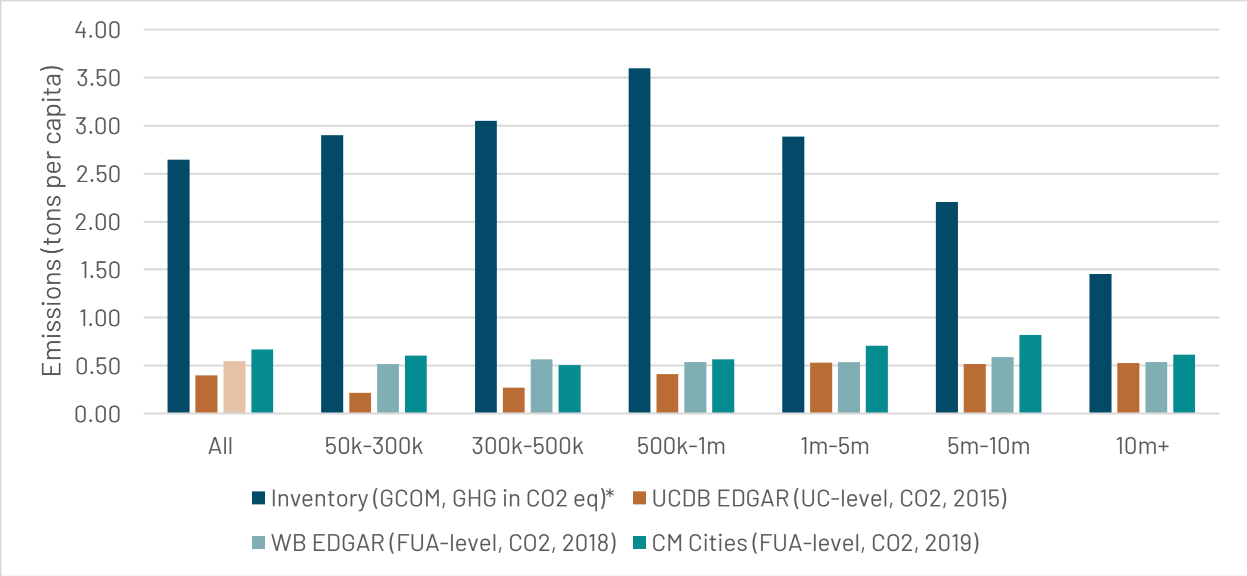

Figure 20: Urban emissions per capita from the buildings/residential sector, by population size class

Conclusions: Guidance for choosing a data set

The following guidelines may be helpful when choosing a source of urban emissions data.

- Analysis of a single city, for which comparison with other cities and trends over time are not priorities, should use an official emissions inventory based on local data collection, if it exists.

- Analysis requiring comparison or aggregation of emissions data for a large number of cities and/or historic trend analysis should use EDGAR data.
- Analysis of urban emissions at the national level which does not require data on individual cities can use the national breakdown of EDGAR emissions by settlement type. It may be important to compare national data on urbanization based on official urban definitions with the Global Human Settlements typology. For example, the urban population of a given country according to its government may correspond more closely to urban centers only or to some combination of urban centers, suburbs, and towns in the Global Human Settlements typology.
- As EDGAR and GGMCF are global gridded data sets, they can be summarized by any spatial boundary, including the urban center and functional urban area boundaries used here. Users should check which among these or other boundaries best represent the spatial unit relevant to their analysis, e.g., by overlaying these boundaries on satellite imagery for their city or country of interest.
- Comparing data from EDGAR and GGMCF can provide some indication of the differences between Scope 1 (territorial) and Scope 3 (consumption-based) CO_2 emissions, although such comparisons should note differences in the methodologies used to produce these data sets.
- Carbon Monitor Cities is best suited to analysis of daily emissions for a recent period. For example, it shows the effects of the COVID-19 pandemic on urban emissions. It could be used to analyze the effects on emissions of policy changes, infrastructure construction, changes in fuel prices, or other changes during this period.
- All the data sets discussed above include CO_2. However, EDGAR also has data on other greenhouse gases (e.g., methane) and pollutants (e.g., particulate matter), calculated and reported separately. Local inventories often combine emissions of multiple greenhouse gases and report them in terms of aggregated CO_2 equivalents. Depending on the context and the focus of an analysis, it may be important to use a data set which includes other GHGs and pollutants beyond CO_2, e.g., nitrous oxide and particulate matter from vehicles, methane emissions from solid waste, etc.

This note represents the state of knowledge as of its writing (mid-2022). However, this is a rapidly evolving field, and potential users of urban emissions data should check for updates to the data sources mentioned here, or the emergence of new ones, before proceeding with their analysis.

Appendix

Sector groupings used in different data sets

EDGAR sector - description: IPCC 1996 code / IPCC 2006 code	National-level analysis by GHS typology (Crippa et al 2021)	Urban Center Database	WB FUA analysis	Carbon Monitor Cities
AGS - Agricultural soils: 4C+4D1+4D2+4D4 / 3C2+3C3+3C4+3C7	Agriculture	Agriculture	Agriculture	Not included
ENE - Power industry: 1A1a / 1A1a	Energy-industry	Energy	Energy-industry	Power
PRO - Fuel exploitation: 1B1a+1B2a1+1B2a2+1B2a3+1B2a4+1B2c / 1B1a+1B2aiii2+1B2aiii3+1B2bi+1B2bii	Energy-industry	Industry	Energy-industry	Not included
IND - Combustion for manufacturing: 1A2 / 1A2	Energy-industry	Industry	Energy-industry	Industry
REF_TRF - Oil refineries and Transformation industry: 1A1b+1A1c+1A5b1+1B1b+1B2a5+1B2a6+1B2b5+2C1b / 1A1b+1A1ci+1A1cii+1A5biii+1B1b+1B2aiii6+1B2biii3+1B1c	Energy-industry	Industry	Energy-industry	Industry
RCO - Energy for buildings: 1A4 / 1A4+1A5	Residential	Residential	Buildings	Residential
TRO - Road transportation: 1A3b / 1A3b	Transport	Transport	Road transport	Ground transport
TNR_Other - Railways, pipelines, off-road transport: 1A3c+1A3e / 1A3c+1A3e	Transport	Transport	Non-road transport	Ground transport
TNR_Aviation_CRS - Aviation cruise: 1A3a_CRS / 1A3a_CRS	Transport	Transport	Non-road transport	Aviation
TNR_Aviation_LTO - Aviation landing & takeoff: 1A3a_LTO / 1A3a_LTO	Transport	Transport	Non-road transport	Aviation
TNR_Ship - Shipping: 1A3d+1C2 / 1A3d	Transport	Transport	Non-road transport	Ground transport
SWD_INC - Solid waste incineration: 6C+6Dhaz / 4C	Waste	Residential	Waste	Not included
CHE - Chemical processes: 2B / 2B	Other	Industry	Other	Not included
FFF - Fossil Fuel Fires: 7A / 5B	Other	?	Other	Not included
IRO - Iron and steel production: 2C1a+2C1c+2C1d+2C1e+2C1f+2C2 / 2C1+2C2	Other	Industry	Other	Not included
NEU - Non energy use of fuels: 2G / 2D1+2D2+2D4	Other	Industry	Other	Not included
NFE - Non-ferrous metals production: 2C3+2C4+2C5 / 2C3+2C4+2C5+2C6+2C7	Other	Industry	Other	Not included
NMM - Non-metallic minerals production: 2A / 2A	Other	Industry	Other	2A1 Cement production included in Industry sector
PRU_SOL - Solvents and products use: 3 / 2D3+2E+2F+2G	Other	Industry	Other	Not included