Why do estimates of urban contributions to global greenhouse gas emissions differ?
Prepared by the Data-Driven EnviroLab
(Diego Manya, Ying Yu, and Angel Hsu)
April 2026

Estimates of the "urban contribution" to global greenhouse gas emissions vary widely, from as low as 40% (EU JRC, 2025) to as high as between 71-76% (Seto et al., 2014). These differences exist as a result of how different studies define and operationalize urban definitions, boundaries and emissions accounting in fundamentally different ways. Some studies base emission estimates on physical measures of built-up urban extent; others treat them as functional urban systems tied to consumption energy demand and infrastructure (Lwasa et al., 2022; IPCC AR6 Ch8), or as administrative jurisdictions that map more directly onto governance and policy authority (Yu et al., 2025\6). Some account for territorial emissions (i.e., emissions resulting from activities occurring within a city boundary, production-based accounting), while others take a more holistic or systems-based approach and base quantification on consumption-based emissions (Gurney et al., 2022). These choices substantially change which activities and emissions are counted as "urban," and therefore the implied magnitude of urban responsibility.

After surveying prior IPCC reports and studies estimating the urban share of global greenhouse gas emissions, this note summarizes the main differences between these studies. Most differences in estimates of the global urban contribution to emissions boil down to three choices: first, how "urban" is defined and bounded (administrative cities vs built-up physical extents or density-based urban clusters); second, how electricity and heat are treated, especially whether power-sector emissions are counted where plants are located (territorial gridded inventories) or re-attributed to cities as a proxy for electricity/heat use; and last, whether "urban contribution" is framed as territorial/production-based emissions (e.g., "Scope 1" emissions occurring inside the urban boundary) or consumption-based footprints (e.g., "Scope 3") emissions embodied in what urban residents and firms consume), including what sectors and gases are included under each definition. Below we discuss some of these issues in detail.

In this explanatory note, we first unpack how three choices impact global contribution estimates: how "urban" is defined; how electricity and heat are treated in global urban emission estimates; and whether "urban contribution" is determined territorially or through consumption footprints. We then make the case for an administrative-boundary approach when an analysis's objective is policy relevance and global comparability, since climate planning and policy authority operate through jurisdictions rather than settlement pixels. We use the Global Administrative Areas Database (GADM) as a globally consistent baseline, recognizing that there are some countries, like the U.S., where more locally-defined urban boundaries are available. We conduct a U.S.-specific case study to show the sensitivity of utilizing GADM as a starting baseline rather than more detailed definitions provided in the U.S. context. We then provide additional case examples to show how different urban definitions systematically shift estimated urban contributions with other existing studies.

1) Identifying "urban" (boundaries and units of aggregation)

A primary reason global estimates of the "urban contribution" diverge is that studies operationalize "urban" using fundamentally different spatial concepts, including pixels, morphological extents, settlement clusters, or administrative jurisdictions (Figure 1 and Figure 2). These differences change what land or area, and therefore what emissions, are included. Pixel-based approaches (e.g., EU JRC's EDGARxGHSL, Crippa et al., 2021 and Crippa et al. 2026) classify emissions as "urban" only when they occur in pixels labeled as urban centres or urban clusters under GHSL at ~1 km resolution. Using this method, global GHG emissions in 2024 are estimated at 53.3 GtCO2e, with urban centres and clusters contributing 23.5 GtCO2e (44%) and rural areas 27.7 GtCO2e (52.2%). Because only dense/built-up pixels qualify as urban, emissions that occur within city administrative boundaries but fall in less dense, industrial, or green-space pixels can be counted as "rural," lowering the estimated urban share within the scope of urban administrative authority and emission reduction responsibilities (≈44% globally in 2024; EU JRC 2025). This definition's sensitivity is also demonstrated by Crippa et al. (2021): urban centres alone account for roughly ~35% of global CO2 in 2015, but that share rises to ~50% when "suburbs" are included and to ~70–80% under a broader "all urban areas" definition.

Other studies define urban extent and boundaries differently. Marcotullio et al. (2013) use gridded population urban extents derived from night-time lights and focus on extents above a population threshold (e.g., >50,000 residents in 2000). Using this approach the estimated urban share of emissions was reported between 36.8 to 48.6 % of total emissions or between 12.8 and 16.9 billion tons CO2-eq for the year 2000. Applying such a population threshold could also be problematic in aligning with city climate actions, since the median population of a European city participating in the EU Covenant of Mayors for Climate and Energy, one of the major urban climate initiatives that includes more than 10,000 local authorities committing voluntary emission reduction targets in line with or exceeding the EU's own mitigation goals (Hsu et al., 2020; Hsu et al., 2022). Meanwhile, Moran et al. (2018; GGMCF) aggregate from 250-m gridded surfaces to define "cities" as contiguous high-density urban clusters (rather than administrative boundaries), which often include suburbs/exurbs.

In contrast to these pixel/cluster approaches, Yu et al. (2025) explicitly frame "urban" in administrative terms using GADM 4.1 (jurisdictions aligned with governance authority). They classify all administrative units as urban centres, peri-urban, or rural using multiple indicators (e.g., population, GDP, built-up area, electricity consumption), and once an administrative unit is classified as urban, all emissions within that boundary are counted. This yields substantially higher global urban shares, since urban centers plus peri-urban areas are counted and attributes 81% of global consumption-based emissions (using Moran et al., 2018's data) and 73% of EDGAR territorial emissions to urban areas in 2022. Focusing on established urban centers alone, the urban share is 43% of global consumption-based emissions and 30% of EDGAR territorial emissions. Yu et al's (2025) administrative boundary approach is consistent with an accountability framing where cities are responsible for emissions occurring within their jurisdiction, providing a more inclusive and realistic perspective in terms of the mitigation responsibilities and opportunities cities have to influence their emissions. For example, by discounting green spaces within urban areas, cities' may not be aware of the opportunity to invest in nature-based solutions or account for these areas as critical carbon sinks to help them achieve net-zero. Moreover, relying solely on a dense urban core definition discounts the contributions of suburban and peri-urban areas to greenhouse gas emissions.

2) Treatment of electricity-based emissions (Scope 2)

A second major driver of divergence is how studies handle electricity and heat emissions, especially whether power-sector emissions are attributed to where electricity is generated or where it is used. EDGAR's main product and Moran et al.'s (2018; abbreviated GGMCF) have opposite approaches for accounting for electricity-based emissions. EDGAR is a territorial (Scope 1), gridded emissions inventory: it first estimates national emissions from activity data and emission factors, then spatially allocates them to ~0.1° grid cells using proxies such as power-plant locations and other spatial data; as a result, power-sector emissions are counted where plants are located, not where electricity is consumed, so a city that imports electricity can have territorial emissions that are low if they do not include power plants in their administrative boundary. Building sector emissions exclude grid electricity use because these emissions are recorded under the power sector. Moran et al. (2018) measures consumption-based emissions by downscaling from national consumption footprints using an multi-region input-output table (MRIO;Eora). This dataset splits urban vs rural footprints using national household expenditure patterns as a proxy for subnational consumption patterns, and then downscales to 250m grid cells using population and purchasing power before summing cells to urban boundaries using the EU Global Human Settlement Layer (GHS-SMOD). Practically, that means electricity-related emissions are attributed to what city residents consume (including the upstream electricity embodied in goods/services and imported power), rather than to the physical location of power plants. However, Moran et al. (2018) acknowledge the substantial variation in their estimates (99% CI that the correct consumption-based value is within ±300%-3000% of the model estimated result).

Gurney et al. (2022), the source of IPCC AR6's WGIII's Chapter 8's 2015 estimation of urban emissions occupying 62% of the global total, then effectively hybridizes these approaches for scenario analysis. They use national territorial GHG trajectories from CMIP6/IAM pathways and convert them to national consumption-based trajectories using a consumption-to-territorial ratio constructed from Global Carbon Project data (1990–2018) and extrapolated to 2100. However, Gurney et al. (2022) doesn't provide a clear distinction for electricity-based emissions and effectively collapses the electricity boundary issue rather than resolving it and therefore electricity trade and grid heterogeneity aren't explicitly modeled at the urban scale. Marcotuilio et al. (2013) use EDGAR gridded emissions but report a range for the urban contribution to global CO_2 emissions based on accounting for electricity-based emissions. They estimate that urban areas account for 36.8%-48.6% of emissions in 2000, depending on whether they includes only territorial emissions physically occurring within urban land (low estimate - 36.8%)

or also re-attributing CO2 from thermal power plants located outside urban extents back to cities as a crude proxy for urban electricity/heat use (high estimate 48.6%). They also note why the high estimate can overshoot: this reallocation can over-assign power-plant emissions to cities and it does not capture transfers of electricity between cities or other within-country flows.

3) Territorial vs. consumption-based emissions

The third foundational difference is whether "urban contribution" refers to territorial/production-based emissions (e.g., "Scope 1" emissions occurring inside an urban boundary) or consumption-based footprints (e.g., "Scope 3" emissions embodied in the goods and services consumed by urban residents and firms). EDGAR's main product and studies that use it directly (including EU JRC's EDGARxGHSL, Crippa et al., 2021 and Yu et al., 2025) are primarily territorial: they report where emissions physically occur in space and therefore depend strongly on whether power plants and industrial facilities fall inside the urban boundary definition being used. Moran et al. (2018)'s GGMCF is explicitly consumption-based, shifting attribution from production locations to final demand and using MRIO-consistent footprints that incorporate imported and supply-chain emissions, though at the cost of coarse downscaling assumptions and large uncertainty bounds. Gurney et al. (2022)'s scenario framework includes both: it begins with territorial IAM trajectories but then "consumption-adjusts" national totals before distributing across cities, enabling consistent urban consumption projections but leaving electricity attribution and internal trade heterogeneity implicit. Yu et al. (2025) work is positioned as a policy-relevant bridge by using the EDGAR and Moran et al. (2018) data to calculate estimates of both territorial (EDGAR within administrative boundaries) and consumption-based emissions across all administrative units, since administrative units better align with governance authority and the policy levers cities can actually deploy, whereas pixel/cluster units can be less directly actionable.

A further consideration is how cities themselves report their own emissions. Most citywide emissions inventories are compiled under the GPC (Global Protocol for Community-Scale GHG Emission Inventories), which reports emissions by scopes. In that framework, Scope 1 covers emissions that occur physically within the city boundary, while Scope 2 covers indirect emissions from grid-supplied electricity/energy consumed within the city boundary, even when generation occurs outside the boundary. Importantly, Scope 2 electricity is not "consumption-based" in the MRIO sense: it is an indirect accounting that attributes power-sector emissions to electricity use inside the city, but it does not attempt to reattribute all upstream supply-chain emissions for goods and services, which is closer to a consumption-footprint / Scope 3 accounting). Many cities report at least the minimum reporting level, which includes Scope 1 and Scope 2 emissions from stationary energy and transportation (plus selected waste emissions), reinforcing that electricity is typically treated as a distinct Scope 2 component rather than folded into a full consumption footprint.

Table 1 presents a summary of both the results and approaches for each study previously mentioned:

Study	Estimate Urban Share	Physical / Pixel	Territorial or	Electricity

		or Administrative	Consumption	based-emissions
Marcotullio et al. (2013)	Year: 2000 36.8 to 48.6 % (12.8 and 16.9 billion tons CO2-eq)	Physical / Pixel	Territorial	Allocation of national electricity emissions by area
Moran et al. (2018)	68% of global Carbon footprint	Physical / Pixel	Consumption	Implicit though consumption
Crippa et al. (2021)	Year: 2015 Urban centres: 35% Urban areas to include suburbs: ~ 50% All urban areas: 70 - 80%	Physical / Pixel	Territorial	Considered at power-plant location
Gurney et al. (2022)	Year: 2015 Urban Share: 61.8% Considering CO2 and CH4	Physical / Pixel	Consumption	Unclear
Yu et al. (2025) (Proposed classification)	Year: 2022 Urban Cluster: 29.50 - 37.21% Peri-urban Cluster: 38.6 - 42.46% **Urban Share:** **71.74 - 75.18%** Rural Cluster: 24.18 - 28.26%	Administrative	Territorial	Considered at power-plant location
Yu et al. (2026) (GHSL - DUC classification)	Year: 2022 Urban Cluster: 33.53 - 42.62% Peri-urban Cluster: 40.35 - 45.92% **Urban Share:** **79.58 - 82.97%** Rural Cluster: 17.03 - 20.54%	Administrative	Territorial	Considered at power-plant location
Crippa et al (2026)	Year: 2024 Cities: 21% Towns and semi-dense areas: 24% **Urban Share: 44%** Rural Areas: 53% CO2eq	Physical / Pixel	Territorial	Considered at power-plant location

Table 1. Summary of results and methodological considerations for studies that have identified the urban share of GHG emissions.

Why an administrative boundary approach?

Pixel or morphology-based approaches are well suited to describe where emissions occur relative to built form or population density, but they do not necessarily map cleaning onto the jurisdictions through which climate mitigation or adaptation planning authority, budgeting, infrastructure investment and regulatory accountability operate. The result is a persistent mismatch between measurement units and decision-making boundaries: emissions may be attributed to, or excluded from, “urban” definitions, even when the relevant policy levers and responsibilities sit with an administrative jurisdiction that spans dense urban cores, peri-urban zones, and infrastructure corridors. This mismatch directly affects comparability across countries and the stability of urban typologies intended to guide action, since typologies and resulting classifications can become sensitive to how “urban” is operationalized rather than reflecting meaningful governance opportunities or responsibilities between different places.

Adopting an administrative-boundary approach is therefore one way to align emissions accounting with political units that plan and implement climate action. Urban climate governance is increasingly characterized by multi-level interactions and coordination across municipalities, counties, metropolitan regions and higher levels of government (Bulkeley and Betsill, 2013; Lee and Koski, 2015). Local governments often need to coordinate regionally because key resources and systems (e.g., energy, waste, transport) cross municipal boundaries (Armstrong, 2023). Recent reviews of city climate action plans show that a substantial share of a city’s community-wide emissions can originate in sectors where cities may have limited direct authority, reinforcing the need to interpret “urban responsibility” for climate emissions and actions through governance rather than settlement footprints alone (Burley-Farr et al., 2023; Cohen et al., 2025). Particularly in countries (e.g., the United States) with substantial and growing urban growth beyond urban centers, studies demonstrate the importance of supra-local coordination, with responsibilities extending into the urban-rural fringe where residents tend to have higher carbon footprints that often go unmanaged due to their location beyond an urban core (Armstrong, 2023; Cohen et al., 2025).

While no perfect global database of urban administrative boundaries exists that is consistent across regions and localities, the Database of Global Administrative Areas (GADM) provides a practical global starting point for a governance-aligned approach. GADM provides consistent, multi-level administrative boundaries worldwide (categorized into levels 0 to 5, with 0 at the national-level, 1 generally corresponding to states/provinces, with lower levels beyond that) and is a widely used baseline in global comparative research because many countries lack harmonized, high-resolution subnational boundary products with consistent attributes across space and time (GADM.org). While more detailed and regularly updated boundary systems exist for specific regions, such as national statistical geographies in the United States and the European Union, globally comprehensive boundary systems are uneven outside of these contexts. GADM therefore is not a perfect representation of local governance everywhere; rather it provides a globally consistent minimum viable unit of comparison from which robust, policy-relevant typologies can be built and iteratively refined as higher-resolution and more detailed administrative datasets become available.

A governance-aligned boundary approach is particularly important for developing robust typologies because it reduces sensitivity to modifiable boundary choices and supports interpretation in terms of policy levers. Subnational governments do not formulate climate action plans or allocate adaptation budgets based on pixel or morphology-based classifications. The risks of scale and boundary sensitivity in climate action analysis are well documented. For example, in the UK, research on data scaling shows how shifting the unit of analysis can alter apparent priorities for governance (Sudmant, 2024). Similarly, research on functional urban areas notes that predefined "urban systems" may not match policy needs when different factors are weighted or additional variables introduced for specific policy questions (Khalil et al., 2018).

Case study: Comparing urban definitions in the U.S. context

A critique of GADM for U.S. applications is that the lowest tier (Level 2) corresponds to counties, which could appear to overlook the autonomy and legal authority exercised by municipal governments. This critique is valid, however U.S. governance is highly heterogeneous and city and municipal governments vary quite substantially in their ability to implement climate actions. Counties provide or coordinate essential services and systems that shape emission and climate risk outcomes, including transportation and electric infrastructure, public health and human services, environmental management that often includes water, wastewater, stormwater management at scales that are not managed by a single municipality alone.

This governance reality is important when comparing U.S. "urban" definitions commonly used in emissions studies. Metropolitan and micropolitan statistical areas (and their combinations, such as core based statistical areas) are delineated by the U.S. Office of Management and Budget and the Census Bureau primarily for statistical reporting, representing a core population nucleus plus economically integrated surrounding counties; they are not, however, governance units with a single climate plan, budget, or regulatory authority (Census.gov). Likewise, census "urban areas" are morphology and density-based definitions that represent densely-settled cores and associated adjacent territory rather than administrative jurisdictions. For example, as illustrated in Figure 1, when urban areas are defined using Core-based statistical areas metropolitan (populations above 50,000) and micropolitan areas (e.g., populations between 10,000 and 50,000; CBSA-Metro+Micro: Purple in Figure 2), estimated "urban-area" emission contribution totals (87.8% for ODIAC in 2022) are relatively close to governance-aligned urban area totals from Yu et al. (2026) estimated as 85.4% using ODIAC for 2022, since these definitions include extensive suburban and peri-urban territory through county-based integration rules. A comparison using only the Metropolitan areas (73.3% in 2022 using ODIAC) shows a difference of only 15% compared to the urban area estimate from Yu et al (2026). In contrast, Census Urban Areas (UAC: Magenta in Figure 2) are morphology or density-based with an estimated contribution of 39.8% of total emissions using ODIAC in 2022, significantly lower than the previous estimations and closer to the "urban core" definition proposed in Yu et. al (2026) with an estimated contribution of 21.5%, albeit higher due to the incorporation of all small and medium sized cities in the US.

Many emission sources that matter for policy management, including industrial activity, freight and transportation corridors, major roads, and electricity generation, as well as suburban communities, sit outside dense settlement pixels while remaining in the jurisdictions that plan infrastructure and regulate land use. Utilizing a pixel or population-based threshold such as the UAC therefore fails to account for these areas' emissions, even when governance responsibility and mitigation levers are tied to urban and peri-urban jurisdictions. In this sense, even with the previously mentioned limitation on the use of counties, these boundaries do encompass many relevant sources of emissions, achieving similar coverage compared to the US-specific definitions of CSBA, while keeping their alignment to one level of subnational government.

For example, while the New York–Newark–Jersey City metropolitan statistical area can be delineated as a functional urban region for statistical or analytical purposes, it could not be associated with specific policies because it is not a single governance unit for which a unified climate action plan, budget, or regulatory authority exists, since 23 counties are part of this MSA. Climate planning in practice is articulated through states, counties, municipalities, and regional agencies with distinct mandates. At the same time, counties themselves are increasingly active climate actors. As of March 2026, the ClimActor v2.0 database of subnational climate commitments (Manya et al., 2025) identifies at least 12 U.S. counties (Los Angeles, CA; Howard, MD; Honolulu, HI; Broward, FL; Cuyahoga, OH; Dane, WI; Boulder, CO; King, WA; Orange County, NC; Miami-Dade, FL; Santa Fe, NM; and Arlington County, VA) with county-level climate action plans that encompass multiple municipalities. While dozens of U.S. cities have also adopted climate plans, decision-making and implementation are distributed across administrative tiers, and jurisdictional accounting must be able to represent both municipal and supra-municipal governance.

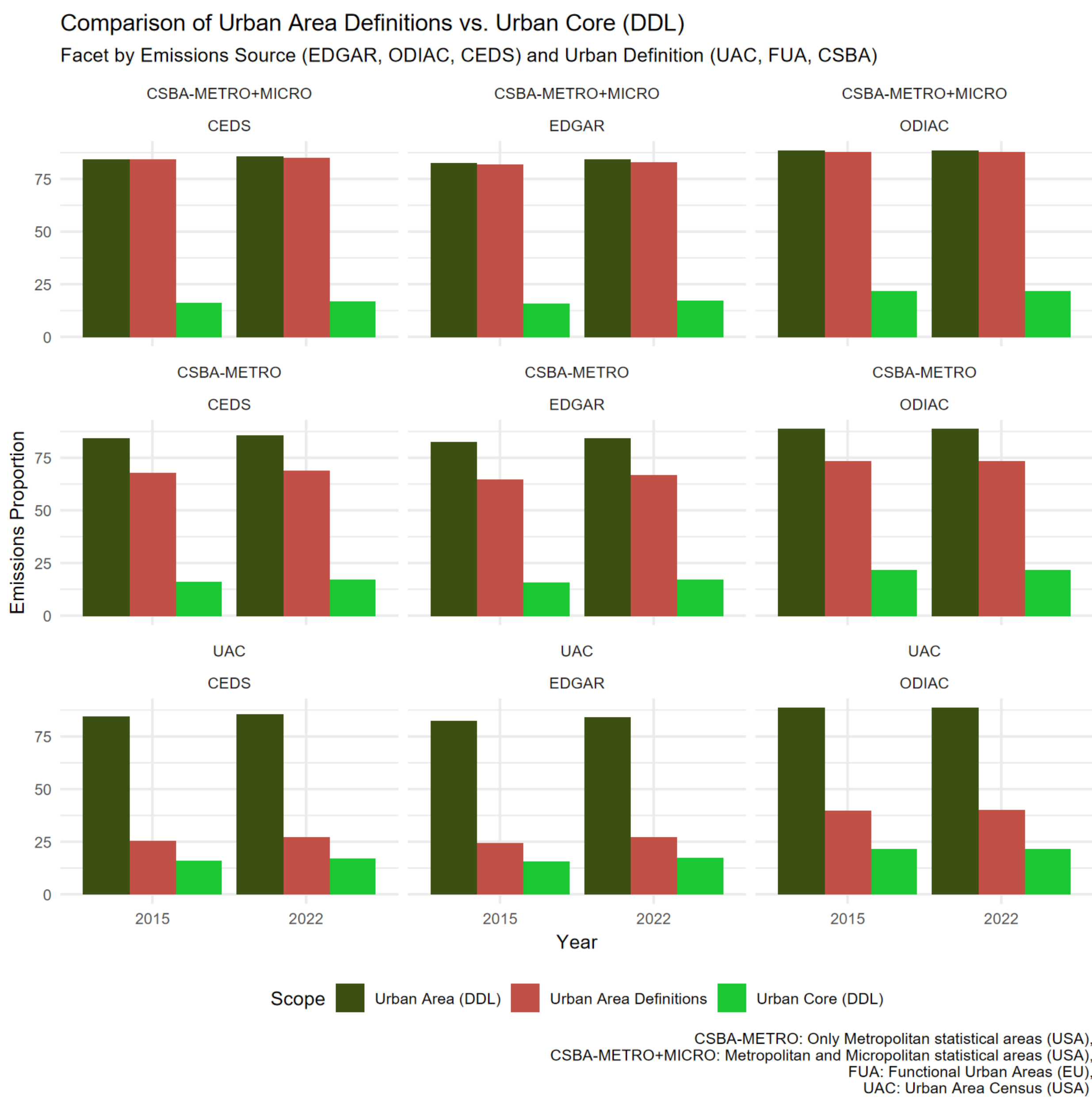

Figure 1. Comparison of urban share of emission under different ‘urban’ definitions in the US

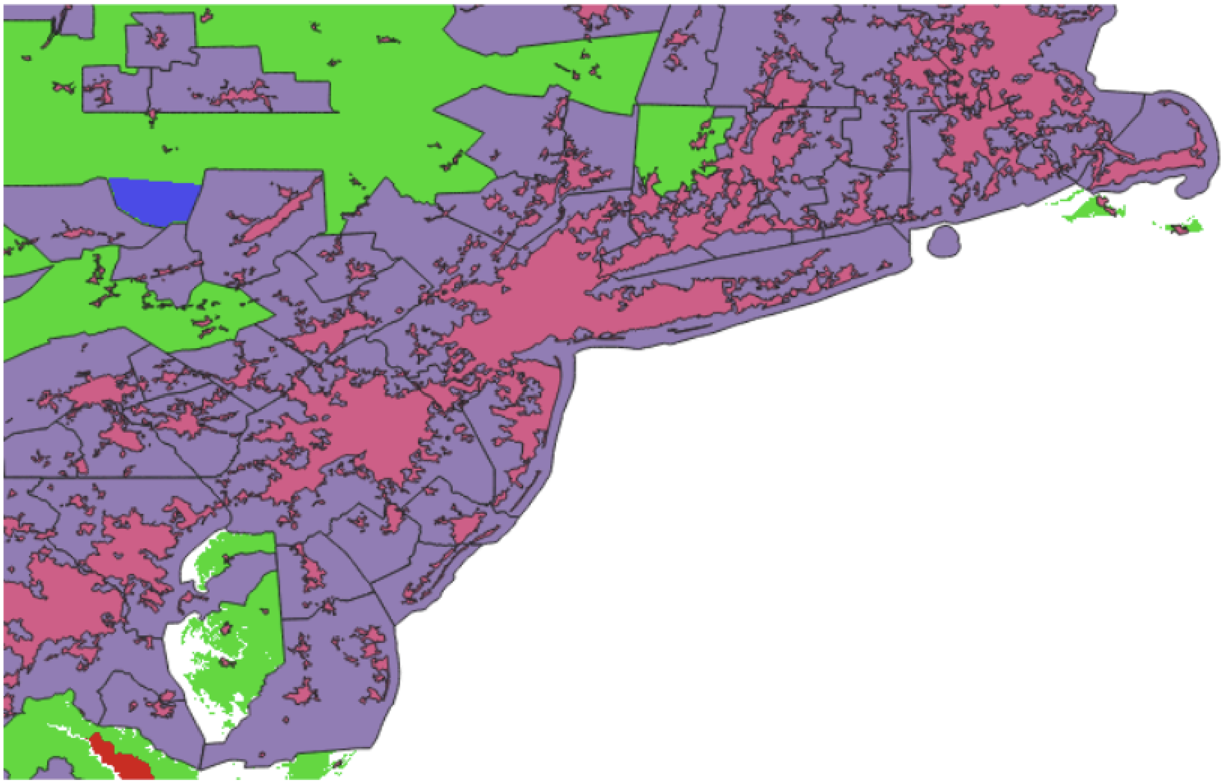

Figure 2. Magenta - Census Urban Areas (UAC); Purple - Metropolitan and Micropolitan areas (CBSA); Green - county classified by GADM.

Case study: Comparing the EU JRC estimation of urban territorial emissions using EDGAR and by IPCC regions

The EU JRC provides estimates of urban/rural GHG emissions by IPCC sector by integrating emissions information from the EDGAR database and the Global Human Settlements Layer (GHSL) using solely 1 km x 1 km pixels. From their 2024 data, global greenhouse gas emissions in 2024 were 53.3 GtCO2e, with rural areas contributing 27.7 GtCO2e (52.2% of global emissions) and urban centers and urban clusters contributing 23.5 GtCO2e (44% of global emissions; Figure 3). These pixel-based estimates or GHG emissions consider urban emissions only if the pixels in which they occur are classified as urban centers or urban clustered based on the GHSL dataset. Under this approach, only densely populated and built up pixels are counted as urban centers or urban clusters. As a result, a substantial share of emissions that occur within city administrative boundaries but that are not dense or built enough are attributed to “rural” areas, yielding a much lower urban contribution to global greenhouse gas emissions (≈44% globally in 2024; EU JRC 2025).

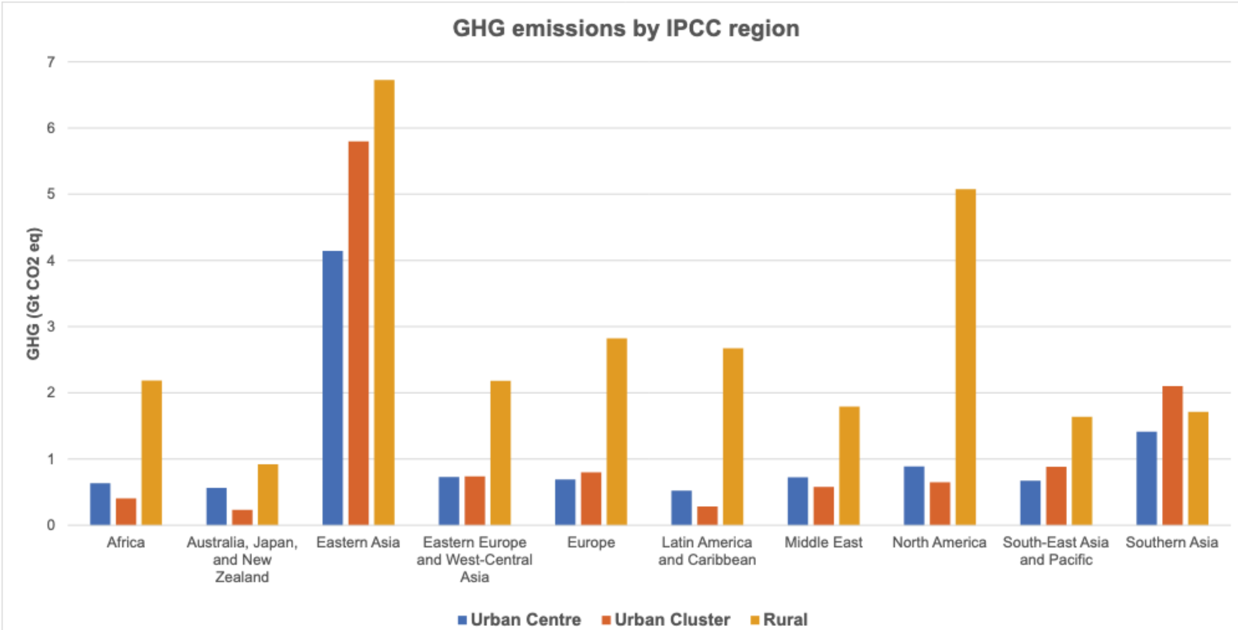

Figure 3. GHG Emissions by IPCC Region using pixel-based estimation (EDGAR - JRC). https://edgar.jrc.ec.europa.eu/edgar_smod

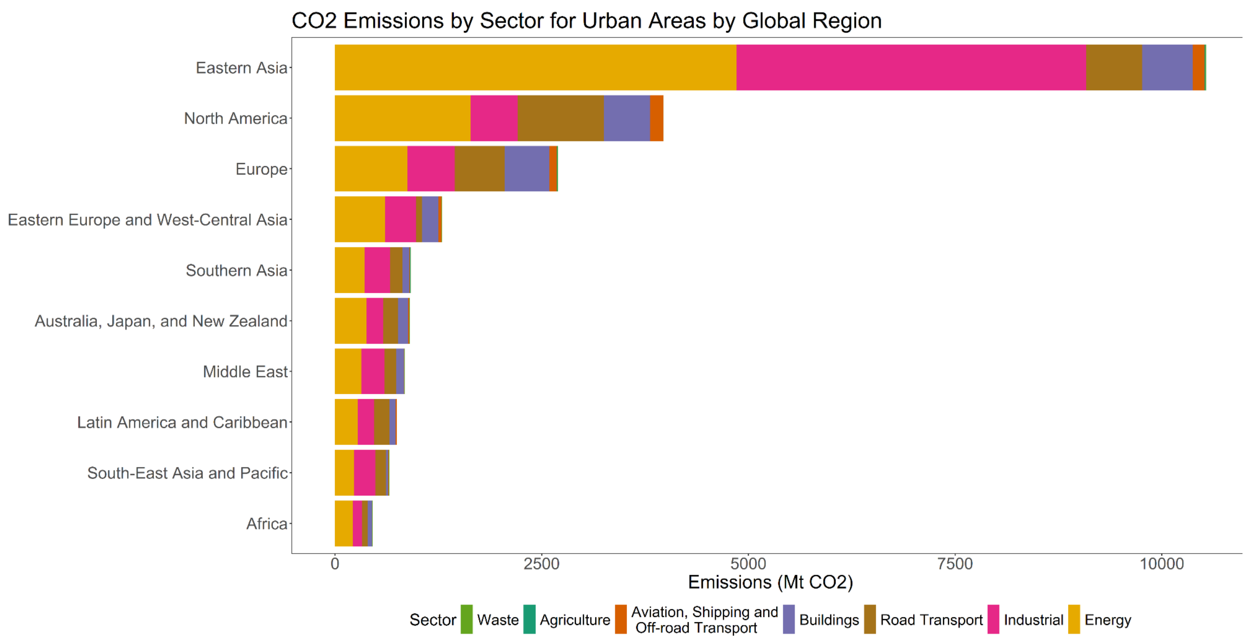

Figure 4. GHG Emissions of Urban Areas by IPCC Region using administrative-units. Based on data from Yu et.al (2025)

To better align the calculation of the “urban contribution” to global carbon dioxide emissions worldwide based on administrative boundaries that reflect cities’ authority to manage emissions, our recent paper (Yu et al., 2026) estimates urban emissions based on administrative boundaries (GADM 4.1), as opposed to solely pixels. We developed a new urban-rural classification approach using population, GDP, built-up area, and electricity consumption indicators to classify all administrative units as urban centers, peri-urban areas or rural areas. Once an administrative unit is classified as urban, all emissions occurring within that boundary are counted as urban. Because most economic activity, infrastructure, energy use, and associated emissions are governed and planned based on administrative units, this approach captures emissions from dense urban cores as well as less populated areas that are administratively under a city's governance. Consequently, Yu et al.'s (2026) administrative-unit-based classification yields higher urban shares (urban centers + peri-urban areas) of global emissions (81% of global consumption-based and 73-77 % of territorial emissions in 2015), although the emission share for urban centers alone using this administrative-boundary approach is in line with the EU JRC's estimate, with urban centers alone contributing 43% of consumption-based emissions and ~30 to 37% of territorial emissions for 2015, consistent with an accountability framework where cities are responsible for all emissions within their jurisdiction (Figure 4).

To better visualize these differences, Figure 5 presents a selection of areas where the difference between pixel-based and administrative entity-based classification can be observed (a = Madrid-ESP, b = Philadelphia-USA, c = Rio de Janeiro-BRA and d = Shanghai - CHN). These examples highlight that in many administrative units classified as urban or periurban, while they are composed of a consolidated urban or periurban groups of pixels, there is also an important number of pixels that are classified as rural that could have multiple types of land use (i.e., green space, undeveloped areas, sparsely populated, industrial areas, etc.) but that fall under the jurisdiction of the administrative entity in question, and thus should be considered when estimating their territorial GHG emissions.

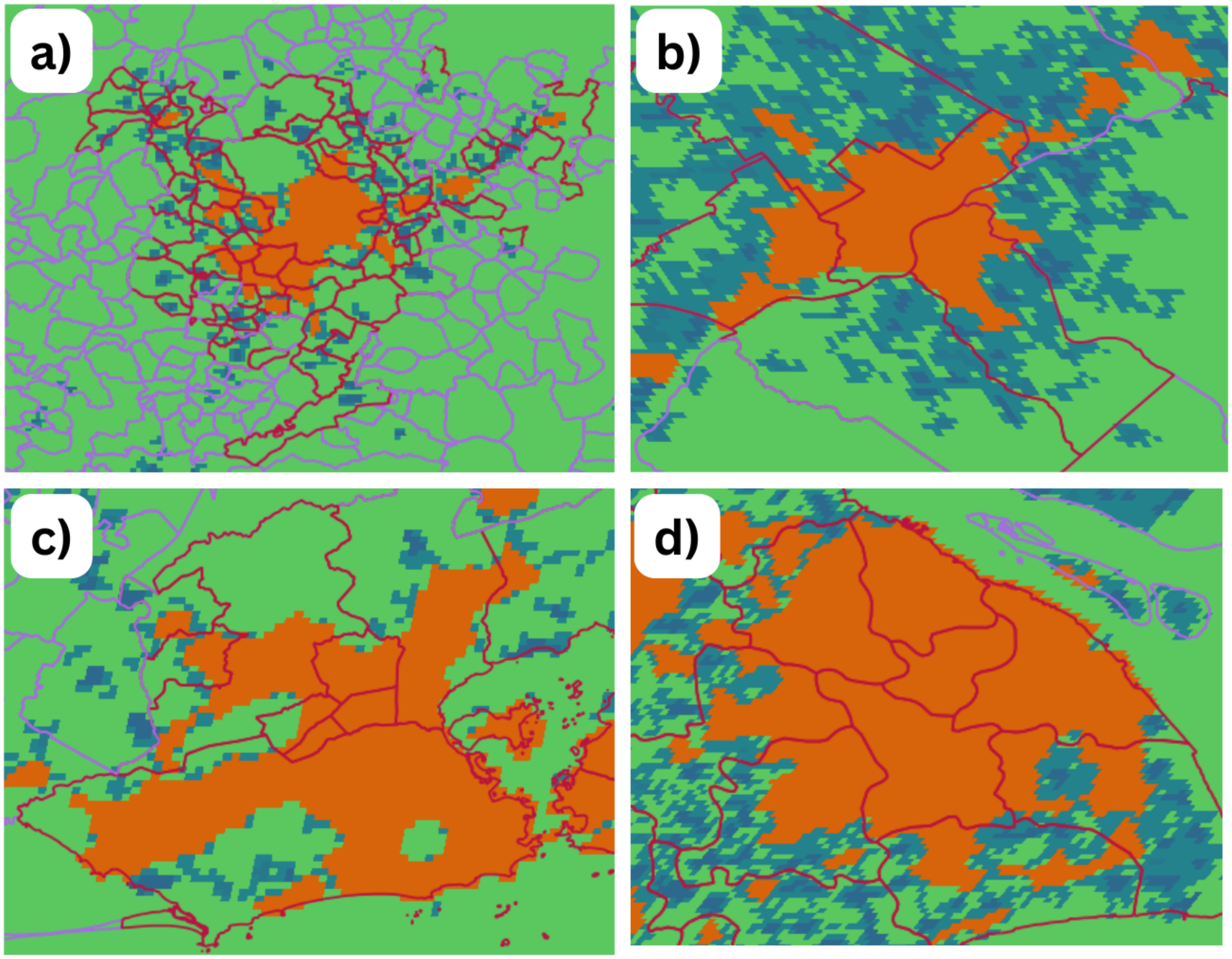

Figure 5. Differences in pixel-based classification or urban areas vs administrative - based classification (Yu et al 2026). Background pixels identify the type of settlements based on GHSL data (Orange = Urban, Blue = Peri-urban, and Green = Rural) while boundaries represent the classification based on administrative areas (Red = Urban, Purple = Periurban).

Case study: Comparing estimates of administrative-boundary based territorial emissions
Yu et al. (2026) compare emission estimates with the Global Degree of Urbanization Classification of administrative units delineated by GADM (GHS-DUC) (Schiavina et al., 2023), which uses the previously mentioned pixel-based classification, and classifies each administrative unit as Cities, Towns or rural areas based on the proportion of population living in each type of pixel to the entire population of the unit in question. For example, Schiavina et al. (2023) classify an administrative entity as a city if at least 50% of its population are living in an urban area. Under these results, the urban contribution is estimated to be approximately 87% of global consumption-based emissions and 78-82% of global territorial emissions in 2015. While these numbers are closer to Yu et al. (2026)'s estimates, the results of this classification approach overestimate urban and periruban areas due to their exclusive use of population and the thresholds selected (see Supplementary notes in Yu et al 2026), which results in large and sparsely populated administrative units like some entities in Greenland, Saudi Arabia to be entirely classified as urban because more than 50% of their population lived in a relative small

area classified as cities. Yu et al (2026)'s methods use additional data to better differentiate between urban, periruban and rural administrative entities, reducing the misclassification of rural areas as urban which ultimately leads to slightly lower estimates on the urban contribution to GHG emission.

In summary, the discrepancy between the JRC-EDGAR estimates and Yu et al. (2026)'s results arises from differences in the spatial definition of urban, periruban and rural and the unit that are used for the aggregation: pixel-based methods measure emissions exclusively from urban or periruban pixels, while our approach methods measure emissions from urban or periurban jurisdictions, which are composed of urban, periruban and rural pixels. Many emissions counted as "rural" in pixel-based approaches occur within administratively urban areas, explaining why pixel-based urban contributions are systematically lower since they represent only a fraction of the area actually managed by a regional or local government.

References

Armstrong, John H. "Formal local government coordination to mitigate climate change." Urban Climate 51 (2023): 101636.

Cohen, M., Baker, M., Bush, M. et al. A review of U.S. city climate action plans. Climatic Change 178, 61 (2025). https://doi.org/10.1007/s10584-025-03887-7

Crippa, M., Guizzardi, D., Pisoni, E., Solazzo, E., Guion, A., Muntean, M., ... & Hutfilter, A. F. (2021). Global anthropogenic emissions in urban areas: patterns, trends, and challenges. Environmental Research Letters, 16(7), 074033.

Crippa, M., Guizzardi, D., Pisoni, E. GHG emission in cities, towns and rural areas, 18 January 2026, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-8405392/v1]

Crippa, M., Guizzardi, D., Ciarlantini, S., Pagani, F., Banja, M., Muntean, M., Pisoni, E.: EDGAR_GHG_by_settlement_2025, dataset, https://edgar.jrc.ec.europa.eu/edgar_smod, 2025.

Data-Driven EnviroLab. (2024). Cities Climate Action Report Card. Prepared by: Burley Farr, K., Hsu, A., Carney, W., & Chung, C. Available: https://datadrivenlab.org/cities_climate_action_report_card_nov2024/.

Gurney, K. R., Kılkış, Ş., Seto, K. C., Lwasa, S., Moran, D., Riahi, K., ... & Luqman, M. (2022). Greenhouse gas emissions from global cities under SSP/RCP scenarios, 1990 to 2100. Global Environmental Change, 73, 102478.

Hsu, A., Tan, J., Ng, Y. M., Toh, W., Vanda, R., & Goyal, N. (2020). Performance determinants show European cities are delivering on climate mitigation. Nature Climate Change, 10(11), 1015-1022.

Hsu, A., Wang, X., Tan, J., Toh, W., & Goyal, N. (2022). Predicting European cities' climate mitigation performance using machine learning. Nature Communications, 13(1), 7487.

Khalili, A., van den Besselaar, P., de Graaf, K.A. (2018). Using Linked Open Geo Boundaries for Adaptive Delineation of Functional Urban Areas. In: Gangemi, A., et al. The Semantic Web: ESWC 2018 Satellite Events. ESWC 2018. Lecture Notes in Computer Science(), vol 11155. Springer, Cham. https://doi.org/10.1007/978-3-319-98192-5_51

Lwasa, S., K.C. Seto, X. Bai, H. Blanco, K.R. Gurney, Ş. Kılkış, O. Lucon, J. Murakami, J. Pan, A. Sharifi, Y. Yamagata, 2022: Urban systems and other settlements. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.010

Marcotullio, P. J., Sarzynski, A., Albrecht, J., Schulz, N., & Garcia, J. (2013). The geography of global urban greenhouse gas emissions: An exploratory analysis. Climatic Change, 121(4), 621-634.

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.

Schiavina, M., Melchiorri, M., Freire, S., 2023. GHS-DUC R2023A -GHS Degree of Urbanisation Classification, application of the Degree of Urbanisation methodology (stage II) to GADM 4.1 layer, multitemporal (1975-2030).
https://doi.org/10.2905/DC0EB21D-472C-4F5A-8846-823C50836305

Seto, K. C., Dhakal, S., Bigio, A., Blanco, H., Carlo Delgado, G., Dewar, D., ... & Zwickel, T. (2014). Human settlements, infrastructure, and spatial planning.

Sudmant, A. Data Scaling: Implications for Climate Action and Governance in the UK. Environmental Management 74, 414–424 (2024). https://doi.org/10.1007/s00267-024-01991-5

Yu, Y., Manya, D., and Hsu, A.(2026). Aligning emissions with decisionmaking: estimating urban contributions to global carbon dioxide emissions. Pre-print: https://doi.org/10.31223/X5PB02