City Climate Finance Gap Fund

GAP FUND TECHNICAL NOTES

GHG EMISSIONS INVENTORIES: AN URBAN PERSPECTIVE

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GHG Emissions Inventories: An Urban Perspective

Gap Fund Technical Note[1]

Introduction

In 2020, humans were responsible for emitting around 50 GtCO2e (about 6.4 tonnes per person). Under the Paris Agreement, national governments have agreed to rein in these emissions to almost zero within 30 years. In order to accomplish this, greenhouse gas (GHG) emissions inventories are needed to prioritize initiatives and track progress. The task is too large and urgent to leave to national governments alone: communities and businesses must also identify their emissions, set ambitious targets, and monitor progress.

The 6.4 tonnes per person is a global average and can range from as high as 29.8 tCO_2e per person in Rotterdam to as low as 0.2 tCO_2e per person in Dar es Salaam. Moreover, even in Rotterdam and Dar es Salaam these values are averages. A well-travelled, affluent individual may generate more than twice the Rotterdam average (60 tCO_2e), and some of the poor in Dar es Salaam likely are responsible for less than 0.05 tCO_2e (i.e., 50 kg)[2]. Community-scale inventories help to refine national estimates and quickly highlight priority areas for mitigation.[1]

The Paris Agreement binds Parties to collectively limit global temperature increases well below 2°C and pursue efforts to limit the increase to 1.5°C. All Parties agreed to put forward their best efforts through "nationally determined contributions" (NDCs), and to report regularly on their implementation efforts. There will also be a global stock-take every 5 years to assess collective progress and adjust individual actions by Parties as may be required. The Agreement recognizes voluntary cooperation among Parties (e.g., emissions trading) and reaffirms the obligations of developed countries to support the efforts of developing country Parties to build clean, climate-resilient futures (e.g., climate finance).

The Intergovernmental Panel on Climate Change (IPCC) created in 1988, is the international body for assessing the science of climate change. An important function of the IPCC is to provide, and regularly refine, guidelines on national GHG inventories.[3] These national GHG inventories support the UN Framework Convention on Climate Change (UNFCCC) and underpin efforts such as the Paris Agreement. National GHG inventories are territorial (i.e. total emissions generated within a specific country or territory). For example, adding the territorial inventories of the 193 Parties

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[2] Ranges in resource use and emissions are often greater within a city than between cities (Hoornweg *et al* 2011).

[3] https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

of the UNFCCC, plus marine and aviation emissions would equal the global total 50 $GtCO_2e$ of 2020.

Since 1992, when the world's nations agreed at Rio de Janeiro to avoid dangerous anthropogenic interference with the climate system, and established the UNFCCC, annual GHG emissions have increased by 40 percent. More than half the world's GHG emissions occurred after this agreement. With limited progress so far, humanity will need to reign in GHG emissions to net zero by 2050 to meet the aspirational goal of the Paris Agreement. This is a Herculean task. The global response to COVID-19 is modest in comparison to the climate action efforts promised (again) by signatories of the Paris Agreement.

National GHG inventories illustrate well the limited progress made at mitigation since 1992. These same inventories are now scrutinized as the world endeavours to significantly reduce GHG emissions. As action intensifies, communities and businesses will be called on to drive much of the world's mitigation effort. To accomplish this, they need emissions inventories that are complementary to national territorial inventories, but are sufficiently comprehensive to capture what changes in purchasing habits, or local operations, could be undertaken by the specific city or business (see Table 1).

Calling on Corporations and Cities

As national GHG inventories tracked growing GHG emissions (corroborated by atmospheric measurements) concerns grew. Progressive businesses responded to public demands by vowing to reduce their overall GHG emissions. In order to track the progress, businesses needed an inventory consistent with national territorial inventories, while still being sufficiently comprehensive to account for all emissions through a businesses' activities. Cities and sub-national jurisdictions followed. For example, at the 1992 Rio conference cities suggested 'Local Agenda 21s' with GHG emissions mitigation targets with credible inventories for monitoring (e.g., ICLEI supported members). Businesses and cities (i.e., customers and residents) may well take on the lion's share of climate mitigation (tracked by credible GHG inventories that are broader than national territorial inventories).

Launched in 1998, the GHG Protocol is a partnership of businesses, NGOs, governments, academic institutions and others convened by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). WBCSD and WRI were responding to requests from progressive corporations wanting to measure their GHG emissions across all operations. Companies may have several offices and manufacturing facilities around the world, and needed to account for emissions associated with upstream emissions from suppliers and resource extraction. A company headquartered in London or Switzerland, for example, needed inventories sufficiently comprehensive to capture worldwide impacts and opportunities. These inventories needed to be more comprehensive than the territorial approaches used by countries, and they needed to account for all emissions, without 'double counting' GHG emissions outside the company's host country.

In 2001, WRI and WBCSD published a GHG Protocol for corporate accounting. This initiated the 2006 ISO 14064 standard, 'organization level for quantification and reporting of greenhouse gas emissions and removals' (revised 2018). Key aspects of organizational inventories are boundaries, emissions factors, reporting protocols and the ability to verify emissions trading and offsets (e.g., carbon sinks). The Protocol introduced the concept of Scopes to denote where emissions are generated: Scope 1 (emissions within administrative boundaries), Scope 2 (emissions associated with imported electricity), and Scope 3 (transboundary life-cycle supply-chain emissions).

In reporting GHG emissions cities can follow various approaches. Cities could provide territorial inventories, similar to their host country (aka production). Add all territorial emissions from cities and other jurisdictions and this should be the country total. Another approach, similar to corporate inventories, accounts for lifecycle emissions of residents and businesses across the influence of the city. In the territorial approach, the city is a local component of the national emissions inventory, while in the broader approach, the city is a spatial area representing the collective community-wide life-cycle (global) actions of residents and businesses.

- Corporations and cities measure GHG emissions differently to avoid 'double counting' across national inventories and to account for upstream and downstream (out of boundary) emissions.
- Scopes 1, 2 and 3 provide both generation and 'consumption based' emissions.

Urban Areas and Cities

Large urban areas have a disproportionate impact on the world's economy, culture and GHG emissions. For example, residents of just 100 cities account for 20 percent of humanity's overall GHG emissions[4]. Only 600 urban centers (20 percent of the world's population) generate 60 percent of worldwide GDP[5] (and a corresponding share of GHG emissions).

Urban areas possess a powerful characteristic. For patents, innovation, cultural and relationship contacts, cities scale super-linearly (~1.15). Double a city's size and you get more than a doubling of social quantities such as the economy, jobs and post-secondary graduations. On the other hand, double a city's size and infrastructure costs like roads, meters of wires, and number of fire stations scale sub-linearly (~0.85).

Systems observed in nature tend to use energy more efficiently as they grow larger, but cities do not. Larger cities use disproportionally more energy than smaller cities, which has been observed empirically in super-linear scaling of electricity consumption (Bettencourt, 2007). It has been theorized that large cities require more energy for growth and maintenance (Bristow and Kennedy, 2013), for example by building higher-order infrastructure, such as public transportation networks, that drive even more energy consumption and associated emissions (Sugar and Kennedy, 2020).

Following the success of ISO 14064 (initiated by WBCSD and WRI) and its ability to measure the worldwide GHG emissions of business activities, consistent with national IPCC-supported

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[4] From Scientific American, June 27, 2018 – referencing Moran *et al* (2018). In Hoornweg *et al* (2011) the world's urban residents are attributed with more than 80 percent of GHG emissions (Scopes 1-3).
[5] McKinsey (2011): Urban world: mapping the economic power of cities.

methodologies, WRI, ICLEI and C40 launched an similar GHG inventory for cities (Global Protocol for Community-Scale Greenhouse Gas Emission Inventories[6]).

What to Measure

Figure 3 and Table 3 provide a schematic of how Scopes 1, 2 and 3 interact with each other, and what should be measured for urban area and city GHG inventories. Cities now typically report GHG emissions as 'BASIC' or 'BASIC+'. These definitions are outlined in the open-source Global City Protocol[7] (and Table 3). BASIC and BASIC+ denote the degree of comprehensiveness in what is measured.

C40 provided an important update on this approach in 'Consumption-based GHG emissions of C40 cities' (2018). The need for this approach is confirmed through GHG inventories for Madrid and London (Fig. 3, Andrade *et al,* 2018). Five GHG methodologies for the two cities were applied:

Territorial, BASIC, BASIC+, DPSC[8], and Consumption Based. Per capita values range from a low of 5.7 tCO2e and 3.8 tCO2e (Territorial) to a high of 14.2 tCO2e and 12.2 tCO2e (Consumption Based, CB) for London and Madrid respectively. C40 confirmed these more comprehensive values for consumption-based accounting. Some of the 79 C40 cities included in the study increased overall GHG emissions by 60 percent when measured through CB inventories. Individual CB GHG emissions varied from 1.8 to 25.9 tCO2e/capita.

In order to bring about the large-scale and rapid GHG mitigation targets envisaged globally for C40 cities, an approach that takes into account transboundary life-cycle emissions is needed. Urban areas in low-income countries may suggest that they do not require a more comprehensive GHG inventory (arguing that the simpler BASIC or BASIC+ is sufficient); however this misses the power of a common standard applied globally (that encourages all cities to fully reflect their overall GHG contributions).

Similar to businesses, urban areas should account for the broad suite of life-cycle GHG emissions. Ramaswami *et al* (2021) show that seven systems contribute more than 90 percent of global GHGs (energy, mobility and connectivity, buildings, water supply, waste/sewage management, green infrastructure, food supply). This 'BASIC+7' is sufficient to capture all GHG emissions at an urban scale.

Municipal governments often prefer to publish only those emissions for which they have jurisdiction, e.g. corporate processes and perhaps energy and in-boundary transportation. Broader life-cycle Scope 3 emissions in items such as imported food and building materials are typically outside the municipal authority. This reflects an inherent challenge within city GHG inventories, a hesitancy to publish the emissions more attributable to residents and businesses (for which the municipal government has limited influence) and the difficulty in using the inventories as performance based mitigation metrics. C40 deserves praise for providing the

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[6] WRI-ICLEI-C40 GPC, see: https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

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

[8] DPSC: Direct Plus Supply Chain is the British Standards Institution (BSI) PAS2070:2014, developed for Greater London Authority

consumption-based inventories of member cities. A next step may be in providing the GHG inventories for the overall urban area[9], e.g. DKI Jakarta (9.6 Mn) within Metro Jakarta (33.4 Mn).

An additional hybrid household or 'carbon footprint' inventory (consumption-based footprint) emerged in the last 15 years, especially in high-income countries (Table 2). The household approach attempts to capture all emissions associated with a specific household (sometimes presented per person) and the emissions associated with energy and material consumed.

The Value of Measuring GHG, City-Level Carbon Accounting

With regard to GHG inventories, utility accrues from consistency of measurement. GHG inventories provide value as they highlight progress (or lack of it) against trends. Human nature often encourages comparisons between cities and countries (and businesses). This is of course a powerful motivator, however the urgency and broad nature of global GHG mitigation, suggests greater dependence is needed on aggressive baseline efforts and cooperative support.

Cities need to credibly measure GHG emissions in order to maximize access to climate finance and monitor contributions to national objectives such as those announced in Intended Nationally Determined Contributions (INDCs). More than 100 cities have announced targets of being net-zero carbon by (or before) 2050. GHG inventories are need to prioritize actions and monitor progress toward these goals. The inventories need to be consistent with national versions.

GHG inventories should not emerge as the sole metric for success in development projects (or be the sole target for climate finance). Urban mitigation activities usually have several associated co-benefits such as improved health, reduced zoonotic disease transmissions, reduced local flooding, and less ocean plastics. If GHG inventories take on too much importance, there can be increased scrutiny on the *what* of measurement rather than the more helpful prioritization that GHG inventories support. Large co-benefits might not be adequately accounted for.

- Consistency, ideally annual, in GHG inventories is more important than accuracy (i.e., get started as soon possible with a flexible approach that can be adjusted as more data become available).
- Cities should measure all emissions associated with residents and businesses within the city, typically with less emphasis on 'corporate emissions' (the municipality's own activities) which typically are less than 5 percent of a city's overall GHG emissions.

Why Measuring can be Complicated

"If you can't measure it, you can't improve it" (Peter Drucker). As humanity responds to climate change and GHG emissions, enormous financial resources are about to be allocated to mitigation (and adaptation). Governments of all levels worldwide will endeavour to receive maximum funds (or minimize contributions) as mitigation programs are developed.

[9] 'Urban area' is not consistently defined, however the World Bank's Urban Partnership Report (https://openknowledge.worldbank.org/handle/10986/18665) and UN DESA provide useful starting points.

Measuring GHG emissions can become more complicated when inventories need to be legally (financially) defended. Several aspects need to be considered: what is the area of measurement (e.g., specific city or urban area); what is being measured (e.g., which greenhouse gases); what is the balance between accuracy and timeliness and ease of recording. Increasingly, political considerations may influence inventories and their publication.

As hard as scientists and technocrats try to provide objective definitions and tools, measuring something as complex as a country or city requires opinions, assumption, and limits. Metrics are political.

Gurney *et al* (2021) reviewed 48 self-reported inventories and claimed 'under-reporting of GHG emissions by U.S. cities' (of about 18%). Hundreds of media outlets quickly reported the claims. ICLEI USA refuted the findings arguing that the methodology used by Gurney *et al* "failed to capture activities for which the city has urban policy levers" (i.e., measuring atmospheric CO_2 with satellite imagery at one km^2 scale, adding and extrapolating citywide did not provide differentiation by municipal services).[10]

This highlights the political nature of GHG inventories. For example, an argument could be made that less than a 20 percent variance between self-reported and satellite inventories at this early stage in measurement is positive and as methodologies are refined, consistency may well be possible (and helpful to all cities). This also cautions against proprietary software or data collections (as the host organization strives to maintain or exert prominence).

Metrics are political. Comparisons and defensiveness are inevitable. This should however not stop publication of GHG inventories.

Software and measurement tools should be open-source and data should be retained by the city with regular publication of results (ideally annually)

Cities should encourage multiple agents to measure GHG emissions, e.g. all large cities should have a local university regularly measure and publish local GHG emissions (e.g., a down-scaled IPCC approach).

Why Measuring is Critical

About 22 percent of the world's GHG emissions (12 Gt CO2e) are included in one-of-61 emissions trading systems (ETS)[11]. The role of ETS and associated carbon finance is likely to grow.[12] Cities stand to be large beneficiaries of these trends as activities within urban areas make up the lion's share of GHG emissions. How to identify these emissions, and implement curtailment programs

[10] https://www.google.com/search?q=iclei+usa+under-reporting+of+GHG+emissions+by+U.S.+cities&client=firefox-b-d&sxsrf=ALeKk01bGVOy6rS7SsZIPKynJozS3nPd7w:1614791904637&source=lnms&sa=X&ved=0ahUKEwiAmfLO0JTvAhUsGVkFHRfhAJcQ_AUIDigA&biw=1536&bih=701&dpr=1.25

[11] World Bank, State of Trends in Carbon Pricing, 2020

[12] Article 6 of the Paris Agreement establishes the framework for a global carbon market (emissions trading). An effective carbon market has the potential to reduce global carbon mitigation costs by more than $250 Bn per year (IETA); however, the market requires accurate and reasonably verifiable GHG inventories. Cities, where more than 70% of the world's GHG emissions originate, need to be well-integrated into these inventories.

is under development. Framework GHG inventories in which specific infrastructure projects and public policies are nested, are a key prerequisite for city participation.

National governments will prepare their own GHG inventories as outlined under UFCCC protocols. Cities will contribute to these; however, cities (and urban areas), like businesses, will also want broader locally specific mitigation programs that rely on changes in behavior of residents and new infrastructure.

GHG inventories are likely to emerge as detailed and regularly updated versions of Table 3, with Scope 1, 2 and 3 values. Ideally, any potential climate finance (mitigation targeted) would be based on progress captured by these inventories. The inventories as now developed are however not sufficiently detailed to capture the impact of specific infrastructure initiatives, e.g., a new wastewater treatment plant. If climate finance needs to be allocated against specific projects, the projects should be reflected in the community inventory (by category) however detailed measurement of GHG mitigation for the project will likely need to be derived from first principles, i.e., based on size and functionality.

- Credible GHG inventories are a prerequisite for any type of climate finance.
- The scale of GHG mitigation espoused in the Paris Agreement is so large and immediate, cities need to be fully engaged and need to monitor their progress.
- To maximize mitigation potential, larger cities especially, will need to proceed within the metropolitan scale as this facilitates broader opportunities, e.g., transportation, electricity generation, building design, waste and wastewater. This requires a commensurate GHG inventory for the urban area.

GHG inventories serve two broad purposes: (i) research, policy development and trend analysis, and (ii) attribution. UNFCCC Parties provide territorial inventories that underpin international agreements (based on national attribution). Cities may contribute information to these territorial inventories, and provide key data, especially in areas such as electricity consumption (and generation) and transportation. Cities are likely to provide their own (local) Nationally Determined Contributions. These agreements (presumably with financial support) would likely be subsets of national (territorial) inventories and may be part of these inventories.

Urban areas (and cities), still need the broader CB inventories that support city claims such as 'net zero' targets. These broader inventories are more comprehensive and should be fully consistent with territorial inventories. However, they are required to bring about the wholesale social change and public policy needed to drive GHG mitigation of the scale called for under the Paris Agreement.

- Many categories of emissions can be estimated with +/-10 percent accuracy (through downscaled national values or 'bottom-up' accounting). This is often sufficient.
- The WRI-C40-ICLEI Global Protocol is sufficiently detailed and accepted that it can serve as a starting point for all cities (apart from the rare territorial approach for cities, all other approaches are derivatives of the GPC).
- Cities can readily estimate the top seven Scope 3 (life-cycle supply-chain) emissions (initially based on population and wealth).

GHG Inventories and Future Projections

A key aspect of the IPCC research program involves scenario planning with varied population, urbanization and GDP per capita. Five shared socioeconomic pathways (SSPs) provide narratives of: sustainable development (SSP1), middle-of-the road development (SSP2), regional rivalry – rocky road (SSP3), inequality (SSP4), and fossil fuel development (SSP5). The SSP narratives are an important complement to quantitative model projections, especially in areas such as long-lived infrastructure and urban development.

Cities need a credible baseline against which to measure future scenarios. As a minimum a city should have its baseline projected to 2050 as 'business as usual' (SSP2) and 'sustainable development' (SSP1). In low-income countries especially, climate mitigation efforts will largely be to reduce the upward arc of the business as usual trajectory to that of sustainability.

- Scenario planning such as the IPCC's SSP1 – SSP5 narratives can also be applied to cities (in addition to countries and regions). Cities should highlight how their activities will reduce emissions trajectories from 'business as usual' toward 'sustainability' to at least 2050.

GHG Inventories and Climate Finance

As cities more commonly and regularly publish GHG inventories, a pattern is likely to emerge. Cities in low-income countries have very little to mitigate today. Typically, per capita emissions are less than 2 tonne CO_2e. As much as a third of their GHG emissions may be from solid waste (as individual energy consumption and purchasing power for products with embodied carbon is low). The potential for climate finance likely rests in stemming the inevitable growth in GHG emissions. This involves urban form (e.g. density reducing transportation emissions) and the means of electricity generation (low-carbon vs coal and natural gas).

GHG inventories for cities in low-income countries may benefit from a 'business as usual' trajectory applied against a 'climate mitigation' alternative. As low-carbon energy sources and transportation alternatives are developed, significant mitigation efforts can be monitored.

Cities in middle-income countries typically can reduce GHG emissions today by reducing fossil fuels in electricity generation and the transportation sector, and promoting a circular economy, e.g. greater recycling, waste minimization and 'smarter' consumption.

- Climate finance for low-income cities is likely to initially focus on solid waste (as they have little other emissions).
- Slowing of the growth trajectory is the largest source of mitigation potential.

Possible Next Steps on GHG Inventories

Life-cycle supply-chain GHG inventories (BASIC+7) are a systems approach to cities, similar to 'urban metabolism' and 'circular economy' that seek to better reflect overall energy and resource use of cities, and corresponding effluents such as GHG emissions, solid waste and wastewater. Similar to how countries (even those with well-less than 5 million population) regularly have economy, well-being and material flows data published, e.g. annual World Development Report and UNEP and UNDP year books, larger urban areas need similar monitoring and public data provision. As there are about 600 urban areas over 1 million population (compared to some 200 countries regularly tracked by international organizations), a common platform may be required. Programs such as ISO 37120, GEF's Sustainable Cities Platform and others could readily be consolidated to regularly provide key development data (starting with GHG emissions). A key aspect will be, that similar to national inventories, the measurement of key indicators from cities and urban areas should be consistent (common definitions) and carried out regularly (ideally annually).

Recommendations on urban GHG inventories:

- Cities can start with simplified 'Basic' and Basic+' methodologies as outlined in the GPC. Despite additional work, and some uncertainty, all cities should endeavor to eventually provide the more comprehensive 'BASIC+7' GHG inventories that will include more than 90 percent of all global emissions associated with a community's residential and business activities.
- For urban areas over 1 million population local post-secondary institutions should be empowered to collect and report (ideally annually) GHG inventories (these can be collected without software requirements).
- The World Bank (e.g., IFC), along with other agencies, should consolidate GHG inventories on an open source website (or support another organization to do the same). Hopefully other agencies will provide similar collation (however measurement should be consistent).
- The collection and publication of urban GHG inventories should *not* be affiliated with potential funding opportunities (IFI or national). Similar to the businesses community, city-based GHG inventories are likely to proceed outside national accounting mechanisms.
- Urban GHG inventories are evolving as they balance comprehensiveness with ease of data collection. Urban practitioners, news media and politicians should see GHG inventories as approximations and not as sole arbiters of the effectiveness of local government climate action plans. Annual updates will highlight how inventories continue to evolve and enhance comprehensiveness.
- Local governments that base their urban policy levers on GHG inventories should communicate to residents and businesses the relationship between their GHG inventory and a consumption-based inventory (if they differ). Local governments should provide caveats when publishing their corporate (municipal operations) emissions as they tend to be a small and declining share of overall emissions.
- Local governments that provide data through proprietary software or ISO standards should make the raw GHG emissions data publicly available.
- As much as possible urban GHG inventories should be published in tCO_2e per person (resident).

- Local governments that declare 'climate emergencies' and net-zero carbon targets (or similar) should reflect these ambitions in CB GHG inventories (ideally in 5-year increments to 2050).
- Local governments should be encouraged to provide local input to Nationally Determined Contribution plans.
- Ideally, cities should provide GHG inventories through metro areas for urban areas over 1 million as maximum mitigation potential exists through an urban systems view.

Common Questions

Q1. How do we estimate GHG emissions from cities?

When measuring GHG emissions from cities there are two broad approaches. The territorial approach to emissions is used by countries within UN agreements, e.g., the UNFCCC and IPCC methodologies. Each country, or territory, accounts for all emissions within their border – add all 193 'parties' plus aviation and marine emissions sum to the total global. A city's territorial emissions are a sub-set of the national inventory and account for all emissions with the city boundary.

The other, life-cycle approach is more complicated but more accurate. A consistent methodology can be applied to cities and subnational jurisdictions (Global Protocol for Community Scale Emissions, GPC) and companies/organizations (GHG protocol, Corporate Standard). This approach considers all emissions, including those emitted outside the area, and ensures no 'double-counting' occurs. This approach uses Scope 1 (emissions within administrative boundaries), Scope 2 (emissions associated with imported electricity), and Scope 3 (associated with imports, aka embodied, vicarious or consumption emissions). Standards for businesses and organizations are available in ISO 14064 (developed jointly by WRI and WBCSD) and for cities and subnational jurisdictions the GPC (developed by WRI, C40 and ICLEI) supported by ISO 37120.

Ancillary approaches exist such as household inventories and 'carbon footprints'. So too proprietary approaches such as remote sensing (e.g., Vulcan Data Tool) and software (e.g., ICLEI's ClearPath). The first known municipal GHG inventory was published in 1991, with 1988 data for the City and Metropolitan Toronto[13]. By 2000 more than 500 of ICLEI's member cities established GHG baselines using software developed by Torrie-Smith Associates, under the Partners for Climate Protection (Kennedy et al, 2011).

Either a top-down or bottom-up approach can be used to estimate city and urban area GHG emissions. The top-down approach typically uses atmospheric observations (often remote sensing) and allocates these emissions to urban areas through direct measurement and modelling. Bottom-up inventories are derived by direct measurement and the use of emission factors. They typically include Scope 1 (direct), Scope 2 (imported energy) and increasing comprehensiveness of Scope 3 (supply chain – less exports).

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[13] A profile for the City of Toronto and the Municipality of Metropolitan Toronto, ICLEI – for presentation at Meeting No. 2, Hannover and Saarbrucken, Germany, 4-8 November 1991.

Q.2. How reliable are urban GHG emissions; how reliable do they need to be?

The world has a very accurate (+/- 2%) measure of CO_2 and CH_4 in the atmosphere, e.g., the Keeling Curve has daily CO_2 readings (17-03-2021 reading: 416.94 ppm[14], up from 313 ppm in May 1958). A reasonably accurate global GHG inventory (+/- 5%) is provided through UNFCCC-agreed methodology. Estimates for total GHG emissions in 2019 are 49.5 Gt[15] (36.4 Gt CO_2, 8.4 Gt CH_4, 3.2 Gt N_2O; for a global average of 6.4 tonnes per person). National inventories are commonly verified through remote sensing applications and academic peer-review. National territorial inventory accuracy is within +/- 10 percent, and likely iterating toward +/- 5 precent accuracy.

Cities and subnational jurisdictions (using Global Protocol for Community Scale Emissions, GPC) and Companies/organizations (using GHG Protocol Corporate Standard) typically measure GHG inventories within 10-20 precent accuracy. The *comprehensiveness* of the inventory is typically of more concern than its accuracy. For example, businesses will be challenged to provide overall GHG emissions, as complete as possible, for their product or service from 'cradle to grave'. Cities and subnational jurisdictions face similar challenges on comprehensiveness of GHG inventories. Toronto, where the first ICLEI GHG inventory was completed, provides an illustrative example. The City of Toronto's per capita GHG emissions are about 9.5 tonnes. Metropolitan Toronto per capita GHG emissions are about 11.6 tonnes (and within that jurisdictions household or residential emissions can vary from a per person low 1.31 tonnes (North York) to high 13.02 tonnes (Whitby)). The Province of Ontario per capita emissions are 17 tonnes, while Canada collectively is about 24.5 tonnes per person. Using and comparing inventories requires sensitivity to what is, and what is not being included.

Reasonable accuracy of GHG inventories is within 10 percent to 20 percent. Reliability increases significantly with baseline frequency. Ideally cities and urban areas should have annual inventories – perhaps through a detailed assessment every five-years, and annual updates. Trust in the inventories will increase with inclusion of jurisdictional comments, e.g., outlining the differences in per capita values by city, region, state and nationally. These differences are typically captured through Scopes 1, 2 and 3. Reasonable estimates can be made.

Q.3. If a city (local government) does not have control over the emissions, is it fair to report them against the city?

An early challenge with GHG inventories for cities was how the delineation of Scopes conflates which entity has jurisdictional control over the emissions. Cities were reluctant to publish information on emissions from areas such as electricity generation or transportation fuel, as they typically had little ability to control these emissions. Often, they could not get reliable data from power utilities or transportation agencies.

Rotterdam, with per capita GHG emissions around 30 tonnes, provides a good example of community-specific inventories. The city's emissions (among the highest in the world) are significantly impacted by the contribution of the Port and marine shipping. Some cities might be home to national airports or heavy industry and may have higher emissions relative to neighboring communities.

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[14] The Keeling Curve (ucsd.edu)

[15] Available at, and regularly updated: www.wri.org and www.climatewatchdata.org

As Scope 3, consumption, emissions are typically reported, cities and urban areas will increasingly report overall GHG emissions from activities of local residents and businesses. This is of course a shared responsibility, where the local government may be a relatively small contributor.

A related challenge in city and urban area GHG emissions is the local government's abilities and agency support. Member-based organizations like ICLEI and C40 provide support to local government staff and elected officials. Therefore, their priority is municipal representation and member support, e.g., ICLEI's ClearPath software support.

Organizations like the World Bank and other IFIs such as GCF are managed through national representatives. Therefore, their support tends to be focused through national objectives and programming.

Q.4. Why do urban areas need to be involved in global climate change mitigation?

If all production and consumption-based emissions that result from lifestyle and purchasing habits are included, urban residents and their associated affluence likely account for more than 80 percent of the world's GHG emissions (Hoornweg *et al,* 2011). GHG emissions are mostly a by-product of urbanization, and as the world continues to urbanize the pressures for more energy and materials, and associated emissions, grows.

Cities are an optimum scale for meaningful actions (e.g., urban areas that use energy-efficient transportation within a compact setting can halve GHG emissions) as they catalyze individual actions (residents and businesses) while also able to influence other levels of governments and stakeholders. Pilot initiatives in one city can be quickly replicated by others.

Urban areas will also drive accomplishment of the SDGs. Efforts to mitigate GHG emissions are readily transferrable to areas such as poverty reduction, biodiversity, international trade, equity and improved health.

As urbanization continues, larger urban areas (i.e., ~130 cities > 5 Mn) are likely to take on an even greater role. Most of these areas are made up of two or more contiguous local governments and need to accommodate individual local government priorities, with the 'commons approach' of urban areas. Large-scale mitigation initiatives, like improved transportation, decarbonizing electricity, and enhanced waste disposal practices, are best addressed at the urban area scale.

Q.5. What are the priorities for cities to mitigate urban emissions?

GHG mitigation priorities for cities are consistent with global priorities: decarbonize electricity generation, replace fossil fuels in the transportation and industrial sectors, and reduce GHG emissions associated with agriculture. By encouraging compact urban form with effective transit and active mobility, cities can reduce GHG emissions by some 40 percent over more-sprawling alternatives (also improving local air quality and reducing overall infrastructure costs). Cities also have considerable scope to reduce the GHG emissions associated with water supply, wastewater and solid waste management (about 5 percent of global emissions).

As cities and urban areas expand inventories to include Scope 3 (consumption) emissions, additional priorities are likely to emerge. Local governments, and their representatives, will need to work with residents and businesses to reflect on the total impacts of products and activities.

The shift to a 'circular economy' with less energy and material consumption will be led by cities. For example, almost all the final customers for natural climate solutions (agriculture and forestry) reside in urban areas. Most ocean plastic can be attributed to urban residents (through waste management practices or maritime activities associated with their products).

Q.6. What is likely next for urban GHG inventories?

The Paris Agreement binds Parties to collectively limit global temperature increases well below 2°C (with aspirational goal below 1.5°C). To meet this objective the scientific community and IPCC have estimated a remaining global 'carbon budget' from 2020 onward of 935 $GtCO_2$ for 66% chance of remaining within 2°C and 440 $GtCO_2$ for 1.5°C[16]. Much uncertainty exists with these budget allocations and the scope of reductions so large, that a consensus is emerging that in order to stabilize global temperatures, there is a need to achieve net-zero CO_2 emissions as quickly as possible. More than 70 countries, 100 cities and 500 businesses have set net-zero emissions targets for a specified year[17].

Associated with this rush to mitigate emissions, is a promise of climate finance and provisions within the Paris Agreement to authorize carbon trading as a means to intensify mitigation targets. These programs require GHG emissions inventories to measure progress against. Cities and urban areas will need credible GHG inventories to maximize potential funding from international finance and national governments. National governments will not be able to meet proposed NDCs without extensive participation of cities and urban areas.

As outlined in this note, city-based GHG inventories are typically more complex than national inventories as city-inventories need to reflect upstream and downstream activities (i.e., Scope 3). There are also far more cities than countries, most with less capacity to undertake and update GHG inventories. Therefore numerous part-inventories are available, and comprehensiveness often depends on ad hoc support to local governments. Programs such as ISO 37120 and municipal agencies like ICLEI and C40 will likely quickly complete these city-based inventories (e.g. Carbonn and CDM now have more than 1,000 city-inventories available on websites).

Increasingly there will likely emerge surrogate measures through satellite imagery and remote sensing, e.g., Moran et al, 2018 and Gurney et al, 2021. Artificial intelligence and 'big data' will also play a role as relatively robust GHG inventories (and other sustainability metrics) will be possible through local data mining. These developments should be welcomed as seen to be simplified approaches (and they will all still need to be subsumed within national IPCC inventories).

Cities in the mix – Calculating a city's carbon budget

As countries have carbon budgets so too cities[18]. City carbon budgets are typically more comprehensive as they include community-wide lifecycle emissions of residents and businesses. C40 published the report Deadline 2020: How cities will get the job done[19] outlining how each of the 76 member cities has a limited budget, and how this might be achieved to meet

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[16] From www.constrain-eu.org and Matthews *et al*, 2021
[17] Emissions Gap Report 2020 | UNEP - UN Environment Programme Most target years are 2050, some slightly sooner, some like China (2060) slightly later.
[18] The median population of the UNFCCC Parties (countries) is about 8 million (there are more than 80 cities with populations over 5 million).
[19] deadline-2020 (c40.org)

global objectives. The Stockholm Environment Institute (SEI) and EcoEquity developed a web-based calculator that provides a platform to allocate carbon budgets to countries based on the objective, i.e., limit to 1.5°C or 2.0°C global warming and adjustable equity settings (historical share, future responsibility)[20]. This platform is being adapted for cities while expanding the C40 methodology[21].

As these platforms and specific city budgets are published and publicly vetted, they will likely underpin local and global actions. As countries further urbanize, cities will anchor most Nationally Determined Commitments.

GHG Inventories: Getting Started

Tables 2 and 3 provide a comprehensive list of what to include in an urban GHG inventory. Definitions and methodologies are available in the WRI-C40-ICLEI GPC Greenhouse Gas Protocol and ISO 14064 and 37120. Cities, or their agents, should provide values (or reasonable estimates) for all sources covered by GPC (ticked boxes). Seven key physical provisioning systems contribute more than 90 percent of global GHGs (energy, buildings, water, waste/sewage management, infrastructure, and food), Ramaswami et al 2021. Kennedy et al, 2011, suggest a similar list for sufficiently comprehensive urban GHG inventories with inclusion of Scope 3 emissions of: energy associated with transportation of people and goods outside city boundaries (allocated equally to origin and destination); embodied emissions associated with production of food, transport fuels, water and wastewater (if outside city boundary), building materials (particularly cement and steel).

By using Scopes 1-2-3 accounting, with only a small list of Scope 3 items, the city or broader urban area, is well positioned to participate in carbon trading activities or apply for targeted climate finance against specific mitigation activities. Inventories will also have sufficient information to facilitate international comparisons and support national (territorial) inventories as defined by the UNFCCC. Residents of cities may always have different per capita inventories when defined by city, state or nationally (as items accounted for may vary), however the clear and consistent methodology with Scopes 1-2-3 enable relatively simple communications with the community.

Setting The Framework: Task Team Leaders and Possible Terms Of Reference

A task team leader (TTL) on an urban support project may need to obtain outside support to develop a GHG inventory for the supported city. Three broad options are possible: local and/or international consultants; city representatives and/or their designated agencies, e.g., ICLEI, C40; or local universities.

Terms of reference for all approaches should include: reference to national (territorial) inventories most recently published as part of the country's NDC; consistency with ISO 37120 (which is based on GPC and follows ISO 14064 methodology); approaches on how the inventory will be updated (by whom); comparators; peer review (local universities are often well-versed in these areas, civil and environmental engineering departments typically maintain GHG

[20] Climate Equity Reference Calculator, accessed 28-3-2021
[21] For example, Sustainability Solutions Group | The Art and Science of City Carbon Budgets (ssg.coop)

inventories of local communities). Where the GHG inventory will be published should be agreed-to prior to work commencing (e.g., self-report to agencies such as ICLEI and CDP).

A relatively straightforward approach in preparing TORs for urban inventories may be to include a copy of Table 3, 'Sources and Scopes of GPC' and ask retained consultant (or university) to complete the table to he best of their ability with either top down (e.g. downscaled national values) or 'bottom up' (estimating through number of buildings, vehicles, energy use) approaches, or a combination. Values should be presented by total and per capita.

Tables

Table 1

City Approaches to GHG Inventories	
Territorial	Down-scaled national approach uses Scope 1 only. Rarely used.
BASIC	Stationary Energy (Scope 1&2); Transportation (Scopes 1&2); Waste within the city (Scopes 1&3).
BASIC+	BASIC plus Stationary Energy (Scope 3); Transportation (Scope 3); Industrial Processes and Product Use (IPPU - Scope 1); Agriculture, Forestry and Other Land Use (AFOLU - Scope 1).
BASIC+7	BASIC+ including energy, mobility & connectivity, waste & sanitation, water, food, buildings (e.g. cement, steel, wood), public/green spaces.
Consumption or Other Scope 3	BASIC+ plus Fugitive emissions (Scope 3): Off-road transportation (Scope 3); IPPU (Scope 3); AFOLU (Scope 3); 'Other' (Scope3, typically fuel, building materials, and food).

Table 2

What Cities (and urban areas) Should Include in GHG Inventories

Scope 1		
Stationary Energy Buildings Manufacturing and construction Energy production Fugitive emissions	Transportation Roads and Rail Marine Aviation Off-road	Waste Municipal Solid Waste disposal Wastewater
Industrial Processes	Industrial Product use	Agriculture, Forestry, and Land Use (AFOLU) Livestock, Land, Other agriculture
Scope 2		
Stationary Energy Buildings Manufacturing and construction Energy production Fugitive emissions	Transportation Roads and Rail Marine Aviation Off-road	
Scope 3		
Stationary energy Transport fuel production Food production Cement, steel, wood production Water production Share of transportation to/from urban area Telecommunications and data management		

Table 3

Approaches to the GHG Inventories

Several approaches and methodologies are available to cities and those supporting them to establish GHG inventories. Key questions that drive the approach include:

What is the geographic scope (border) of the inventory?	A single city or two or more contiguous jurisdictions making up a metro or urban area? A single city tends to be simpler, but the urban area is better to define and monitor larger scale interventions.
Who will 'own' and regularly update the inventory?	Most often this is the municipal government, e.g., through ISO 37120, ICLEI-CDM, C40 or through retained consultants. Local universities can also compile inventories (usually Civil Engineering, Urban and Environmental Studies).

Is the local GHG inventory a synchronized part of the national inventory?	If so, the national government should supply emissions factors, e.g., carbon intensity of electricity, and provide methodology (and likely software and data platform).
Will the local GHG inventory support efforts to obtain climate finance and underpin locally declared targets?	In this case inventories will need third-party verification (consistent with GPC), synchronization with the national inventory, and in larger urban areas should include an inventory for the broader area (to maximize potential mitigation opportunities). The inventory should also be projected to at least 2050, so that mitigation activities against 'business as usual' can be identified and monitored.
Resources for GHG Inventories	
GHG Protocol Tool (GPC)	WRI key contact; baseline inventories; Excel tool available free of charge; online tutorials; supported with Scopes 1, 2 and 3; when published ISO 37120 data is consistent with the GPC approach (by local government only). Municipal governments most likely to use this methodology when completing inventory with own staff (needs to be broader than municipal corporate activity emissions alone). https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities
IFC – EDGE and APEX	IFC and WB initiated; sector-based (energy, transports, water & waste); EDGE is buildings focused; cost ranges from $85K full version APEX, and 6 months – online platform in EDGE free; sector-based approach; web-based tool; supports strategy development; IFC-WB support – some online processes available; subsumes CURB; does not have Scope 3, consumption emissions. https://www.apexcities.org/ and https://edgebuildings.com/
C40 – CIRIS	About 75 cities (municipal boundary, e.g., City of Chicago); Excel tool is free of charge – targeted to local government staff; offline excel-based tool; sector-based & consumption-based approach. https://resourcecentre.c40.org/resources/reporting-ghg-emissions-inventories
ICLEI – ClearPath and Carbonn	Shared data base at Carbon.org and Clean Development Mechanism (more than 1,000 cities); ClearPath is US-only with annual fee; based on GPC methodology; action plans can be derived (and monitored). https://icleiusa.org/clearpath/
Retained Consultancies	Many firms available – can be retained by local or national government, city-agency, IFI; firms usually follow GPC methodology with varying degrees of

	comprehensiveness for Scope 3, consumption. Most cities have a starting point – average costs up to $100,000 per initial inventory. Results should be publicly available and discussed against typical comparators.
Government and International Financial and Development Institutions	National governments support some local governments; organizations such as UNEP and UNDP have provided initial inventories; World Bank and other IFIs support local government inventories as part of project development; growing importance for prioritization and tracking of climate finance.
Universities and Research Community	More than 5,000 cities available in peer-reviewed publications; an IPCC-like city-based peer group emerging; progress on city-led data collection meshed with remote sensing and AI approaches; underpin mitigation research.

Table 4

Sources and scopes covered by the GPC

Sectors and sub-sectors	Scope 1	Scope 2	Scope 3
STATIONARY ENERGY			
Residential buildings	✓	✓	✓
Commercial and institutional buildings and facilities	✓	✓	✓
Manufacturing industries and construction	✓	✓	✓
Energy industries	✓	✓	✓
Energy generation supplied to the grid	✓		
Agriculture, forestry, and fishing activities	✓	✓	✓
Non-specified sources	✓	✓	✓
Fugitive emissions from mining, processing, storage, and transportation of coal	✓		
Fugitive emissions from oil and natural gas systems	✓		
TRANSPORTATION			
On-road	✓	✓	✓
Railways	✓	✓	✓
Waterborne navigation	✓	✓	✓
Aviation	✓	✓	✓
Off-road	✓	✓	
WASTE			
Disposal of solid waste generated in the city	✓		✓
Disposal of solid waste generated outside the city	✓		
Biological treatment of waste generated in the city	✓		✓
Biological treatment of waste generated outside the city	✓		
Incineration and open burning of waste generated in the city	✓		✓
Incineration and open burning of waste generated outside the city	✓		
Wastewater generated in the city	✓		✓
Wastewater generated outside the city	✓		
INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU)			
Industrial processes	✓		
Product use	✓		
AGRICULTURE, FORESTRY AND OTHER LAND USE (AFOLU)			
Livestock	✓		
Land	✓		
Aggregate sources and non-CO_2 emission sources on land	✓		
OTHER SCOPE 3			
Other Scope 3			

✓ Sources covered by the GPC

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources required for territorial total but not for BASIC/BASIC+ reporting (*italics*)

Sources included in Other Scope 3

Non-applicable emissions

GHG inventories for urban areas (> 1 million) should include all Scopes 1, 2 and 3 (Green + Blue + Orange – Purple). For 'Other Scope 3', estimates can be used (e.g. downscaling national values)

Table 5

Policy goals and approaches for urban GHG accounting and local decarbonization

Policy goal, approach	Carbon Accounting Methodology	Unit of Analysis	Examples of Accounting Tools/Protocols	Pros/Cons
Monitoring (IPCC requirements) Measure location-specific sources of GHG (Sub-set of national emissions). Can include other air pollutants.	***Territorial Approach***: Track direct GHG emission sources; in-boundary only. All territorial emissions from cities and regions equal the national inventory.	Land bounded by administrative (territorial) boundary. [Scope 1 GHGs only]	Vulcan Data Tool: for territorial fossil fuel use Scope 1 GHGs (US only). Territorial values downscaled from national inventories or derived locally. Very few cities do only Scope 1 accounting.	Pro: easiest approach; fully consistent with national inventories and IPCC guidelines; does not require metro area aggregation; can be supported with remote sensing. Con: Limited data; minimal policy guidance; very few cities using this approach.
Inform community-wide integrated urban infrastructure transition planning across "Key sectors*."	***Communitywide Infrastructure supply chain:*** *In-boundary plus Transboundary supply chain GHGs* of key provisioning sectors* to the whole community (consumers and all producers): supply of energy, mobility, buildings, water, waste/sewage management, key infrastructure and food systems. Includes changes in biogenic C from land/green infrastructure.	Community-wide provisioning key sectors. Scope 1 + Scope 2 (GHG imported electricity); + Scope 3 (GHGs in supply chains of other provisioning sectors such as food and building materials)	Scope 1 & 2 Tools: e.g., ICLEI USA Protocol. GPC Basic (Scopes 1+2+3): Buildings, energy, mobility & Waste. GPC Basic+ (Scopes 1+2+3): All seven provisioning systems. Various open-source and proprietary accounting software available.	Pro: GPC BASIC and BASIC+ are emerging as global standard with clear delineation on what is, and what is not, included. Con: Even BASIC+ fails to capture as much as 40% of overall emissions in some cities. Easily conflated with municipal 'corporate' emissions (local government activities) which are typically less than 5% of overall emissions.

				Local governments often reluctant to publish emissions for which they have minimal control over. Process requires an agent such as IFC, ICLEI or local university (or municipality) to complete, and regularly update inventories.
Mitigate household carbon footprint analyzing all consumer expenditures beyond those for key provisioning systems	***Consumption-based household 'carbon footprint':*** Tracks in- plus transboundary GHGs linking production-to-final consumption only by homes; (excludes exporting businesses in a city)	Household expenses and household fuel combustion (within a boundary). Scopes not easily mapped to city boundaries.	Common Tools available: e.g., Cool climate calculator. Focusses on household consumption.	Pro: can capture household variance within city; specific policy recommendations to householders; Con: suggests a spatial equivalence; challenging to interpret per capita variation by scale, e.g., household, neighborhood, city, state, country; does not include out-of-household emissions, e.g. generation at work, school, etc.
Global Carbon Governance with Local- to-Global Trade Linkages	***Total Supply Chain Accounting*** (Transboundary; links production-to-consumption and exports; all sectors)	All imports and exports to homes, businesses and industry in a boundary Same as Method 2, with all transboundary GHGs linked with all supply chains included as Scope 3	BASIC+ and Scope 3 for at least building materials, food, and transportation.	Pro: most comprehensive and best able to influence national and international action. Net-zero carbon trade in food and other provisioning systems**

				Con: requires additional data. To reflect potential mitigation efforts by low-income cities a 'mitigated' vs 'business as usual' projection required.
'Net-zero' or local carbon budget. Applied across temporal scale, e.g., by 2050	Community approach to international targets and commitments Similar to corporate (businesses) GHG accounting, requires LCA for total emissions – generated within and beyond boundaries.	As above: all imports and exports to homes, businesses and industry within the urban boundary All transboundary GHGs linked with all supply chains included as Scope 3 – values projected to 2050 (or alternative date).	BASIC+ and Scope 3; projected to 2050 (or 2060)	Pro: cities (urban areas) are optimum area of analysis and action for GHG mitigation. Facilitates climate finance and supports national NDCs Con: requires data and initiatives beyond city-managed activities. Estimates need to be projected, monitored and regularly adjusted.

Adapted from Ramaswami et al. (Nature Sustainability, 2021)

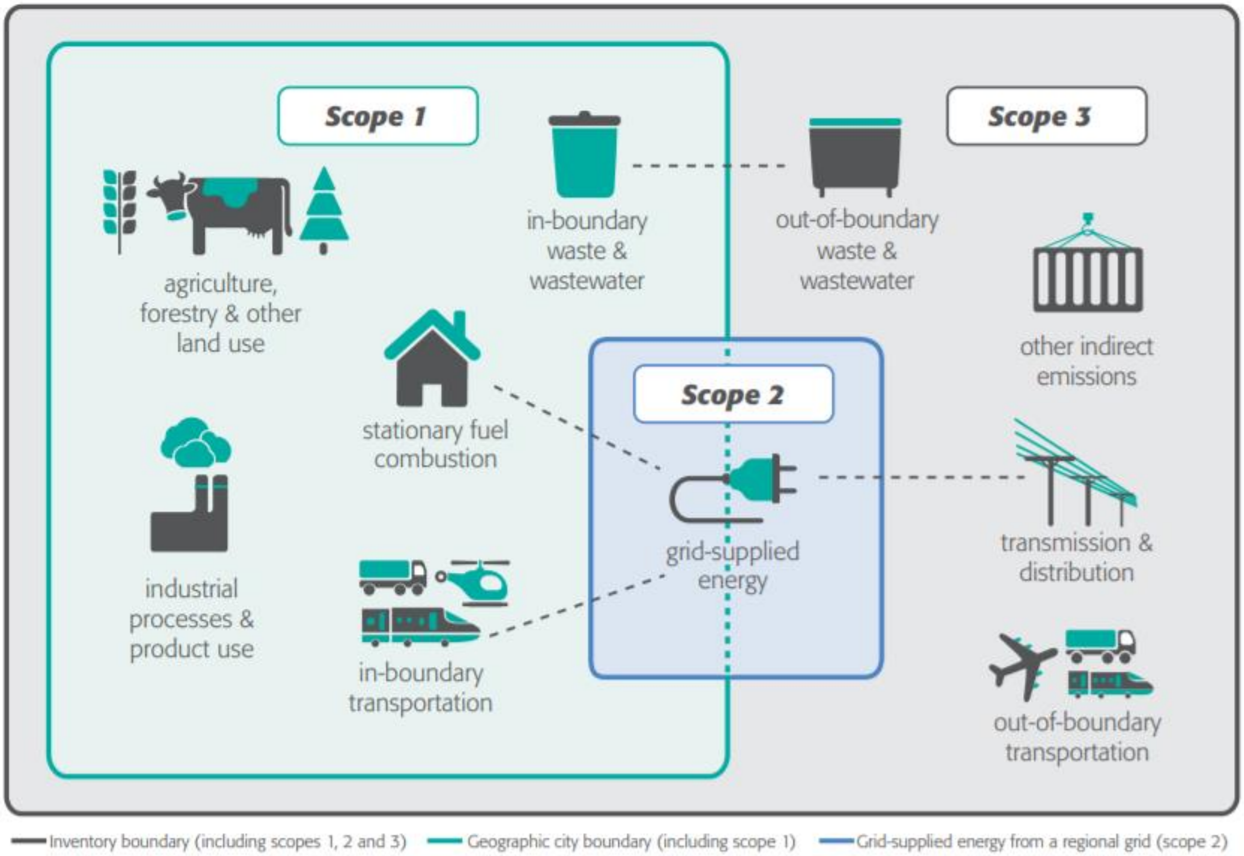
*: Eight infrastructure provisioning sectors account for >90% of global GHGs; excluding only de-forestation and industrial processes for chemicals & petrochemicals production

**: Decarbonising the key physical provisioning systems will result in decarbonised trade.

#: Where input-output tables are used, final consumption by government and business capital expenses (e.g., construction expenditures) can also be computed

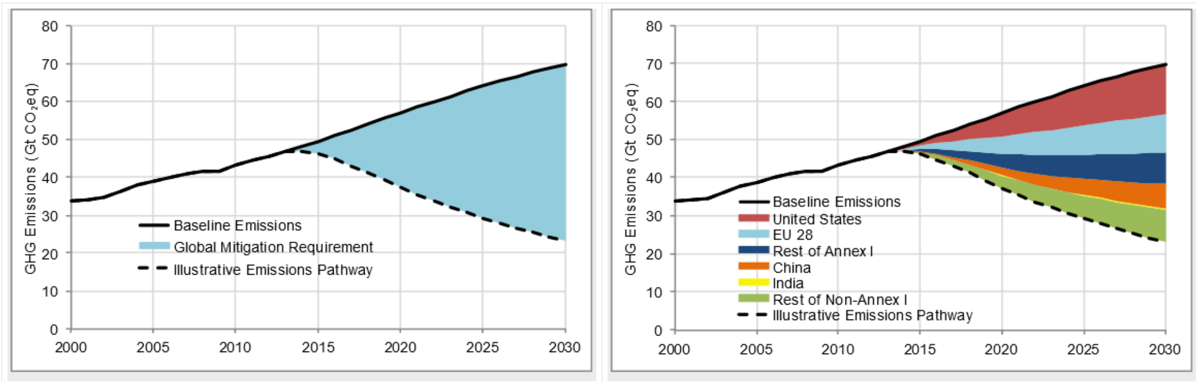
Figures

Figure 1: Sources and boundaries of city GHG emissions; From GPC for GHG Emissions Inventories[22]



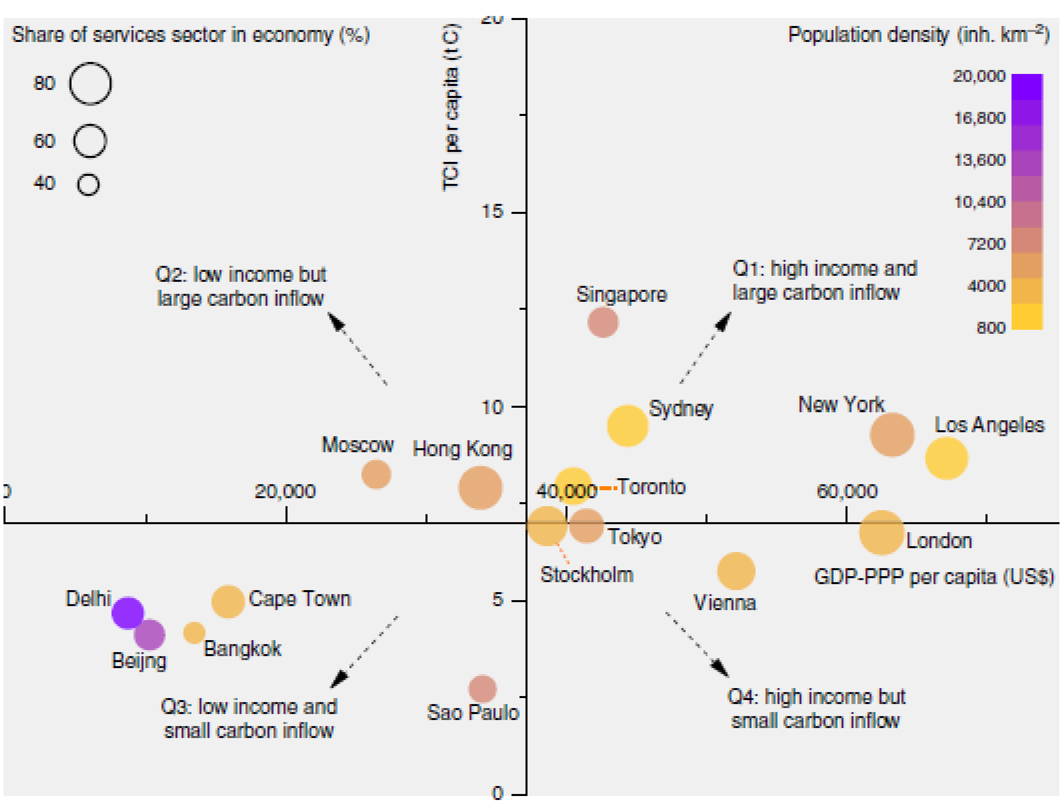
[22] https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

Figure 2: Indicative emissions reduction requirements to 2030 (for 2°C mitigation pathway)[23]



Globally required mitigation (blue area) divided among countries in proportion to their share of global responsibility and capacity. (The example here, and it is only an example, features the "Strong 2°C" global mitigation pathway and the "medium equity" settings. See the National Fair Shares report for an overview set of illustrative cases.)

Figure 3: Per capita GHG emissions vs GDP (Chen et al, 2020)



23 https://calculator.climateequityreference.org/

Figure 4: Illustration of Scopes 1, 2 and 3 (Consumption) Emissions, (C40, 2018)

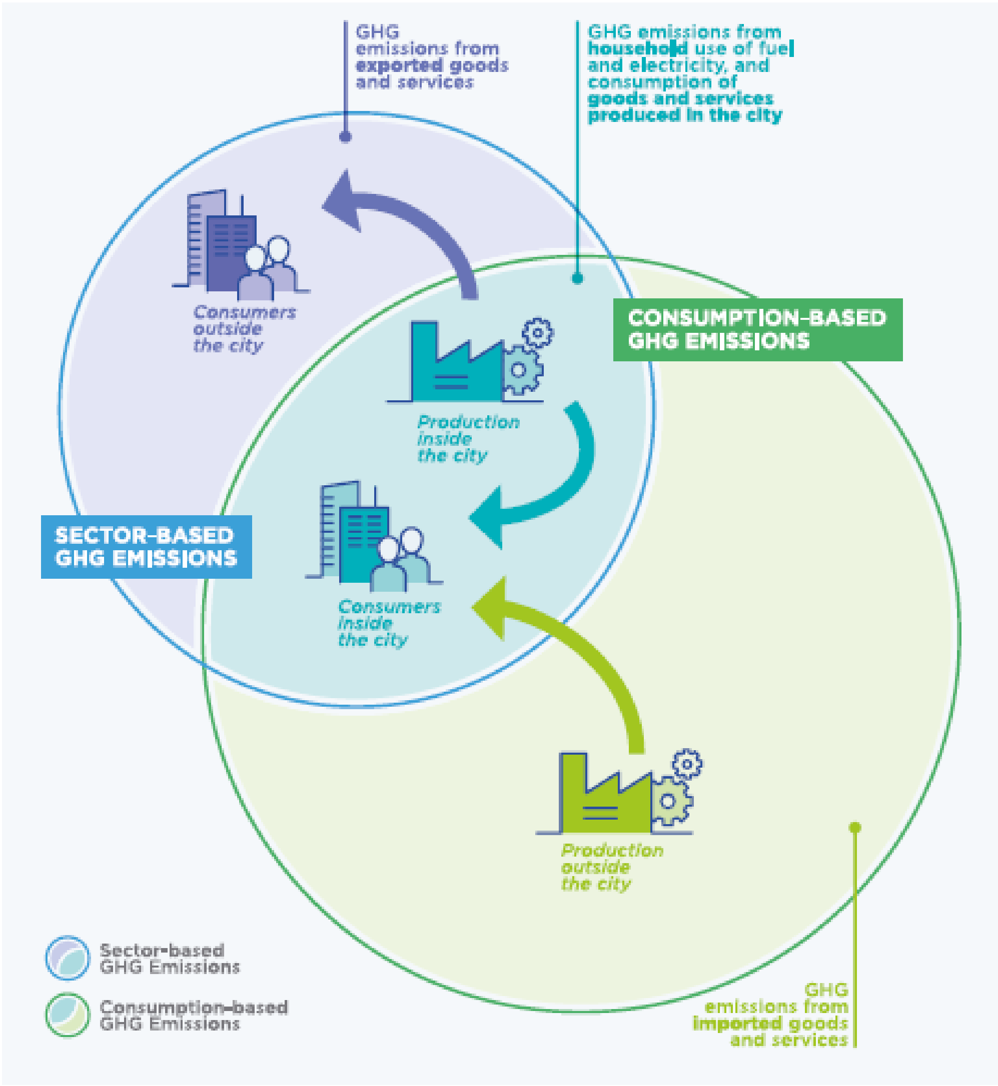


Figure 5: Range of consumption based emissions for C40 member cities, by Region, (C40, 2018)

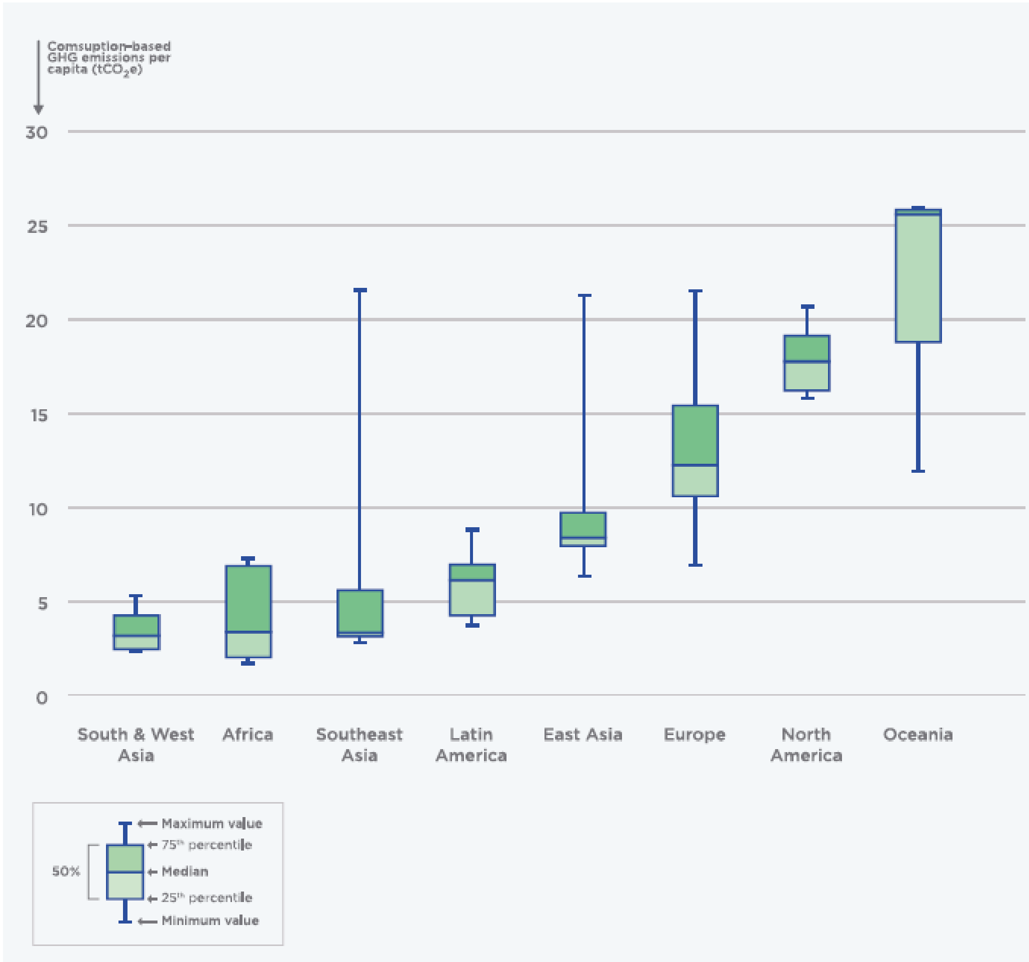
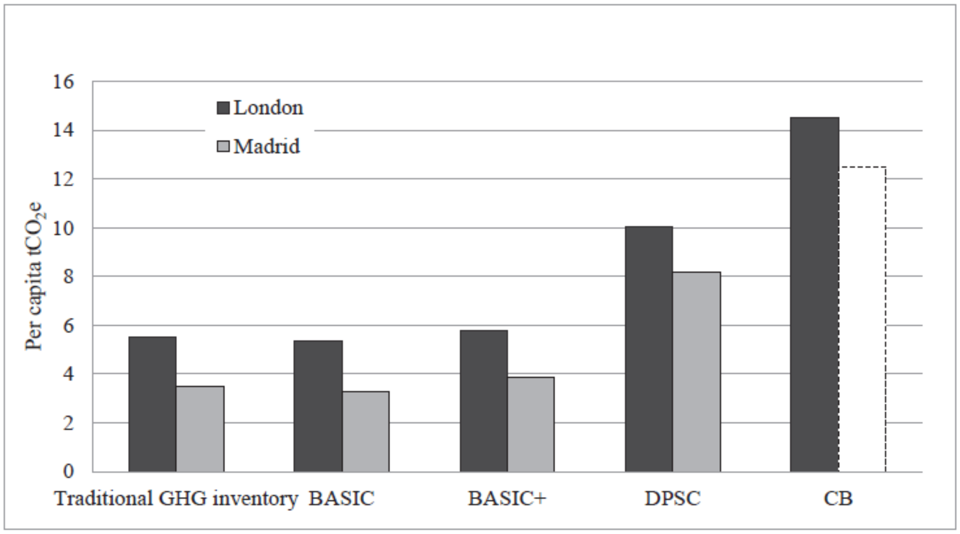


Figure 6: Emissions by methodology for Madrid and London, (Andrade et al, 2018)



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