

Tackling out-of-boundary emissions in climate change mitigation action at city level

State-of-the-art on greenhouse gas accounting and mitigation action, including scope 1, 2 and 3 emissions – Preliminary report

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2025



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JRC142411

Ispra: European Commission, 2025

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How to cite this report: Bastos, J., Banja, M., Vitel, A.E., Steen-Olsen, K., Baltrusiewicz, M. et al., *Tackling out-of-boundary emissions in climate change mitigation action at city level - State-of-the-art on greenhouse gas accounting and mitigation action, including scope 1, 2 and 3 emissions – Preliminary Report*, European Commission, Ispra, 2025, JRC142411.

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Abstract

The EU Green Deal has set ambitious climate change mitigation targets, and cities play a key role in achieving them. Initiatives such as the Covenant of Mayors for Climate & Energy Europe and the EU Mission for 100 climate-neutral and smart cities have brought together EU cities committed to reduce their greenhouse gas (GHG) emissions. Within these initiatives, cities develop GHG inventories to inform action planning and to monitor progress.

City-level GHG accounting frameworks have mostly focused on emissions occurring within territorial boundaries and/or associated with local energy use. However, researchers and practitioners have increasingly acknowledged the importance of GHG emissions occurring beyond city borders. A shift to consumption-based accounting has been observed in recent years, which may be associated with increased complexity, higher data requirements, and subjective methodological choices. Limited guidance and data are currently available to support EU cities, who need consistent GHG accounting frameworks and data, aligned with their needs, priorities and resources.

This preliminary report provides a brief state-of-art review on current practices in GHG accounting and action in the EU, and on available methods and data to support more comprehensive accounting. It provides a knowledge base and recommendations towards the development of a flexible accounting framework, combining different methods and approaches, to develop relevant, comprehensive and consistent GHG inventories at city level.

Acknowledgements

This work has been developed by the European Commission's Joint Research Centre as a joint deliverable in support to the EU Mission for 100 climate-neutral and smart cities and to the Covenant of Mayors for Climate and Energy Europe.

We thank DG RTD, DG ENER and DG CLIMA for their strategic vision and guidance, and JRC colleagues and Cities Mission partners who provided comments and feedback, contributing to improving the quality of the report.

Version	Preliminary Report V1.0
Date	26.06.2025
Dissemination level	Own dissemination (Cities Mission and CoM Europe partners, city representatives, researchers)
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Executive summary

This technical report provides a state-of-art review on greenhouse gas (GHG) accounting and action in EU cities. It aims to support the future development of a more comprehensive accounting framework that can capture the overall GHG emissions associated with urban areas, including emissions that occur beyond territorial boundaries. It builds on current guidance and frameworks to account for GHG emissions at city level in the EU, and on state-of-the-art methods and tools to discuss potential opportunities and steps forward.

Policy context

The EU Green Deal and the EU Climate Law have set ambitious climate change mitigation targets, and cities play a key role in achieving them. Initiatives such as the Covenant of Mayors for Climate & Energy Europe (CoM EU) and the EU Mission for 100 climate-neutral and smart cities (Cities Mission) have brought together EU cities committed to reduce their GHG emissions. Within these initiatives, cities develop GHG inventories to inform decision-making and to monitor progress.

City-level GHG accounting frameworks in the EU have typically focused on territorial-based emissions (scope 1 and 2), excluding a significant share of upstream and downstream emissions (scope 3) associated with urban activities. The globalisation of supply chains has resulted in an increased significance of GHG emissions occurring beyond city boundaries. Increasingly ambitious mitigation targets call for advances in GHG accounting frameworks and guidance. More comprehensive inventories are needed to adequately account for, tackle and monitor GHG emissions associated with cities.

Key conclusions

Emerging approaches to GHG accounting have shifted the focus from territorial- to activity-based emission accounting, and in particular to consumption-based accounting. A wide range of methods, tools and data are available that provide opportunities to expand the scope and boundaries of GHG inventories, to develop more comprehensive and relevant GHG data to cities. Since they offer different strengths and limitations, they can be applied in different contexts, and used for screening or in a tier-based system, adapting to the resources, needs and priorities of cities.

Main findings

In the last decades, the path towards more comprehensive GHG inventories at city-level has mostly built on a shift from territorial- to consumption-based approaches. Due to the complexity of cities and resource requirements (including data, time and expertise) to develop process-based inventories, research and practice has often adopted input-output (IO) modelling, often focusing on household consumption (through expenditure data) in consumption-based GHG accounting.

While IO-based accounting may be an adequate and relatively easy framework to estimate GHG emissions associated with urban consumption, it is strongly limited by aggregation and homogeneity assumptions that result in significant uncertainty at higher levels of disaggregation (e.g., by sector), which are critical to inform GHG mitigation action at city level. Process-based modelling should be used to detail and inform targeted actions for particularly significant consumption areas (e.g., buildings, transportation and food). Significant developments in life-cycle (LC) approaches and data in recent years have improved their applicability to cities.

Related and future JRC work

This report builds on JRC work supporting cities on GHG accounting under the CoM and the Cities Mission. It provides groundwork to further developments on methodological guidance and data provided by the JRC for GHG accounting at city level, in particular on the development of more comprehensive GHG inventories.

Quick guide

The preliminary report is structured in 7 sections: sections 1 and 2 provide an introduction and context on GHG accounting and mitigation under the CoM EU and the Cities Mission; section 3 provides a summarized overview of reference city-level GHG accounting frameworks typically the European context, and section 4 the motivation to advance current common practice, toward more comprehensive GHG inventories; section 5 provides insight on available methods, tools and data sources that can be used in this context; section 6 illustrates some examples of good practices in the Cities Mission, accounting for or tackling GHG emissions beyond common practice; and section 7 briefly concludes the report providing recommendations and next steps.

1 Introduction

This report aims at providing insight on state-of-the-art accounting and tackling of greenhouse gas (GHG) emissions associated with cities,¹ to support the future development of more comprehensive and holistic GHG inventories and action at city level. The report provides a summarized overview of:

- current guidance, frameworks on GHG accounting at city level, in the European context;
- potential significance of GHG emissions “beyond common practice”;
- methods, tools and data that can be used for more comprehensive GHG accounting; and
- good practices and examples where cities have accounted for or tackled emissions beyond common practice and scope in climate mitigation action.

Concerning GHG accounting, we first provide a summarized overview of existing guidance and frameworks, from reference organizations and relevant to the EU context, to account for GHG emissions at city level. Drawing on this overview, we establish a reference for ‘common practice’. Second, we discuss the motivation to develop more comprehensive GHG inventories, including the potential significance of GHG emissions that have been typically excluded from GHG inventories and climate action plans, and the increased opportunities they provide for cities to contribute to climate change mitigation. Then, we review state-of-the-art methods and tools – as well as potential data sources – that can be used to account for GHG emissions at city level, beyond common practice. The review includes a brief discussion of potential features, advantages and limitations of available methods, quality data, typical methodological choices and assumptions.

To complement the analysis, we provide a selection of good practices and examples focused on climate action plans developed by cities in the context of the EU Mission on 100 Climate-Neutral and Smart Cities. While these examples are non-exhaustive, they illustrate actual steps already taken by cities, and demonstrate their ambition to go beyond common practice.

This report draws on scientific research publications and city climate action plans, and it is important to advance common practice by prioritizing the next steps to support more relevant, holistic and consistent GHG accounting, which can ultimately support more effective and significant climate change mitigation action. It serves as a basis for the future development of a concrete methodological framework and guidance for tackling and accounting for GHG emissions associated with EU cities in comprehensive manner.

The state-of-the-art provided in this report is not meant to be an exhaustive, comprehensive or systematic review, instead, it is a scoping review focused on potentially relevant frameworks, methods and actions in the context of EU climate change mitigation initiatives.

¹ The terms “city” and “urban” are used throughout this document with a generic meaning, including subnational geographical areas that can include municipalities, metropolitan areas, towns, communities, among others.

2 Tackling greenhouse gas emissions associated with EU cities

To achieve the strategic long-term vision of the European Commission for a prosperous, modern, competitive and climate neutral economy, greenhouse gas (GHG) emissions must be drastically reduced. The EU Green Deal sets ambitious objectives (COM/2019/640): a GHG reduction target of 50%-55% by 2030, and achieving climate neutrality by 2050, in line with the EU's commitment to global climate action under the Paris Agreement.

Cities play a key role in achieving EU Green Deal objectives and climate change mitigation targets in particular. They concentrate population and economic activities, which account for over 65% of overall energy demand and GHG emissions globally (Balouktsi 2020). In the EU, cities take up only 4% of land area, but they are home to 70-75% of EU's population (Marelli et al. 2025; EEA 2019; World Bank Group 2018). To date, cities have mostly focused climate change mitigation action on (i) local GHG emissions (i.e., occurring within their geographical boundaries), and (ii) GHG emissions associated with generation and supply of energy used locally (i.e., emissions associated with energy used within their geographical boundaries, which might occur elsewhere) (Balouktsi 2020). However, GHG emissions and other environmental impacts of urban activities go well beyond this scope and boundaries.

Extraction and processing of natural resources has increased dramatically over the last decades. UNEP's 2024 Global Resource Outlook estimated that, since 1970, global resource use grew from an average of 23 to 39 kg of materials used per person per day. This is associated with significant environmental implications: the extraction and processing of natural resources is estimated to account for over 60% of our climate change impacts (UNEP 2024).

To effectively tackle climate change and achieve climate neutrality targets, a local 'operational' or 'energy use' perspective is no longer enough. Ambition and action need to step up, and cities need to advance current practices to tackle significant GHG emissions associated with their activities that occur beyond their boundaries, in a comprehensive and integrated manner, with a life-cycle perspective.

Comprehensive GHG mitigation action needs to be supported by accurate and relevant data. The relevance, quality and consistency of city-level GHG inventories is crucial to support effective climate change mitigation action at local level. Consistent, reliable and transparent GHG inventories are important to increase trust and uptake, and they also ease comparability and benchmarking, which facilitates knowledge sharing and collaboration.

In recent years, scientific research has advanced methods and quality data availability to quantify and monitor GHG emissions, including local activity-based accounting methods, modelling and observation tools (e.g., measurement of atmospheric GHG concentrations). Bringing these advances to practice can help increasing the scope, accuracy and relevance of GHG inventories at city level.

Across the EU, cities have been actively engaged in climate change mitigation, and important EU initiatives such as the EU Mission on Climate Neutral and Smart Cities (Cities Mission) and the Covenant of Mayors for Climate & Energy Europe (CoM EU) have been established. The JRC provides scientific and technical support to the Cities Mission and to the CoM EU, developing guidance, tools and data, to accelerate the transition to climate neutrality throughout EU cities. In this context, this document provides a scoping review of current and state-of-the-art practices in cities to tackle and account for GHG emissions, beyond typical scope and boundaries.

At city level, challenges related to data availability, scope and boundary selection, and to allocation of emissions, have prevented more comprehensive GHG accounting and mitigation action. Among these challenges, GHG inventories have often excluded potentially relevant and significant GHG emissions associated with urban activities. Emissions that have been typically excluded in city GHG inventories include, for example:

- transboundary transportation emissions, beyond city boundaries;
- upstream supply chain emissions of food and other products; and
- management of waste beyond municipal solid waste (MSW) and wastewater (e.g., C&D waste).

The next subsections provide a summarized context of GHG mitigation objectives and scope in the Cities Mission and in the CoM EU.

2.1 Cities Mission

EU Missions were introduced in the Horizon Europe research and innovation programme for 2021-2027. They are a coordinated effort to pool the necessary resources in terms of policies and regulations, and to mobilise a diversity of actors, such as Member States, local and regional authorities, research institutions, and other public and private stakeholders, to support ambitious action with lasting impact, across a range of Commission priorities, such as those defined in the EU Green Deal.

The EU Mission for 100 Climate-neutral and Smart Cities (Cities Mission)² has two central objectives:

- to deliver 100 climate neutral European cities in the EU by 2030;
- to ensure that these cities act as experimentation and innovation hubs to put all European cities in a position to become climate neutral by 2050.

The Cities Mission brings together a diverse group of cities – 100 cities in the EU and 12 in countries associated to the Horizon Europe programme – in a concerted, innovative and ambitious effort to reach climate neutrality by 2030, thereby preparing the way for all EU cities to follow by 2050. The Cities Mission has clear, time bound and measurable objectives, but it adopts a flexible approach, based on individual needs of cities (a “demand-led approach”). It aims to enable these cities to fast-track their way towards climate neutrality, by deploying innovative solutions, and making the best use of existing programmes, as well as to address their funding and financing gaps.

GHG emissions that occur outside the geographical boundaries of cities (upstream and downstream) are – except for emissions associated with waste and wastewater treatment – not covered by the Cities Mission scope (under its climate neutrality definition.³ Nevertheless, several highly ambitious cities have showed a clear intention to start systematically monitoring and tackling consumption-based, upstream and/or downstream GHG emissions. In fact, several cities have already addressed in their Climate City Contract (CCC) – at least partially – scope 3 emissions, beyond the waste sector.

The JRC plans to engage advanced and interested Mission cities (in the form of a “task force”), facilitated through the Cities Mission platform, to collect additional good practices and to tailor the upcoming guidance on GHG accounting to cities’ needs, co-developing a consistent and comprehensive GHG accounting framework.

2.2 Covenant of Mayors for Climate and Energy Europe (CoM EU)

The Covenant of Mayors for Climate and Energy Europe (CoM EU) initiative brings together about 12 000 local authorities fostering the design and implementation of effective climate change policies and strategies (Melica et al. 2024). In the CoM, signatories voluntarily commit to developing and implementing a Sustainable Energy and Climate Action Plan (SECAP), which includes the compilation of GHG emission inventories (Davide et al. 2025).

In the CoM, climate change mitigation focuses mainly on reducing final energy use and its associated GHG emissions (Bastos et al., 2025). Thus, GHG accounting focuses mostly on energy-related activities under direct control or influence of cities (local authorities). In terms of scope and coverage, SECAPs and their GHG emission inventories shall cover at least the four CoM key activity sectors, which essentially correspond to Buildings (Stationary energy) and Transportation sectors. It is nonetheless recommended to include waste and wastewater treatment, and any other relevant activity sectors.

² [Climate-neutral and smart cities - European Commission](#)

³ See Cities Mission Info Kit for further details (<http://ec.europa.eu/mission-cities>).

3 GHG accounting at city level: current practice

GHG accounting is key to understand, monitor and effectively tackle GHG emissions associated with cities. This report draws on published peer-reviewed journal articles, city climate action plans and GHG accounting guidance documents and reports, to provide a preliminary overview of current GHG emission accounting approaches and practices at city level. To provide insight on current and future research and practice, it follows a scoping review approach that explores an array of literature sources to provide a broad overview of a complex and vast topic (Peterson et al. 2017), rather than a traditional systematic or comprehensive review. Its main goal is to contribute to research, practice and policy, as a starting point for further investigation and work, toward more comprehensive GHG accounting.

GHG inventories provide estimates of GHG emissions and removals from a range of sources and sinks, for a given geographical area and period of time. Under the United Nations Framework Convention on Climate Change (UNFCCC), countries develop annual national GHG inventories on a regular basis, which are paramount to inform policymaking, to monitor progress and to communicate – in transparent manner – the status, targets and trends of GHG emissions. Since cities play a key role in climate change mitigation, accurate and consistent activity and GHG data is crucial. GHG inventories at city level are needed to inform decision-making, to ensure transparency and credibility and to promote the uptake and success of effective GHG mitigation action at local level (Balouktsi 2020; WMO 2022). A selection of guiding principles for city-level GHG inventories is presented in Box 1.

Box 1. Guiding principles for city-level GHG inventories

To effectively inform policymaking, city-level GHG inventories shall be ‘decision-useful’ – they should be relevant, usable and insightful. A balance needs to be found between (i) scientific rigor, completeness and accuracy, and (ii) practical and timely applicability. Guiding principles behind city-level GHG inventories and data include being (Bastos et al. 2025; EC 2021a; IPCC 2006, 2019; TCFD 2021; WMO 2022):

- **Relevant and representative:** Activity and GHG emission data should be relevant to and representative of the specific context of the city, and able to inform and be applied by a range of practitioners and stakeholders, both scientific and non-scientific.
- **Consistent, objective and comparable:** city GHG inventories should be consistent over time, comparable among cities, and complementary to national accounting systems, tools and methodologies. Consistency in methodological approaches, choices and assumptions across inventories is important to ensure comparability.
- **Flexible and action-oriented:** GHG emission accounting to inform city-level action calls for simplicity of use and application, keeping flexibility to suit various regional and local context, and to accommodate the needs and resources of different cities, reflecting their specific characteristics and challenges, and taking into account their policy-making priorities, resources, capacity and regulatory context.
- **Complete and accurate:** city-level GHG inventories may not be exhaustive, but they should cover all relevant sectors and associated GHG emissions to provide meaningful data and insight. Complete and relevant GHG inventories are key for supporting the design, implementation and monitoring of effective climate change mitigation action and for monitoring progress. GHG inventories should be as accurate as possible, and represent a reasonable estimate of the urban activities and associated GHG emissions. This requires reliable local activity data and robust well-established methodologies.
- **Clear, transparent and verifiable:** Data sources and methodology for calculating GHG emissions should be transparent, detailed and well documented. It is also important to ensure availability of reliable data across time. Transparent and detailed data is important for inventories’ reliability, credibility, comparability, interoperability and validation.

Different reference organizations, initiatives and experts have proposed frameworks and guidance on GHG emission accounting at city level, typically in line with the IPCC Guidelines for national GHG inventories (IPCC 2006, 2019). However, frameworks and guidance are often in dispersed and fragmented information, they build on different assumptions and methodological choices, chosen according to specific objectives, scope and context, which can make their application, interpretation and comparability difficult (Balouktsi 2020). GHG accounting frameworks, including those commonly used in the CoM EU and Cities Mission, have typically followed a territorial-based allocation and categorisation of emissions.

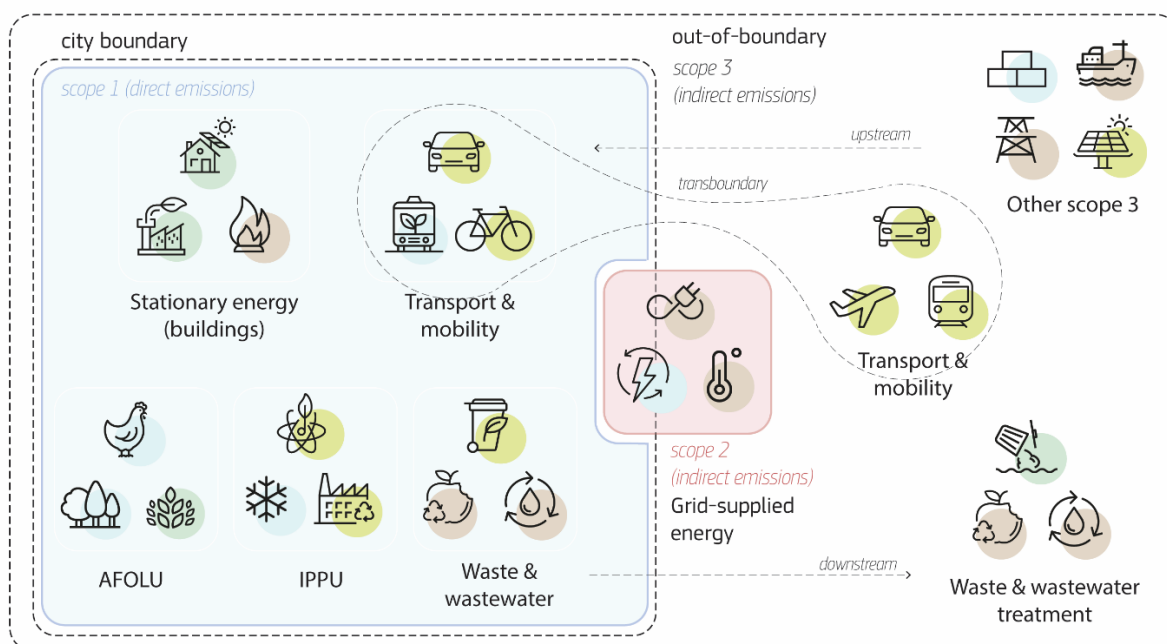
This section first provides an overview of key concepts and definitions commonly used in GHG inventories (section 3.1). Then, it provides a brief overview of reference city-level GHG accounting frameworks and/or guidance in the EU context, focusing on their comprehensiveness and coverage (section 3.2). This overview establishes a reference for current, common or typical practice in GHG emission accounting supporting climate change mitigation at city level. The remainder of the document builds on this reference or baseline, to provide insight on ‘how to go beyond common practice’ in city-level GHG emission accounting and mitigation.

3.1 GHG emission inventories: scope, boundaries and coverage

The definition of adequate scope and boundaries in GHG inventories is key to inform and support effective climate action strategies (Peters 2008). Scope and boundaries generally define what activities and emissions the inventory covers, i.e., what should be included or excluded, and their adequate selection depends mostly on the purpose of the inventory. This includes identifying the greenhouse gases, emission sources (from a range sectors and activities), geographical area and period that is covered in a given inventory. Thus, scope and boundary definition has implications on the comprehensiveness, usability and comparability of GHG inventories.

Figure 1 illustrates the definition and relationships between commonly used concepts, sectors and emissions related to city-level GHG accounting. Definitions of the concepts related to GHG accounting may vary among reference organizations, guidance documents, and their object or system of application.

Figure 1. City GHG accounting: definitions and linkages between key concepts, sectors and boundaries.



Source: JRC elaboration based on C40 (2018).

Inventory year

GHG inventories generally follow IPCC guidelines (IPCC 2006, 2019) and account for GHG emissions occurring in a given calendar year. A consistent sequence of regularly updated GHG inventories (time series) is important to adequately monitor and promptly inform GHG mitigation action.

Geographical area

Geographical boundaries in city GHG inventories often correspond to administrative boundaries (e.g., municipality). Inventories are developed to support action of local authorities, and thus they are closely linked to the geographical area under their governance, i.e., where they have the (direct) power to intervene (Bastos et al. 2025). Administrative boundaries are also likely to be the easiest to communicate to many relevant stakeholders (Balouktsi 2020). Moreover, these usually have correspondence with Local administrative units (LAU) of the Nomenclature of Units for Territorial Statistics (NUTS)⁴ classification, for which quality statistical data may be readily available.

It is important to note, however, that cities may go beyond the “municipality” scale and consider metropolitan or functional boundaries,⁵ for example, in GHG emission accounting and mitigation action. Action drawing on the coordinated efforts of different municipalities and public administrative organizations in a metropolitan area, among other spatial and administrative levels, can leverage synergies and significantly increase effectiveness and impact.

Sectors and activities

GHG inventories are generally structured by sectors, which group categories of activities and emission sources. Five main sectors have been typically used, following IPCC guidelines (2006, 2019):

- Stationary energy: the stationary energy sector consists of two main types of sources: (i) fuel combustion and (ii) fugitive emissions associated with production and distribution of fossil fuels. It covers all sectors of the economy that convert primary energy sources (fuels) to produce heat or power (energy industries, other industries, transportation, agriculture, housing, services, etc.), which emit mainly CO₂ and CH₄.
- Transport: the transport sector consists of mobile emission sources. It includes freight and passenger transport, across water, road, air and rail modes. It also includes emissions associated with off-road vehicles and machinery.
- Industrial Processes and product use (IPPU): includes emissions from chemical reactions involved in processes across the production (incl. manufacturing) and consumption of mineral compounds, chemical industries and metal production (e.g., production of cement, some food and beverages, aluminium). These comprise non-energy-related processes that may emit GHGs (mainly CO₂, N₂O and F-gases, as by-products and as fugitive emissions).
- Agriculture, Forestry and Other Land Use (AFOLU): includes (i) agriculture emissions (e.g., N₂O and CH₄) due to enteric fermentation, manure management, agricultural soils, wetlands and cultivation; and (ii) emissions from Land Use and Land-use change and Forestry (LULUCF), which represent the change in carbon stocked in soil and forestry biomass.

⁴ <http://ec.europa.eu/eurostat/web/nuts/overview>

⁵ A functional urban area consists of an enlarged city definition that includes a ‘local administrative unit’ (LAU) and its commuting zone, i.e., other surrounding areas whose labour market is highly integrated with the city, i.e., a significant share of their residents work in the city (Dijkstra et al. 2019). Thus, the functional urban area is generally defined through travel-to-work connections and flows.

- **Waste:** Emissions from waste and wastewater treatment processes, including disposal in landfills, organic waste treatment, composting, solid waste incineration, among others. Waste treatment processes with energy recovery are excluded from this sector, and considered in the ‘Stationary energy’ sector.

These sectors comprise a range of activity (and emission source) categories and sub-categories. In city-level GHG inventories, urban sectors and sub-sectors have often been applied, such as (i) ‘Buildings’, including ‘Residential buildings’, ‘Municipal buildings’, ‘Commercial buildings’, or (ii) ‘Transport’, including ‘Public transport’, ‘Municipal transport’, or ‘Private cars’.

GHG emissions that can be associated with residential buildings, include for example (i) use-phase direct emissions associated with biomass stoves, (ii) use-phase indirect emissions associated with grid-electricity generation and supply, and (iii) indirect emissions associated with the production and supply of construction materials. In GHG inventories, these emissions are categorized as scope 1, 2 and 3, depending on where they physically occur.

Direct and indirect emissions

According to the Contribution of Working Group III to the Sixth Assessment Report of the IPCC (IPCC 2022):

- Direct emissions are ‘emissions that physically arise from activities within well-defined boundaries of, for instance, a region, an economic sector, a company, or a process’; and
- Indirect emissions are ‘emissions that are a consequence of the activities within well-defined boundaries of, for instance, a region, an economic sector, a company or process, but which occur outside the specified boundaries’.

The classification of emissions depends on the boundaries considered and, in other words, on the relationship between the ‘point where emissions physically occur’ and the system (e.g., economic sector, process, region) under analysis. City-level GHG emissions typically consider sectoral boundaries and geographical boundaries.

Applying the IPCC definition to sectoral boundaries, e.g., to the residential building sector, emissions associated with small-scale building heating systems based on local combustion of fuels, e.g., a wood stove or natural gas boiler providing heating to an apartment or a multi-family building, are direct emissions.

In the case of combustion emissions from a power plant using woody biomass to generate and supply heat to residential buildings, however, two sectoral boundaries can be considered: in the analysis of emissions of the *energy sector*, these are direct emissions; while in the analysis of emissions of *residential buildings* these are indirect. Essentially, the direct or indirect classification of emissions depends on the relationship between the source – where and when emissions physically occur – and the activity or sector.

If we consider geographical boundaries, the definition of direct and indirect emissions may be established based on the ‘point of emission’ being within or beyond geographical boundaries. This is a ‘territorial-based’ perspective, distinct from an ‘activity-based’ one. Territorial-based accounting principles, focus on GHG emissions occurring within defined geographical borders. In this context, the classification of emissions from a district heating power plant may depend on the location of the power plant, i.e., they would be direct emissions of a city if they occurred within the city’s boundaries, and indirect if they occurred outside. In both cases, emissions of this plant associated with the generation of heat to be used in the city should be included in its GHG inventory.

The GHG Protocol has typically established a distinction between direct and indirect emissions based on ownership or control of emission sources (WBCSD and WRI 2015). This is associated with the primary purpose and nature of the protocol, which focuses on accounting GHG emissions of an organization, a ‘reporting entity’. The boundaries for direct emissions in this context are related to the infrastructure,

processes and activities that the organization owns and/or controls, and indirect emissions are those associated with sources beyond their own activities and infrastructure (upstream or downstream).

Scope 1, 2 and 3 emissions

The classification of emissions into scopes is related to the definition of direct and indirect emissions (above). Generally, scope 1 emissions are direct emissions, scope 2 emissions are energy-related indirect emissions (i.e., emissions associated with upstream energy generation, in particular with conversion processes), and scope 3 emissions are other (non-energy related) indirect emissions (i.e., upstream and downstream emissions associated with the life-cycle of materials and products).

In the application to cities, the classification into scopes is directly linked to their spatial/geographical boundaries, and where emissions generally occur:

- Scope 1 emissions occur within the city, i.e., these are emissions from sources located within the city geographical boundaries – they may be referred to as *local, direct or territorial emissions*;
- Scope 2 emissions are upstream emissions associated with grid-supplied energy generation, including electricity, steam and/or heating/cooling, used in the city – these are direct emissions of energy generation, and they often occur outside the city's geographical boundaries; and
- Scope 3 all other out-of-boundary GHG emissions not included in scope 2, i.e., GHG emissions that occur outside the city geographical boundaries as a result of final end-uses and activities that take place in the city, excluding emissions associated with grid-supplied energy use. These include upstream and downstream emissions occurring outside the city's geographical boundaries.

The relationship and linkages between GHG emissions classification into direct/indirect and scope 1, 2 or 3 (on a territorial-based perspective) in city-level GHG inventories is not always straightforward. For example, GHG emissions associated with waste treatment are direct emissions of this sector (occurring at the waste treatment facility), but they can be scope 1 or scope 3 in city inventories, depending on whether treatment activities take place within or outside the city geographical boundaries.

Other terminology that may be used related to direct and indirect, or scope 1, 2 and 3 emissions, includes supply chain, value chain, embodied or embedded emissions, which generally refer to upstream emissions associated with materials or products until they are supplied or delivered to the final user – they include emissions associated with raw material extraction, processing, production, manufacturing, transport, and packaging, for example. In cases, they may also include downstream emissions (e.g., associated with waste treatment).

It is important to note that the classification of emissions into direct or indirect, and into scopes 1, 2 and 3, is independent from whether they should be accounted in the city inventory: emissions within city boundaries may be excluded from inventories, and emissions outside city boundaries may be included, depending on the inventory purpose and goals.

Activity-based accounting: production- and consumption-based perspectives

As mentioned, GHG accounting at national, regional and city level has been typically bound by and based on territorial boundaries, accounting for emissions that occur within a territory, or associated with energy generation and use, and supply to the territory (Tukker et al. 2016). GHG inventories often include both production and consumption processes – for example, inventories include passenger transport emissions, which would be consumption, as well as emissions associated with manufacturing and transporting of products that may be exported and used elsewhere.

Cities could, in principle, follow a strictly territorial-based⁶ and direct emission accounting approach, considering scope 1 emissions only (i.e., all GHG emissions occurring within their geographical boundaries would be accounted for, and all GHG emissions occurring elsewhere would be excluded). Most commonly, cities have considered scope 1 and scope 2 emissions. This eases accounting, monitoring, comparability and aggregation among inventories at city and other spatial scales. However, a significant share of GHG emissions associated with urban activities occurs outside cities' boundaries, and these offer important GHG mitigation opportunities that can be leveraged by local city-level action. Consumption in one city drives production in value chains, which may cross several cities, regions and countries (Tukker et al. 2016).

In this context, GHG accounting frameworks may adopt an 'activity-based' approach. The underlying principle of an activity-based approach is to account for GHG emissions that are associated with (or induced by) urban activities. Activities taking place in the city can be associated with emissions that may occur in the city or elsewhere. The principle is similar to that of including scope 2, or energy-related indirect emissions of energy use in the territory, regardless of where these GHG emissions occur. 'Activity-based' approaches typically adopt one of two perspectives to the allocation of activities and GHG emissions: a production- or a consumption-based perspective. As the name suggests, a production-based approach (PBA) generally accounts for emissions associated with production, while a consumption-based approach (CBA) accounts for emissions associated final consumption (Allan, Connolly, and Maurya 2023; Balouktsi 2020; Lin et al. 2017).

In principle, a production-based inventory includes all GHG emissions associated with the production of goods occurring in a city, regardless of whether the goods are used within the city or exported. A consumption-based inventory, on the other hand, accounts for GHG emissions associated with consumption in a city, or by its population, regardless of where goods are produced. In other words, emissions of production and transport of goods (e.g., food) may be allocated either to the producer or to the consumer territory, depending on the perspective. Both production- and consumption-based accounting approaches are valid and useful to support GHG mitigation action. These two perspectives provide relevant complementary insights on GHG emissions associated with trade, and on GHG emissions associated with the whole value chain, which both producers and consumers are able to influence and reduce (Allan, Connolly, and Maurya 2023; Balouktsi 2020; Hung, Hsu, and Cheng 2019).⁷

Since EU cities have been mostly and increasingly significant as places of consumption, which heavily rely on other territories that produce and supply goods, consumption-based approaches have gained traction in the last couple of decades, and they have been increasingly adopted in GHG accounting frameworks and practices (Balouktsi 2020; C40 2018). Consumption-based approaches aim to capture GHG emissions of goods and services across their value chain (from raw material extraction, to manufacture, processing, distribution, use and disposal) associated with the city's activities, or used by the city, regardless of where these emissions occur (C40 2018). As such, consumption-based GHG inventories should (i) include life-cycle emissions associated with final products and services used within the city boundaries (or by the city population, as explained next), and (ii) exclude any emissions occurring within (or upstream) city boundaries associated with the life-cycle of any products or services that are exported from the city, or local treatment of waste generated elsewhere (C40 2018).

⁶ Territorial-based GHG accounting has also been referred to as 'production-based', 'domestic' or 'sector-based' (e.g., Jakob, Steckel, and Edenhofer 2014; Peters 2008). While their boundaries reflect 'where emissions are produced', they include emissions from both production and consumption activities occurring in the territory, e.g., emissions of energy generation or industrial processes, as well as emissions from combustion of fuels in private car travel. For the sake of clarity, production-based emission accounting in this report refers to accounting of emissions associated with production processes only, as opposed to consumption-based emission accounting, and not to territorial-based emission accounting (i.e., including all emissions occurring in the territory). The term 'sector-based' is not applied in this report: both territorial- and activity-based approaches can be applied to develop GHG inventories structured by sectors.

⁷ This is also observed at country level, where PBA and CBA are outlined as complementary approaches and providing information on the gap between production and consumption in a territory.

Consumption-based (CB) emission accounting can be (i) population- or (ii) area-based. Population-based CB inventories account for emissions associated with the activities of the city's population for a given year, regardless of where they occur, i.e., including out-of-boundary activities such as work travel or tourism activities of the city's residents. Area-based inventories account for emissions associated with activities occurring within the city, including activities of commuters and tourists from other cities and regions (also referred to as 'daytime population').⁸ Consumption-based GHG emissions may also be referred to as carbon footprints, which are the overall GHG emissions associated with a system, region, individual, product or organisation, across its life-cycle (Wright, Kemp, and Williams 2014). Further details on differences and application of territorial-based and emerging activity-based approaches to GHG accounting at city level are provided in Balouktsi (2020).

A city or region can have emissions associated with production activities and with final consumption. While both can be accounted for, summed up in the GHG inventory of a city results in overlaps and double-counting, and impede aggregation and comparability, because the emissions of a given product would be included both in inventories of the 'producer region' and in the 'consumer region'. As such, activity-based city-level GHG inventories usually account for production- or consumption-based activities separately.

3.2 Current frameworks and guidance

While there is no single established methodology for GHG accounting at city level, commonly applied frameworks and guidance across the EU generally draw on similar principles, with some differences regarding the scope and boundaries of GHG inventories.

This section provides a brief overview of GHG accounting guidance and practice in the Covenant of Mayors for Climate and Energy Europe (CoM EU), the EU Mission for 100 Climate-neutral and smart cities (Cities Mission), and the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) (WRI, C40, and ICLEI 2021). For each, it provides insight on the frameworks and methodologies, and on the scope and boundaries of GHG inventories. It summarizes their guidance in relation to: (i) greenhouse gases, (ii) activity boundaries and coverage (which activities should be included in GHG inventories), and (iii) emission sources by sector. This overview provides a reference for 'typical' or 'common practice' in city-level GHG accounting in the EU context.

The three frameworks draw on principles and guidelines of the Intergovernmental Panel on Climate Change (IPCC) for national GHG inventories. This enables transparency, consistency and comparability across cities and other geographical scales. The objectives of the IPCC National GHG Inventories Programme included the development of internationally agreed-upon methodologies and tools to estimate and report national GHG emissions, and to encourage widespread uptake of methodological principles and methods that can ensure scientifically sound and relevant GHG emission monitoring. In this context, the 2006 IPCC Guidelines for National GHG Inventories have been developed, with subsequent revisions and refinements.

Each framework builds on IPCC guidelines and establishes specific guidance for cities, taking into account cities' specific context (e.g., key emitting sources), needs and challenges, in relation to data collection and accounting methods, for example, but also the relative significance of GHG emissions across urban sectors and activities, and the potential opportunities and improvements that can be achieved through local action.

⁸ Per capita metrics (e.g., GHG emissions) based on daytime population are related to the "population equivalent" concept (Mirabella and Allacker 2018), which considers not only residents, but people who use urban services and live elsewhere (e.g., tourists, commuters).

The development of city-level GHG inventories typically follows a bottom-up approach, in which GHG emissions are calculated by multiplying activity data (e.g., on energy use, distance travelled, waste generation), for a reference year, by corresponding GHG emission factors.⁹ For aggregation, emissions of GHGs are converted to CO₂ equivalents using their corresponding Global Warming Potential (GWP), typically with a 100-year time horizon (GWP100 metric), summed up and expressed in terms of “tonnes of CO₂ equivalent” (t CO₂-eq).¹⁰

Table 1. GHG inventory structure: typical sectors and sub-sectors, their definition, activities and emission sources.

Sectors & sub-sectors	Definition, activities and emission sources
Stationary energy	<i>GHG emissions released from stationary energy sources in the process of generating, delivering and using energy (e.g., electricity, heat, fuels). It includes direct emissions from fuel combustion (e.g., biomass, natural gas, diesel), and indirect emissions associated with generation and supply of grid-electricity, heat and cold, used within the city's boundary.</i>
Residential and commercial buildings	GHG emissions associated with final energy use in residential buildings (e.g., final energy use by households), as well as commercial/tertiary buildings.
Institutional buildings	GHG emissions associated with final energy use in public buildings, and buildings of institutional or administrative organizations, such as schools, hospitals, government offices, among others.
Public lighting	GHG emissions associated with energy use in public lighting (e.g., road and street lighting).
Manufacturing industries and construction	GHG emissions associated with final energy use in industrial manufacturing facilities and construction activities, and GHG emissions with energy generation (e.g., combustion of fuels for electricity or heat generation) for own (local) use in these facilities and activities.
Industrial buildings	GHG emissions associated with energy generation and use in industrial buildings, including the energy industries. Emissions associated with energy generation to be supplied and used beyond city boundaries are often excluded (to avoid double counting), as well as industrial and energy generation facilities covered by the EU emission trading system (ETS) regulation.
Agriculture, forestry, and fishing activities	GHG emissions associated with final energy use in agriculture, forestry, and fishing activities (from buildings and stationary machinery/equipment).
Fugitive emissions from extraction, processing, storage, and transportation of fuels	Intentional and unintentional GHG emissions associated with the extraction, processing, storage and transport of fuels in the city, including coal, oil and natural gas. Fugitive emissions from all coal, oil and natural gas activities occurring in the city. The primary sources of these emissions may include fugitive equipment leaks, evaporation losses, and venting, flaring, and accidental releases.
Other (non-specified) sources	Any remaining GHG emissions from stationary sources (buildings and facilities) associated with energy generation or consumption, not specified elsewhere, may be included.

⁹ Emission factors express a rate of emission per unit of activity, e.g., a power plant emission factor expresses the mass amount of CO₂ per kWh of grid-electricity generated/supplied.

¹⁰ IPCC guidance for national GHG emission accounting has been updated, including its GWPs. It is thus important to identify the values (or the respective IPCC version) to ensure consistency and adequate interpretation.

Transport and mobility	<i>GHG emissions from transport within the city boundary (road and rail as a minimum), often disaggregated by municipal fleet, public transport, private and commercial transport.</i> <i>Transport vehicles and mobile equipment or machinery are associated with direct GHG emissions by combusting fuel, and indirect, by consuming grid-delivered electricity.</i>
On-road	On-road vehicles for transporting people and goods on common or public roads, streets, or highways, including buses, cars, taxis, trucks, motorcycles, on-road waste collection, among others.
Railway	Railway transport typically uses energy through combustion of diesel or electricity. Railway can be divided into: urban railway systems including trams and subway, regional commuter rail, national and international rail. Each can be classified as passenger or freight.
Waterborne navigation	Water transportation includes ships, ferries, and other boats operating in the city, as well as marine-vessels whose journeys originate or end at ports within the city's boundary but travel to other destinations.
Aviation	Civil aviation, or air travel, includes emissions from airborne trips occurring within the geographic boundary (e.g., helicopters operating within the city) and emissions from flights departing airports that serve the city
Off-road	Off-road vehicles are designed or adapted for travel on unpaved terrain. This category includes for example airport ground support equipment, all-terrain vehicles, landscaping and construction equipment, among others.
Waste management	<i>GHG emissions associated with disposal and treatment of waste and wastewater generated within city boundaries (incl. solid waste disposal/landfill and biological treatment, through aerobic or anaerobic decomposition, or incineration).</i> <i>Scope 2 emissions associated with energy use in waste treatment and emissions from waste treatment with energy recovery are accounted for in Stationary energy/buildings.</i>
Solid waste disposal	Solid waste may be disposed of at managed sites (e.g., sanitary landfill), and at unmanaged disposal sites (e.g., open dumps).
Biological waste treatment	The biological treatment of waste refers to composting and anaerobic digestion of organic waste, such as food waste, garden and park waste, sludge, and other organic waste sources.
Waste incineration	Incineration is a controlled industrial process, often with energy recovery (in such case reported in stationary energy). Open burning is an uncontrolled, often illicit process with direct emissions and can typically only be estimated based on collection rates.
Wastewater treatment	Wastewater can be treated aerobically or anaerobically. Wastewater can generally be categorized as domestic wastewater or industrial wastewater, and both should be included.
Industrial processes and product use (IPPU)	<i>GHG emissions resulting from non-energy related industrial activities and product use. All GHG emissions occurring from industrial processes, product use, and non-energy uses of fossil fuels. These include chemical processes associated with products and by-products.</i>
Industrial processes	GHG emissions are produced from a wide variety of industrial activities. The main emission sources are releases from industrial processes that chemically or physically transform materials. These include processes for production of cement, lime, ammonia, iron and steel. GHG emissions associated with energy use in industry are reported under Stationary Energy.
Product use	GHG emissions associated with use of products, such as refrigeration equipment, foams or aerosol cans, which can release GHG emissions with significant global warming potential.

Agriculture, forestry, and fishing activities (AFOLU)	<i>GHG emissions associated with agriculture, forestry, fishing, and other land uses. GHG emissions from a variety of pathways, including land-use change that alter the composition of the soil, methane produced in the digestive processes of livestock, and nutrient management for agricultural purposes (incl. emissions/sources removal/sinks).</i>
Livestock	Livestock emissions, e.g., CH ₄ through enteric fermentation, and CH ₄ and N ₂ O through management of their manure.
Land use	Emissions and removals of CO ₂ are based on changes in ecosystem C stocks and are estimated for each land-use category. C stocks consist of above-ground and below-ground biomass, dead organic matter, and soil organic matter.
Other agriculture	Other sources of GHG emissions from land use including rice cultivation, fertilizer use, liming, and urea application.

Source: JRC own elaboration, based on EC (2021), Ridoutt et al. (2016), and WRI, C40, and ICLEI (2021), Bastos et al. (2025).

Most city-level frameworks follow an IPCC sectoral structure and guidelines, while providing some degree of flexibility by setting ‘minimum’ and ‘recommended’ types of guidance. In such cases this section focuses on a restricted set of alternatives within the framework.

Transboundary and out-of-boundary emissions (scope 3) that have typically been excluded from GHG inventories at city level across the EU include (i) transport occurring outside the city, induced by city activities (e.g., commuting to and from the city, out-of-boundary work/municipal travel); and (ii) the extraction, processing, production and supply of final products consumed in the city (e.g., food and drinks). Further details and discussion on GHG accounting frameworks and approaches at city level are provided in Balouktsi (2020).

Box 2. Note on energy-related indirect (scope 2) emissions

There are differences in GHG emission accounting related to the methodology for calculating emission factors. Emission factors express the amount of GHG emitted per unit of activity, e.g., g of CO₂ emitted per 1 l of diesel used, or per 1 km travelled by a vehicle. While discussing methodological aspects and scope of these emission factors is beyond the scope of this report, these are worth noting. For example, the use of generation emission factors vs. supply/consumption emission factors which take into account international trade (imports and exports) of energy affect scope 2 emission estimates, and it is linked to the scope and comprehensiveness of city GHG inventories.

3.2.1 CoM EU

The CoM EU framework for GHG accounting builds on the Common Reporting Framework (CRF) of the Global Covenant of Mayors for Climate and Energy (GCoM), to provide specific and tailored guidance in an EU context. GHG accounting in the CoM focuses on energy-related activities and sources. GHG emission inventories should cover at least the four CoM key activity sectors (Bastos et al. 2025):

- Municipal buildings, equipment & facilities;
- Tertiary (non-municipal) buildings, equipment & facilities;
- Residential buildings;
- Transport.¹¹

It is also recommended to include emissions associated with the treatment of waste and wastewater generated in the city, and any other sectors and activities that may be addressed in local climate change mitigation actions, so that the results of those actions can be adequately evaluated and monitored. CoM inventories typically exclude non-energy-related emissions associated with Agriculture, Forestry and Other Land Uses (AFOLU) and Industrial Processes and Product Use (IPPU) sectors, which are generally considered of limited relevance in an urban context.

Two approaches can be adopted in the CoM framework to calculate GHG emissions: the activity-based and the life-cycle based (LC-based) approach. In both approaches, GHG emissions associated with energy use within the city are accounted for. The ‘activity-based approach’, which is the most frequently adopted, focuses on GHG emissions that occur during energy conversion (e.g., local fuel use, electricity generation), which are estimated based on the carbon content of the fuels used. This approach builds on IPCC guidelines, it is aligned with national reporting practices in the context of UNFCCC, and with EU legislation on climate and energy.

The LC-based approach reflects a more ambitious and comprehensive perspective, as it adds upstream (supply chain) GHG emissions associated with energy generation (e.g., fuel extraction and processing, renewable energy infrastructure production) to the ‘activity-based’ emissions. These can be particularly significant for renewable energy sources and carriers, such as photovoltaic electricity generation.

Three reference long-lived GHGs should be considered in CoM GHG inventories: Carbon Dioxide (CO₂), Methane (CH₄), Nitrous Oxide (N₂O); and the minimum requirement is to account for CO₂ only.

3.2.2 Cities Mission

The Cities Mission is characterised by more ambitious targets to be achieved within a shorter timeframe, and a smaller number of cities involved, in comparison with the other frameworks: 100 EU cities, who commit to significantly reduce GHG emissions associated with all IPCC sectors, to achieve climate neutrality by 2030. In this context, the framework adopts an open and flexible approach, suggesting the use of CoM EU, GPC or other reliable GHG accounting approaches.

The scope, sectors, activities, GHGs and emission sources are mainly established through the Cities Mission ‘climate neutrality definition’, and the Info KIT provides general guidelines and recommendations (EC 2021a). In brief, GHG emission sources in stationary energy, transport, waste, IPPU and AFOLU should be included. GHG emissions may be excluded when sectors, activities or sources are considered negligible; and the overall share of excluded GHG emissions shall not exceed 5% of the GHG emissions in the city’s inventories.

¹¹ Transport is both a macro-sector and a key activity sector, while the other key activity sectors are sectors in the buildings macro-sector.

Mission cities should account for emissions of six reference GHGs: Carbon Dioxide (CO₂), Methane (CH₄), Nitrous Oxide (N₂O), F-gases (hydrofluorocarbons and perfluorocarbons), Sulphur hexafluoride (SF₆) and Nitrogen trifluoride (NF₃). The minimum requirement is to account for carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), if emissions from the IPPU sector are excluded (i.e., in case these are considered negligible). These are the main GHGs targeted since the first commitment of the UNFCCC's Kyoto Protocol.

3.2.3 Global Protocol for community-scale GHG emission inventories (GPC)

The Global protocol for community-scale GHG emission inventories (GPC) provides guidance by WRI, ICLEI and C40. The GPC's "city-induced framework" considers GHG emissions associated with production and consumption activities within city boundaries at two levels, the BASIC and the BASIC+ (WRI, C40, and ICLEI 2021):

- The BASIC level comprises sectors and sources that dominate GHG emissions in most cities – in-boundary stationary energy and transportation sources, as well as in-boundary emissions from locally generated waste.
- The BASIC+ level includes the sectors of the BASIC level and adds emissions associated with IPPU, AFOLU, transboundary transportation, and energy transmission and distribution losses.

The GPC also provides the option of including 'other scope 3 emissions', such as those embodied in fuels, food and construction materials. It is worth highlighting that cities should account for emissions occurring within city boundaries separately, so that they can be used for aggregation of multiple city inventories.

Under the GPC, cities shall also include all reference Kyoto Protocol GHGs: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF₆), and nitrogen trifluoride (NF₃).

3.2.4 PAS 2070

The PAS 2070¹² is a UK national standard that specifies requirements for the assessment of GHG emissions of a city or an urban area for two alternative methodologies:

- Direct plus supply chain (DPSC) covering direct GHG emissions from activities within city boundaries and indirect emissions from grid-supplied energy + transboundary travel + supply chains of key goods and services, e.g., water supply, food and building materials, i.e., scope 1, 2 and a selection of scope 3 emissions.
- Consumption-based approach (CBA) covering direct and life-cycle GHG emissions for all goods and services consumed by residents of a city. It excludes impacts of production of goods and services within a city that are exported for consumption elsewhere, visitor activities, and goods and services provided to visitors.

3.2.5 Summary overview: what is 'common practice'?

A summary overview of the sectors, activities and emission sources typically covered in GHG inventories under the Cities Mission, CoM EU and GPC frameworks are provided in Table 2 and Figure 2.

¹² PAS 2070: 2013 and Amendment 1: 2014 available at <https://www.en-standard.eu/>

Table 2. Summary overview: activity sectors and scopes included city GHG emission inventories in the Cities Mission, CoM EU and GPC frameworks.

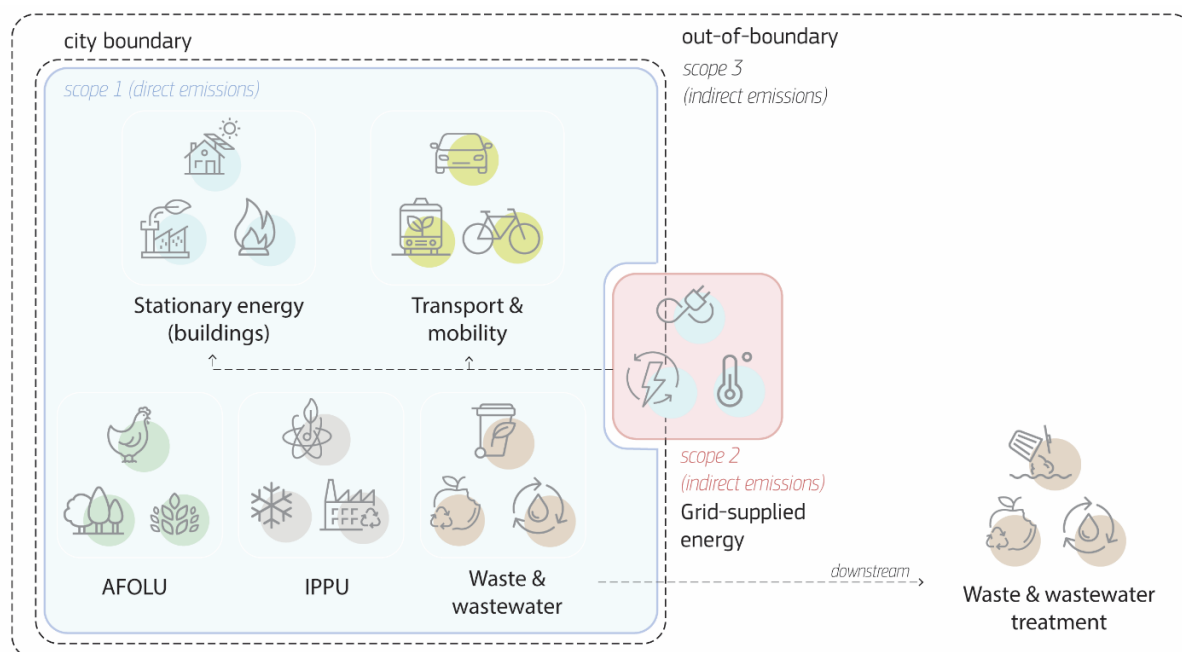
Sector	Cities Mission	CoM EU	GPC	Remarks
Stationary energy	1, 2	1, 2 ⁽¹⁾	1, 2	In GPC, BASIC+ recommends the inclusion of scope 3 emissions. Emissions associated with energy generation (conversion) within city boundaries may be incorporated in inventories through an emission factor that is applied to all sectors using energy (not reported in a specific sector). Scope 1 fugitive emissions should be included in the GPC, and they may be included (optionally) in Cities Mission and CoM EU.
Transport and mobility	1, 2	1, 2 ⁽¹⁾	1, 2	The Cities Mission and GPC BASIC+ recommend inclusion of scope 3 emissions (without currently providing an accounting framework). Transboundary flows should have the share of 'in-city' emissions accounted for. Crossing flows may be excluded (e.g., a highway crossing the territory with no access/exit points to the city). Cities Mission and CoM EU recommend inclusion, if relevant, of scope 1 and 2 emissions for waterborne navigation, aviation, off-road transport sources. In GPC, BASIC+ recommends the inclusion of scope 3 emissions.
Waste ⁽²⁾	1,3	-	1	CoM EU recommends the inclusion of GHG emissions associated with the treatment of waste and wastewater generated within the city. In GPC, BASIC+ recommends the inclusion of scope 3 emissions.
IPPU	1	-	1	-
AFOLU	1	-	1	-

¹ The LC-based approach includes adds upstream GHG emissions associated with energy supply chain.

² Recommendations to account for scope 3 emissions in sectors beyond waste are seldom supported with methodological guidance.

Source: JRC own elaboration based on Bastos et al. (2025), EC (2021), and WRI, C40, and ICLEI (2021).

Figure 2. Common practice in GHG accounting: typical boundaries, sectors and scopes used by EU cities.



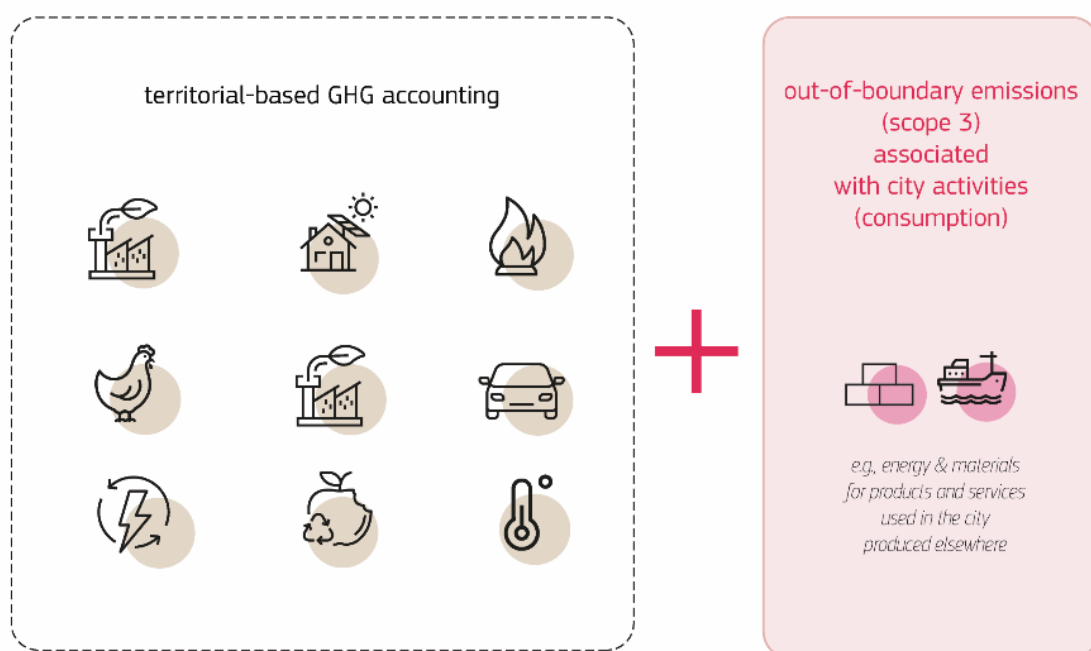
Source: JRC elaboration.

4 Why should we advance common practice?

The brief overview of frameworks and guidance in section 3, provides a 'baseline' – a reference on common GHG accounting practice at city level in the EU context. GHG accounting frameworks and climate change mitigation action at city level have mostly focused on scope 1 and 2 emissions, while scope 3 emissions have often been excluded (Wang and Chen 2018). However, research has demonstrated that scope 1 and 2 emissions account for only part of overall GHG emissions associated with cities. Moreover, with increased urban population, final consumption and globalisation of supply chains, it is likely that the relative share of out-of-boundary emissions associated with urban consumption will increase (Balouktsi 2020).

Natural resource extraction and processing account for about 50% of total anthropogenic GHG emissions, and more than 90% of biodiversity loss and water stress impacts worldwide (IRP 2019). Natural resource extraction grew from 24.5 to 83.5 billion tonnes in less than 50 years, and higher income economies dominate the increasing demand (IRP 2019). Currently, a large share of current final consumption (goods and services) in EU cities relies on global value chains (Allan, Connolly, and Maurya 2023; Cabernard and Stephan 2021). In global value chains, raw materials are often imported by a producer, to then be processed and sold as intermediate product to another producer elsewhere, and eventually sold as a product for final consumption. At each step and location across the value chain, GHG emissions are generated (Cabernard and Stephan 2021). UNEP's International Resource Panel (IRP) published a report on carbon, water stress and biodiversity loss footprints of global material production, which highlights the importance of material production and international trade for carbon footprints (IRP, 2019), in particular in high-income regions such as the EU, which increasingly rely on lower-income regions.

Figure 3. GHG emissions associated with cities:
considering upstream emissions associated with urban consumption.



Source: JRC elaboration.

Territorial-based approaches may overlook potential burden shifting and carbon leakage (Balouktsi 2020). For example, burden shifting may occur when tackling GHG emissions associated with buildings. While GHG emissions of typical or conventional buildings can account for over 80% of overall life-cycle emissions (Huang et al. 2024; Nemry and Uihlein 2008; Sartori and Hestnes 2007), state-of-the-art construction solutions (e.g., zero emission buildings) have sharply reduced GHG emissions associated with the operational phase. However, typical energy efficiency and RES measures for new construction as well as building retrofits, are often associated with increased material demand (e.g., in insulation, photovoltaic panels). Without a life-cycle perspective, stakeholders and policymakers may not be aware of the overall reduction; in fact, a tipping point might eventually be reached, beyond which reducing operational GHG emissions might result in increased overall emissions (Rodrigues and Freire 2014). Lastly, consumption-based and transboundary accounting can inform, encourage and facilitate cooperation among stakeholders, and across cities and regions.

Box 3. The London case study

PAS 2070 aims to provide a robust and transparent method for consistent, comparable and relevant quantification, attribution and reporting of city-scale GHG emissions. It encourages more holistic GHG assessments, greater disclosure and more meaningful benchmarking to help city decision makers identify key emission sources and their drivers, the carbon dependence of their economy, and opportunities for more efficient urban supply chains.

The London case study compares three approaches:

- London Energy and GHG inventory (LEGGI) covering Scope 1 and 2, CO₂ emissions (only) from combustion of energy within city boundaries for transport, power and heat.
- Direct plus supply chain (DPSC) covering direct GHG emissions from activities within city boundaries and indirect emissions from grid-supplied energy + transboundary travel + supply chains of key goods and services, e.g., water supply, food and building materials, i.e., scope 1, 2 and a selection of scope 3 emissions.
- Consumption-based approach covering direct and life-cycle GHG emissions for all goods and services consumed by residents of a city. It excludes impacts of production of goods and services within a city that are exported for consumption elsewhere, visitor activities, and goods and services provided to visitors.

Results highlights: GHG emissions with CB methodology are 40% higher than those calculated with DPSC and 157% higher than those with LEGGI (114, 81 and 44 t CO₂-eq, respectively).

PAS 2070: 2013 and Amendment 1: 2014 available at <https://www.en-standard.eu/>

Another important contribution of more comprehensive GHG emission inventories is their ability to inform on and monitor actions to promote circular economy (CE). In recent years, many cities across the EU have developed CE action plans, and CE actions are increasingly considered in GHG mitigation action. Significant potential of CE actions lies on reducing upstream and downstream GHG emissions, by increasing resource efficiency, and reducing demand and waste generation. However, a lack of indicators and the exclusion of scope 3 from GHG inventories may hinder effective decision-making and monitoring of CE actions (Moraga et al. 2019).

In summary, current GHG inventories provide limited insight on (i) the actual overall GHG emissions associated with urban areas and activities, and on (ii) potential opportunities for GHG mitigation (Wang and Chen 2018). The focus on territorial-based GHG accounting has been criticized in inventories aimed at informing and monitoring reductions in GHG emissions, in particular for not including international transportation and trade, and for overlooking carbon leakage. Trans- and out-of-boundary emissions are difficult to include due to challenges with assigning responsibility and limited data availability (Peters 2008). In order to effectively inform and support increasingly ambitious and urgent climate change mitigation action, city-level GHG accounting frameworks and practice should move toward more comprehensive, relevant and complete inventories.

To capture the actual GHG emissions of final consumption occurring across global value chains, research and practice have increasingly adopted consumption-based accounting (Balouktsi 2020; Hung, Hsu, and Cheng 2019; Lin et al. 2017). These have been applied for countries, organizations and products, but also at city, district and household levels (Balouktsi 2020). As mentioned, consumption-based accounting typically includes the cumulative GHG emissions of a city's consumption, including emissions occurring due to imports for final consumption, but excluding local GHG emissions associated with exports, thus addressing supply chain management (Cabernard and Stephan 2021; Hung, Hsu, and Cheng 2019). Consumption-based GHG accounting provides key insight to inform local climate action (Larsen and Hertwich, 2009). It is important to tackle GHG leakage and support more effective GHG mitigation, and it can provide useful metrics to inform residents, and to help public administrations, organizations, companies and households make better informed decisions on their consumption choices (Lin et al. 2017; Wang and Chen 2018).

Advantages of consumption-based GHG inventories include accounting for international trade and thus covering more emission sources, increasing mitigation options, encouraging cleaner production and avoiding carbon leakage. However, consumption-based inventories also have disadvantages. For example, they may involve more data, calculations, assumptions and uncertainties; they may be seen as a shift in responsibility to consumers, rather than promoting and supporting shared responsibility between production and consumption; and they may go beyond the geographic area of influence and power of geo-political administration/authorities (Peters 2008).

Box 4. C40 analysis of consumption-based GHG emissions of 79 cities

Out-of-boundary (indirect) emissions associated with cities consumption can be more than three times higher than direct, in-boundary emissions (Balouktsi 2020; C40 2018). In some sectors scope 3 emissions may be more significant than scope 1 and 2 combined (C40 2018; TCFD 2021).

An analysis for 79 C40 cities, consumption-based emissions were estimated to be on average 60% higher than territorial-based emissions (C40 2018). Overall territorial-based emissions of the 79 cities were 2.2 Gt CO₂-eq. Consumption-based emissions added another 2.2 Gt CO₂-eq and excluded 0.9 Gt CO₂-eq of territorial-based emissions associated with exports. Cities in Europe, North America and Oceania had strong consumer profiles, with consumption-based emissions achieving more than three times the estimated territorial-based GHG emissions. Consumption-based emissions per capita showed large variability across the globe, from 1.8 to 25.9 t CO₂-eq/capita. EU cities ranged mostly between 10 and 15 t CO₂-eq/capita (C40 2018).

Looking at GHG emissions by consumption area, more than 60% of consumption-based GHG emissions in European cities were associated with (i) utilities and housing (incl. water, electricity and gas consumption), (ii) capital (incl. physical assets such as infrastructure, construction and machinery), (iii) transportation (incl. purchase and operation of vehicles), and (iv) food, beverages and tobacco. Together with (v) clothing, furnishing and household equipment, (vi) government, and (vii) restaurants, hotel and other recreational activities, these sectors accounted for over 90% of consumption-based emissions (C40 2018).

5 Methods, tools and data for more comprehensive GHG accounting

A wide range of approaches have been applied to GHG accounting, and several methods and tools are available that can support the development of more comprehensive GHG emission inventories at city level, including bottom-up, top-down and hybrid methods. This section provides a summarized overview of methods, tools and data available to account for city-level GHG emissions, including consumption-based and scope 3 emissions, and it provides insight on their scope, outputs, strengths and limitations. It draws on state-of-the-art research, including resources for further reading and analyses, and it discusses potential opportunities and gaps to overcome.

Typically, GHG accounting in EU frameworks has mostly relied on bottom-up process-based modelling where input activity data is collected and multiplied by GHG emission factors to estimate overall emissions by sector (Bastos et al. 2024). GHG emission modelling can go from these relatively simple calculations to complex techniques (e.g., using atmospheric inversion models to derive emissions from satellite data on GHG concentration levels). Since this report is aimed at supporting cities and practitioners, and at providing the basis for the development of a consistent and easily applicable GHG accounting framework for EU cities, it focuses on relatively simple approaches using commonly accessible, reliable (and regular) input data sources.

Research on GHG accounting at city level has increased in recent years. Due to the complexity and diversity of activities and emission sources in cities, many applications have used top-down methods, in particular input-output models, to estimate GHG emissions. Such approaches often downscale IO data on economic flows between industries and sectors, and between production and consumption, from the national level, and combine it with environmental data to develop environmentally extended input-output (EE-IO) models (Allan, Connolly, and Maurya 2023). These can include GHG emissions and other environmental impacts associated with economic activities (Allan, Connolly, and Maurya 2023). Bottom-up methods, on the other hand, have seen limited application in research on more comprehensive GHG inventories, including scope 3 emissions, at city level. Some examples can be found using statistical data on consumption, e.g., household consumption surveys at local level to estimate GHG emissions (Allan, Connolly, and Maurya 2023).

Box 5. Types of methods for developing GHG emission information in the IG3IS guidelines

The World Meteorological Organization (WMO) Integrated Global Greenhouse Gas Information System (IG3IS) published a set of urban good practice guidelines based on established and evolving scientific GHG emission accounting methodologies. The first version of these guidelines, titled "Urban Greenhouse Gas Emission Observation and Monitoring Good Research Practice Guidelines," was published in 2021. Since then, several technical areas have matured or expanded. Recently, an updated guidance document has been shared for public consultation, reflecting state-of-the-art research, and highlighting the increasing integration and practical application of alternative methods for GHG accounting.

The IG3IS guidelines (WMO, 2022 and its update, currently under finalisation) identify three main types of methods for developing GHG emission data:

- Process models leverage emissions information, such as activity data and process information (e.g., traffic counts, vehicle characteristics, fuel consumption), to map spatial, time-specific and sector-based emissions. They often provide estimates at the source level, and thus, include details, e.g., on fuel, technology, and sometimes ownership.
- Direct atmospheric observation methods, dependent on the technique, may offer emissions information at various levels of detail. Direct observational methods can be particularly important for validation of results, as well as for communication and outreach.
- Computational modelling techniques, often requiring sophisticated computing tools, are single systems that combine process models and atmospheric observations to deliver robust and validated emissions information.

IG3IS guidelines (WMO, 2022) provide 'Extended technical discussions' dedicated to specific methodologies or techniques, which are intended as a resource to guide researchers and practitioners in implementing these methods.

5.1 Process-based methods

City-level GHG emission accounting in EU frameworks have typically adopted process-based bottom-up approaches. These models use statistical and observation data to describe urban activities (e.g., building floor area, electricity use in buildings, travel distances by car, traffic counts, fuel sales, population/demographic data), and multiply the data by GHG emission factors.

The main advantage of these methods is that they build directly on the link between use/activity and emissions, which is insightful to inform the design of targeted actions. They can provide high disaggregation and granular insight (e.g., disaggregating emissions by sector, activity, fuel, technology, or individual facilities), as well as spatial and temporal details, which is particularly relevant for policymaking (Fong et al., 2014). However, activity data is often downscaled from national or regional to city level (e.g., using proxy data to downscale and/or adjust), which can introduce significant uncertainty. Developing detailed bottom-up emission inventories can also be resource intensive (in terms of time, labour and data). Lastly, bottom-up context-specific methods may be less transparent and have limited comparability among cities.

Extending the scope and coverage of GHG inventories to provide more comprehensive inventories, including trans- and out-of-boundary emissions is likely to increase the challenges associated with process-based methods, i.e., increasing (i) data and resource requirements, (ii) uncertainty associated with the downscaling, extrapolation and other calculations, and (iii) challenges to the interpretation and comparability among cities. In the development of more comprehensive inventories including scope 3 emissions, bottom-up modelling for a whole city has often been considered unpractical and burdensome.

5.1.1 Process-based life-cycle (LC) approaches

Life-cycle assessment (LCA) is a standardized methodology to quantify potential environmental impacts associated with a product, system or service, across its entire life-cycle, from raw material extraction to end-of-life (ISO 14040:2006; ISO 14044:2006). It has been widely applied in a range of research areas, and it can be particularly important to support decision-making because of its function-oriented and holistic nature, which can provide a comprehensive picture and help identifying environmental hotspots and potential burden shifts and trade-offs (Barkhausen et al. 2023). Process-based life-cycle approaches have been increasingly applied in policymaking, including in GHG accounting for products and organisations, for example (Sala et al. 2021). LCA approaches include process-based LCA and economic input-output LCA (EIO-LCA). This section focuses on process-based LCA.

LCA has been combined with material flow analysis (MFA) (Goldstein, Birkved, and Quitzau 2013; Lavers Westin et al. 2019), to account for flows associated with urban areas and then estimate their environmental impacts (with process-based LCA). MFA systematically models and quantifies flows (inputs and outputs) and stocks of materials associated with a system, defined by spatial and temporal boundaries, building on mass balance principles (Brunner and Rechberger 2017). MFA has often been applied in the context of resource, environmental and waste management, as it can provide insight on the use and availability of materials, and on opportunities to improve resource efficiency (Brunner and Rechberger 2017; Graedel 2019). MFA has gained particular attention in recent years, with the raising importance of circular economy in research and policy (Barkhausen et al. 2023; Gao et al. 2020; Graedel 2019; Jacobi et al. 2018). MFA has been used at national level - for example, EU Member States report their economy-wide material flow accounts (EW-MFA) yearly - however, its application at regional and urban levels is still limited mostly due to a lack of a standardized methods and data at city level (Lavers Westin et al. 2019).

Recent research has highlighted the potential of approaches combining MFA and LCA (Barkhausen et al. 2023; Graedel 2019; Sakai et al. 2017; Withanage and Habib 2021), which have been increasingly applied in specific sectors, such as buildings or waste management (Barkhausen et al. 2023; Sakai et al. 2017). However, integrated assessments including a comprehensive set of sectors and systems in a city or region are limited. Widening the application of MFA-LCA frameworks to other geographic levels, such as regional and urban areas, to provide increasingly comprehensive assessments would be a valuable advance and research contribution to support policy-making toward sustainable development (Barkhausen et al. 2023; Graedel 2019). LC-based approaches have also been combined with expenditure data at household level, such as the consumption footprint assessment developed by Ciccolini et al. (2024).

LC-based approaches also offer important advantages compared to IO-approaches. Firstly, process-based LCA enables the compilation of a comprehensive inventory of environmental pressures and impacts compared to MRIO alternatives (Castellani et al., 2019). Secondly, LC-based models have a high level of granularity and disaggregation, providing insight on the linkages between activities, processes and environmental impacts, which can support the identification of environmental hotspots and guide targeted policy action, as well as enable detailed scenario analyses (Sala and Sanyé-Mengual, 2022).

The application of process-based LC approaches to develop city-level GHG inventories has high resource requirements – data, time and expertise requirements, in particular. Its wide application to promptly support GHG mitigation action across EU cities is challenging. Increasing availability of quality LC data that is representative of the specific context and supply chains of EU cities is an important step to improve application and uptake of these approaches in the support of policymaking.

5.1.2 The EU Consumption Footprint

The EU consumption footprint (CF) model estimates life-cycle environmental impacts of household consumption in the EU, considering not only direct impacts (associated with the use of products and services), but also those impacts taking place in other world regions through indirect imported impacts (emissions outside the country associated with imported products for consumption in the country), by considering ‘apparent consumption’, i.e., local production plus imports minus exports (Sanyé-Mengual et al. 2025). The Consumption Footprint Platform hosted by the JRC provides annual data for the Domestic Footprint and Consumption Footprint of EU and EU Member States.

The CF model considers five household consumption areas: housing, mobility, food, household goods and appliances. These were selected based on their relative significance in terms of mass consumption and of their potential environmental impacts (across their supply chains), and considering also emerging consumption patterns (e.g., dietary changes) or environmental issues (e.g., biodiversity loss) (Sanyé-Mengual et al. 2023). For each area, a basket of products was built (representative products of the consumption area) and process-based LCA models for each representative product and consumption area were developed (Sala and Castellani 2019).

In brief, the CF model consists of: (i) selection of representative products by consumption area, (ii) compilation of apparent consumption data by representative product for the year under assessment from statistical data, (iii) modelling life-cycle inventory (LCI) datasets for the selected products representative of the products consumed in the EU (incl. representative use conditions and end-of-life treatment) combining both foreground and background data¹³, and (iv) calculation of environmental impacts per consumption area, country or person through the application of life-cycle impact

¹³ LCA studies rely on background databases that provide detailed inventory data of technological processes, e.g. electricity production, transportation or other manufacturing processes. Background databases allow to transform foreground data (this is primary, context-specific, collected data, e.g., 15 kWh electricity consumed) into a comprehensive list of elementary flows (e.g., kg CH₄ emitted to air). Background databases combine measured and modelled data.

assessment (LCIA) models. For the LCIA, the consumption footprint employs the Environmental Footprint v3.1 method (Andreasi Bassi et al. 2023), as recommended by the Commission for life cycle data (EC 2021b). In the case of GHG emissions, the climate change impact category is currently based on the GWP from the Sixth Assessment Report (AR6) of the IPCC 2021 (Forster et al., 2021), including a total of 219 substances.

Recently, the CF has been applied to the city of Torino, Italy (Genta et al. 2022). The adaptation of the CF model to the city level included: (i) identification of data sources and their geographical resolution and product granularity; (ii) alignment with the consumption footprint structure in terms of consumption, product group and representative product; and (iii) identification of potential unit conversion need (e.g., translate monetary terms (€) into mass-based units (kg)). The city-level consumption data can then be coupled with the GHG emission factors per unit of product from the Consumption Footprint model.

While Genta et al. (2022) employed EU-average GHG emission factors from the CF model, a subsequent work developed a dynamic version of the emission factors that allow for better temporal and geographical representation (Sanyé Mengual et al., 2023). The learnings from Genta et al. (2022) could serve as a basis to develop an LCA-based framework for consumption-based GHG accounting at city level. When discussed with stakeholders, the Consumption Footprint model was identified as promising for monitoring the implementation of circular economy in cities with a potential for refinement and adapting to local conditions (e.g., adding new representative products) (Genta et al., 2025).

5.2 Input-output and expenditure-based methods

Input-output analysis (IOA) is a commonly used methodological approach for economic and environmental assessments at the macro level (e.g., national). IOA emerged as a field in the 1930s, driven by the work of Leontief who was awarded the Nobel prize in economics for his contributions. The approach draws on the quantification of flows of goods and services between sectors in an economy, through production and consumption of intermediate outputs (Leontief 1951, 1966, 1970). IO approaches have been increasingly used at national scale, as they provide an adequate and consistent and holistic framework to account for GHG emissions and other environmental impacts associated with final demand or consumption, including international trade (Wiedmann 2009).¹⁴

The fundamental principle in IOA is that it links how much each sector purchased from all other sectors over the year to the direct production requirements of the sector and to its outputs. This allows an assessment of economic activity of a given demand by tallying the direct input requirements from all sectors, and then doing the same procedure to tally input requirements to produce these inputs, and continuing this process upstream to eventually describe the *total* (overall) requirements, inputs and outputs, of each sector.

IOA is based on input-output tables (IOTs), which describe monetary transaction flows (e.g., inter-sectoral transactions, imports and exports) among economic sectors, which are associated with physical flows of goods and services. These flows can be associated with final consumption by households and governments, for example, but also to intermediate consumption by all industrial sectors. They show the volume of production of each economic sector (output) going to each consumption group or area, expressed in monetary value (e.g., EUR). IOTs are constructed from national supply and use tables (SUTs), which are typically compiled by national statistics offices across the EU, as part of a country's national accounts.

¹⁴ Wiedmann (2009) reviewed around 20 MRIO consumption-based environmental analyses at national level between 2007 and 2009.

IOTs are essentially tabular representations of how much each sector of the economy uses of various goods and services from other sectors, and how much it sells or supplies either as intermediate inputs to other sectors, as goods for final consumption by households or government, or as exports to industries or final consumers abroad. IOTs are typically developed for a given country and year, and the various industries or sectors of the economy appear in the header row and the index column, while the cells in the table describe monetary flows (inputs and outputs) between them, i.e., purchases and sales, as well as sales to final consumers, such as households.

Over the past few decades, there has been a growing interest in applying the IOA framework to assess environmental impacts associated with final demand and different economic flows, sectors and goods. In this context, IO data can be combined with environmental data, to provide insight on GHG emissions and other environmental aspects. Environmentally extended input-output (EE-IO models) add, for example, GHG emissions of production (using GHG emission factors per economic sector) (Tukker et al. 2016). However, the linkages between monetary transactions, flows of physical goods and services, and associated environmental impacts in IO approaches are associated with significant constraints and limitations, in particular due to homogeneity assumptions and sectoral aggregation (Wang and Chen 2018).

In a standard single-region input-output (SRIO) model, an important issue is how to include imported goods, as the model only details the direct input requirements of domestic sectors. The typical assumption has been to consider that the production of imported products has the same input requirements as domestically produced goods (Wiedmann 2009). As supply chains have become increasingly complex and global over the years, this assumption has become more questionable. This can be particularly important for EE-IO analyses, since emission intensities of countries' energy mixes, and thus of their various domestic industries, can be very different.

To address these shortcomings, several multi-regional input-output (MRIO) databases have been developed over the past couple of decades (see section 5.2.2). In principle, these are constructed similarly to a single nation's IOTs, tabulating flows between different sectors in different regions (countries) of the world. MRIO models can describe regional differences in production efficiency and track the supply chain, which is important for understanding international flows and their associated GHG emissions, and for understanding the relative contribution of economic sectors and geographic linkages – they can inform on where GHG emissions associated with consumption occur – which is important to support GHG mitigation action (Xu et al. 2023). However, MRIO databases and analyses involve higher data requirements and modelling complexity to consider detailed import and export data, which is generally not available in national accounts.

5.2.1 Application to cities

Several research advancements have been made to apply, extend and modify MRIO data to allow for more tailored environmental assessments. In particular, IO models have been increasingly applied at regional and city scale to build consumption-based GHG inventories (Wang and Chen 2018; Lin et al. 2017; Peters 2008). IO provides insight on the relationships between production and consumption; its extension to MRIO has allowed to describe and understand these relationships at global level; while environmentally-extended MRIO models enable the development of GHG inventories (Lin et al. 2017; Tukker et al. 2016). Since IO tables are generally compiled at the national level, they are not readily applicable to cities, several approaches have been proposed to disaggregate national IOT data, using regional statistics, or constructing a regional (city-level) input-output table and combining it with a national IOTs or an MRIO database.

An approach that has been increasingly used by researchers and city practitioners is to combine MRIO or national IOT data with local data on household consumption. By combining MRIO tables with detailed data on household consumption, e.g., from consumer expenditure surveys, several studies have provided detailed household carbon footprints, with emission contributions broken down by detailed sectors, products or activities.

MRIO models have been increasingly used in GHG accounting at regional and city scale (Cabernard and Stephan 2021; Lin et al. 2017; Xu et al. 2023). MRIO methods can describe trade of goods and services (domestic and international trade) associated with a city's residential consumption (Xu et al. 2023). For example, Lin et al. (Lin et al. 2017) proposed a city-centric global multi-region IO (CCG-MRIO) model, which focuses on final consumption in individual cities, using sectoral products from a diversity of countries and geographic regions worldwide. Wang and Chen (Wang and Chen 2018) proposed an EIO-LCA carbon accounting framework to quantify sectoral indirect upstream supply chain emissions at city level, including direct emissions, energy-related upstream emissions (scope 2) and complete supply chain emissions (scope 3). In Wang and Chen (2018), scope 1 and 2 emissions account for 28% of total supply chain and use emissions.

Box 6. C40 analysis of consumption-based emissions for 79 cities: methods in a nutshell

The C40 analysis of consumption-based emissions for 79 cities draws on PAS 2070 and uses household expenditure data on goods and services, government providing services and business capital investment. For calculation of supply chain emissions, PAS 2070 recommends using an EEIO model, which can provide spending (final demand) of households and government, as well as business capital expenditure, based on financial flow data from national and regional economic accounts, which are combined with GHG emission factors for each sector/consumption category, depending on the origin of goods and services (local, national or rest of the world, RoW) (C40 2018). The methodology used GTAP – a global MRIO database (see section 5.2.2) – to build an EEIO model analysing expenditure of households and government, and business capital expenditure, based on financial flow data from national and regional economic accounts, and estimates GHG emissions using average GHG emissions for each sector/consumption category. As mentioned, this is a top-down approach to calculated GHG emissions associated with resident population (excluding visitors).

Expenditure-based methods can combine IO data on economic flows, value of goods and emission factors at national level with household expenditure at local level. However, CB approaches based on household expenditure data alone may exclude significant emissions associated with governments, public buildings, infrastructure and capital goods, and services/investments (Balouktsi 2020). There are alternative accounting approaches to consumption-based inventories in relation to how they allocate imports for intermediate consumption, related to the shared allocation of emissions among producers (Peters 2008).

5.2.2 MRIO databases

Due to the complexity and resource requirements involved, MRIO databases have been typically developed by research consortiums over several years.

The Global Trade Analysis Project (GTAP) has developed a global trade database released in several versions over the years (Andrew and Peters 2013), from which a MRIO model can be constructed. The University of Groningen led the development of the World Input-Output Database (WIOD) (Timmer et al. 2014), while a consortium of various European research institutions developed EXIOBASE¹⁵ (Stadler et al. 2018). Researchers at the University of Sydney have developed and published the Eora26 database (Lenzen et al. 2012, Lenzen et al. 2013). Other MRIO databases include the inter-country MRIO database of the Organization for Economic Co-operation and Development (OECD) ICIO (Yamano and Webb, 2018; Yamano et al. 2023) and GRAM (Wiebe et al., 2012).

¹⁵ The EXIOBASE database (www.exiobase.eu) was specifically developed for assessing issues of resource efficiency – it provides details on resource intensive product groups, economic sectors, and trade flows, which link extraction of resources from nature, processing, final consumption and emissions (Tukker et al. 2016).

Available MRIO databases may be associated with different strengths and weaknesses. A MRIO database for GHG accounting and monitoring should be global and cover a consistent time series; it should also be as detailed and disaggregated as possible in terms of economic sectors and geographic regions (Cabernard and Stephan 2021). EXIOBASE3 and Eora26, for example, are publicly available databases with harmonized country and sector resolution, covering a large set of environmental pressures with time series from 1995 to 2015 (Cabernard and Stephan 2021). However, the development and update of MRIO databases is data and resource-intensive, which can result in limited availability of recent data, and limit their applicability for supporting GHG mitigation action and promptly monitoring progress at city level.

Box 7. IO analyses of GHG emissions associated with EU cities and regions

Allan et al. (2023) presented a framework to downscale IO tables to city-level and used them to calculate production- and consumption-based carbon accounts at city level simultaneously, both for area- and person-based perspectives. The framework was applied to Glasgow, Scotland, for 2014, and the results highlight importance of data quality and local context-specific knowledge. It used the publicly available World Input Output Database (WIOD). The authors perform this step both for a production and a consumption-based perspective simultaneously, using the same data sources/inputs to produce two inventories. WIOD provides estimates of emission intensity of individual sectors at national level, which are applied to represent emissions intensity of the same sectors at city level.

The results compared three alternative ways to downscale national emission intensities to reflect local context, while preserving the national overall emissions, and show how these approaches influence the results (Allan, Connolly, and Maurya 2023). GHG emissions were: 3 703 kt CO₂ for the production-based approach, 6 500 kt CO₂ (76% higher) for the area- and consumption-based approach, and 4 575 kt CO₂ for the person- and consumption-based approach. The latter used household final consumption, and excluded final demand of the public sector.

Carbon footprints of consumption of goods and services were developed by Dawkins et al. (2024) at municipal level in Sweden (and postcode level). Top-down approach using EXIOBASE and downscaling national data to municipal and postcode level, population-based approach (focus on residents). Testing downscaling approaches, identify hotspot categories and variation across municipalities. Results show high variability (national average 6.3 t CO₂-eq/capita, cities ranging from 3.7 to 17.8 t CO₂-eq/capita). Strong correlation between income and carbon footprint.

Ala-Mantila et al. (2013) estimated GHG emissions with a consumption-based EE-IO model using expenditure data, including “direct and indirect LC GHG emissions either home or elsewhere, associated with consumption of products and services”. The analysis combined data from a Finnish household budget survey with the EE-IO model ENVIMAT, based on the Finnish economy. The average annual per capita emissions of a Helsinki Metropolitan dweller was 13.5 t CO₂-eq, ranging from 12.6 to 14.3 t CO₂-eq.

Tukker et al. (2016) performed a MRIO-based comparative analysis of EU and non-EU national footprints for carbon, water, land and materials and, through a hotspot analysis, concluded that final consumption of food, transport and housing should be prioritized for reduction efforts along the life-cycle.

5.3 Other potential methods and data sources

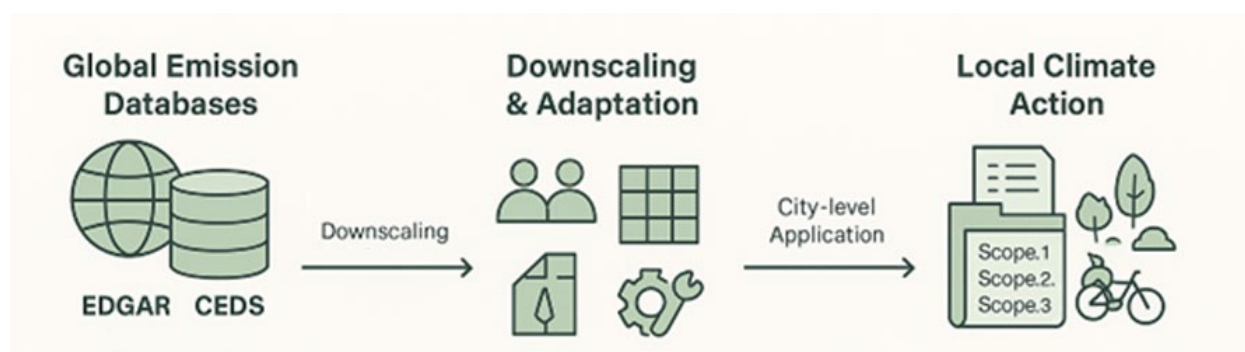
Global granular emission databases are typically developed using national-level GHG and activity data, which are downscaled to finer spatial resolutions (e.g., region, city, or grid-cell level) through top-down methodologies. These databases may offer valuable resources for constructing city-level GHG inventories (Oda et al., 2018; Asefi-Najafabady et al., 2014; Crippa et al., 2021; Gilfillan and Marland, 2021; Hoesly et al., 2018; McDuffie et al., 2020; WMO, 2022). Reference databases include for example: OpenData Inventory for Anthropogenic CO₂ (ODIAC), Fossil Fuel Data Assimilation System (FFDAS), Emissions Database for Global Atmospheric Research (EDGAR), Carbon Dioxide Information Analysis Center (CDIAC), and Community Emissions Data System (CEDS).

While such databases ensure global consistency and comparability, their robustness and accuracy depend heavily on the availability and quality of the data used for disaggregation, as well as the methodological choices made for downscaling. A combination of techniques has often been applied, including:

- Use of surrogate data, such as emission factors or proxy activity data, that represent the emission-generating context;
- Interpolation, which estimates missing values between known data points; and
- Extrapolation, which projects trends beyond the available data series.

Furthermore, observational data, including satellite measurements, have been increasingly used to derive both emission estimates and activity-based data. The IG3IS guidelines (WMO, 2022) provide a comprehensive list of relevant datasets grouped into four key categories: emission magnitude, spatial distribution, temporal distribution, and uncertainty. This growing ecosystem of harmonized global datasets can be key to bridge between global knowledge and consistency, with local action. Figure 4 illustrates this flow and sets the stage for a deeper look into two of the most widely used datasets: EDGAR and CEDS.

Figure 4. From global GHG emissions data to city-scale actions.



Source: JRC elaboration

5.3.1 Emissions Database for Global Atmospheric Research (EDGAR)

EDGAR has become one of the most widely used databases of anthropogenic GHG emissions across the globe. EDGAR offers high-resolution emission data from 1970 to the present, across various sectors including energy, transport, industry, agriculture, and waste (Oreggioni et al. 2022; Oreggioni et al. 2021; Janssens-Maenhout et.al., 2019). Its sectoral and spatial detail supports not only national and global inventories, but also city-level assessments and integration with bottom-up approaches.

EDGAR plays an essential role in supporting urban GHG accounting by offering accessible, comparable, and policy-relevant data. It supports cities in understanding their emission profiles, setting climate targets, and evaluating policy impacts—even in the absence of granular local data. One of its key features is the high spatial resolution of its gridded data ($0.1^\circ \times 0.1^\circ$), which provide the possibility to overlay cities' administrative boundaries with EDGAR's datasets to estimate emissions occurring within their jurisdiction (scope 1).

EDGAR serves as a benchmark tool for estimating Scope 1 emissions, such as fuel combustion from residential and commercial buildings, road transport, and local industrial activities. These emissions are estimated using a globally consistent methodology based on IPCC Tier 1 methodology with some Tier 2 methodology penetration as in the case of enteric fermentation emissions from cattle, ensuring comparability across regions, and over time (Crippa et al. 2024).

For Scope 2 emissions—indirect emissions from the generation of electricity and heat consumed within the city—EDGAR provides emissions from power generation facilities, which can be combined with local

consumption data to approximate a city's energy-related indirect emissions. To date, EDGAR does not estimate Scope 3 emissions.

Although EDGAR is designed for national-scale applications, it has been applied to sub-national and urban-level studies due to its open access, methodological transparency, and regular updates. It has been used by a wide range of stakeholders, including researchers, policymakers, and local authorities. The dataset also contributes to the Global Stocktake process under the Paris Agreement, offering a science-based perspective on emission trends and helping to identify data gaps in national and subnational reporting.

Despite its strengths, EDGAR is not without limitations, particularly when applied at the city scale. The spatial resolution, while relatively fine for a global dataset, can still be too coarse for smaller urban areas or for isolating emissions from closely adjacent cities. In addition, the disaggregation of national activity data to grid cells may introduce uncertainties when compared to bottom-up models. For example, while EDGAR may allocate industrial emissions uniformly within an industrial region, a city with a high concentration of energy-intensive industries may find discrepancies between EDGAR estimates and its own detailed inventory. As a result, EDGAR is best used as a starting point, for screening or validation for urban GHG accounting, ideally complemented by locally derived data, such as energy consumption, traffic counts, and industry-specific reports.

Despite these limitations, EDGAR remains a foundational resource for supporting transparent, consistent, and comparable GHG accounting at all levels of governance. By providing a harmonized framework for emissions estimation, it enhances the robustness of climate action planning and supports the alignment of local initiatives with national and international climate goals.

EDGAR can play an important role in validating and benchmarking self-reported emissions data submitted by cities under international initiatives. For example, in Franco C et al. (2024), EDGAR was used to compare and assess the consistency of GHG emissions reported by cities participating in the CoM. The integration of EDGAR's high-resolution emission data provided an independent reference point to evaluate the quality and usability of CoM datasets. This application supports greater transparency, improves the credibility of self-reported data.

5.3.2 Community Emissions Data System (CEDS)

CEDS¹⁶ is a valuable open-access resource that provides consistent time series of historical anthropogenic emissions. Designed to address gaps in long-term emissions trends, CEDS offers annual estimates from 1970 to the present. These estimates are aligned with IPCC categories and include detailed sectoral and fuel-type breakdowns for a broad range of GHGs.

Similar to the EDGAR database, CEDS compiles national energy and industrial statistics and combines them with emission factors to estimate emissions across countries and sectors. To spatially distribute emissions on a grid, it employs proxies such as gridded population data and night-time light imagery, enabling a sub-national spatial resolution.

Although not developed specifically for city-level applications, CEDS can be a useful tool in supporting urban GHG inventories. It provides historical baselines, helps validate emission trends, and offers insights into broader emission patterns. This is particularly valuable for cities lacking comprehensive local data, as CEDS supports top-down modelling approaches and helps bridge data gaps. However, the system's national-scale, territorial focus and its reliance on spatial proxies are important limitations in its application to cities.

¹⁶ <https://www.pnnl.gov/projects/ceds>

5.3.3 Ecodesign impact accounting (EIA)

The Ecodesign Impact Accounting (EIA) provides data on products regulated under the Ecodesign, Energy Labelling, ENERGY STAR and Tyre Labelling schemes (EC, 2021c). EIA can be a source of consumption data for the EU: it includes sales and stock of a wide range of product groups (299 base case products from 41 product groups), as well as the associated energy consumption, GHG, consumer expenses and business revenues for the years 2010 and 2030. Products are organized in 12 categories, namely: space heating, space cooling, water heating, ventilation, lighting, electronics, food preservation, cooking, cleaning, industry components, transport (tyres) and energy sector (utility transformers). Bills of Materials (BoM) are defined for typical products, such as:

- Building installation products (incl. space and water heating, air conditioning, lighting products);
- Electronic products (e.g., displays, computers);
- Appliances (e.g., refrigeration, washing, cleaning);
- Industrial and other products (e.g., fans, motors, equipment, pumps); and
- Other household consumption (e.g., sales & stock, energy consumption, expense savings).

BoM provide insight on the materials used in sold or installed products, which can be linked with material flows (linking to MFA or LCA approaches), for developing consumption-based inventories. Multiplying the BoM weights per material category (metals, plastics, electronics, etc.) by the EIA-sales or –stock, the total amount of materials contained in sold or installed products is obtained. District heating and very large appliances (e.g. boilers over 400 kW) are not covered.

5.3.4 Direct observation of GHG data

Methods for quantifying GHG emissions include local activity-based estimates, process models and direct observation-based estimates (e.g., observation of atmospheric GHG concentrations at ground level or from space-based platforms). Advances in observation tools to track activity levels and GHG concentrations have increased accuracy and granularity of GHG inventories, increasing local and sector-specific details (WMO, 2022).

Observational approaches add information that can be helpful for particular applications and targeted mitigation action. They can provide important insight to provide geographic and temporal resolution, e.g., to identify key locations or emission sources, or insight on daily or seasonal patterns (WMO, 2022). Direct atmospheric observational approaches can be applied directly, without requiring significant computational modelling. Lastly, observational approaches are particularly strong/effective for communicating with and engaging stakeholders and civil society – as they may be considered more reliable and easier to grasp to a wide range of stakeholders, and visually impactful (WMO, 2022).

Atmospheric concentration measurements can offer reliable and accurate insight on concentrations, but their application in GHG emission accounting is challenging: the link between concentrations and emission sources needs additional modelling and data requirements. Moreover, concentration measurements reflect mostly scope 1 or nearby emission sources (without distinguishing production- and consumption-based emissions), without correspondence to ‘administrative boundaries’, and include background sources (e.g., emissions from sources upwind). Background influence is a large source of uncertainty in urban studies (WMO, 2022). Important aspects that can be addressed by combining methods and data (in particular process models and observation-based data) include: spatial and temporal granularity, continuous and near real-time monitoring, reducing uncertainty.

For example, a municipality may test an action restricting traffic in an urban area for a short period of time (pilot action), and use observation-based tools to evaluate and show its potential benefits in terms of GHG and air pollution reduction, in a prompt and compelling manner. This can be valuable both to inform policymaking, and to engage stakeholders and the wider civil society, increasing acceptability and uptake.

5.4 Strengths and limitations of available methods and data

Developing comprehensive, accurate and detailed city-level GHG inventories is crucial to support effective local action; however, activity and GHG emission data at this level is limited. When quality 'real world' site-specific data is unavailable, proxy data, simplifications and assumptions may be necessary, which may result in significant loss of accuracy and robustness. With the need for immediate and effective climate change mitigation action, a compromise needs to be found to provide accurate, robust and detailed data in timely, transparent and reasonably accurate inventories.

This section presented a non-exhaustive overview of methods, approaches and data sources relevant and applicable in the context of EU initiatives such as the Cities Mission and the CoM EU, for modelling and developing more comprehensive GHG inventories. These methods include top-down, bottom-up and hybrid approaches, covering mass-based (e.g., MFA, LCA) and economic (e.g., MRIO) tools and data. In view of developing a framework in the future, it is important to understand the main strengths, advantages, disadvantages and limitations of these methods and approaches and, for example, how they vary in terms of resource requirements (incl. expertise, time, data).

As mentioned, GHG accounting approaches have typically followed a territorial-based approach, using bottom-up modelling with limited scope and boundaries – for example, for scope 1 and 2 of main key sectors. These tend to draw on simple and well-established calculations, with relatively easy and fast application, and with reasonable data availability and quality, which can be associated with lower uncertainty. However, these might exclude an important share of GHG emissions and relevant information to support climate change mitigation action.

On the other hand, as we aim for a more comprehensive coverage of GHG emissions (e.g., IPPU, AFOLU, transboundary transportation, upstream and downstream emissions) data availability and reliability might be very limited and inventory modelling can become more complex and associated with higher uncertainties. Inventories with more limited coverage (main sectors, scope 1 and 2) may also have easier interpretation by a wide range of stakeholders and increased comparability, as well as the potential for aggregation with GHG inventories for other regions. In fact, only scope 1 emissions allow for the direct aggregation of multiple cities' inventories.

Bottom-up process-based methods, such as the consumption footprint, keep a strong and clear link between activities and emissions, in line with current common GHG accounting practices, while providing a life-cycle perspective. They rely on activity data and mass-based flows, potentially keeping a reasonable level of accuracy at high disaggregation levels. Moreover, LC-based methods have the potential to generate, with minimal or no additional data and effort, an integrated environmental impact assessment including not only GHG emissions, but a wide range of environmental impacts and categories, informing on potential burden shifts, trade-offs or co-benefits (Hellweg et al. 2023).

Nonetheless, bottom-up process-based LC methods have high data and other resource requirements, and given the complexity of cities, and the diversity of activities and flows (urban consumption is now linked to all the world through global value chains), their application in consumption-based approaches has been considered unpractical. Moreover, these methods suffer of truncation errors, which result from the need of defining limited system boundaries, and cutting off processes and emission sources (Wang and Chen 2018).

IO-based methods offer a complete and consistent overview of production and consumption flows and their GHG emissions, with complete system boundaries (no truncation). When EE-IO tables are available, developing GHG inventories can be relatively simple and involve fast calculations (Alamantila et al. 2013; Tukker et al. 2016). Limitations of IO-based accounting include (Balouktsi 2020; Tukker et al. 2016; Heinonen et al. 2020):

- aggregation errors (i.e., sectors with varying emission profiles aggregated into one sector);
- assumptions on linearity of scale and product homogeneity;

- assumptions on technologies associated with production of imported goods; and
- frequency of data updates.

Essentially, products with different physical characteristics and supply chains are grouped in monetary flows, without insight on the group composition, and an emission factor is applied for an ‘average emission profile’, which can result in very high uncertainty (monetary values per physical mass or weight, and GHG emissions per monetary unit value are highly variable) (Xu et al. 2023). Moreover, EE-IO databases tend to have relatively low levels of spatial and sectoral disaggregation, i.e., a wide range of products are grouped into a limited number of sectors (Cabernard and Stephan 2021).

High levels of sectoral disaggregation and detail based on real data can improve accuracy and relevance of GHG emission results; however, IO-based models with increased disaggregation based on further modelling and data processing, can have higher data requirements and uncertainty (Xu et al. 2023). For example, Cabernard and Stephan (2021) proposed an automated, transparent, and comparably time-efficient approach to improve the resolution, quality, and indicator coverage of EXIOBASE3 – the authors disaggregated data spatially by weighting each element with country and sector specific shares, derived from complementary data sources. The significance of spatial and sectoral aggregation errors in MRIO analyses have been studied (Cabernard and Stephan 2021; Su et al. 2010; Xu et al. 2023), with a wide range of results. Nonetheless, research suggests that the limited spatial or sectoral detail in MRIO data may be acceptable for GHG emission accounting, while they may be too inaccurate for informing on other environmental issues, such as water scarcity or land use impacts, for example.

Regarding global granular emission databases, until EDGAR (or other reference databases) develops data to account for scope 3 emissions – i.e., on a multiscale allocation of global emissions, mapping not only where emissions occur, but the location of production and consumption activities driving them – these sources remain valuable, together with observation-based data, for improving and validating territorial-based approaches.

5.4.1 Combining methods, tools and data

Territorial-based GHG inventories focused on scope 1 and 2 emissions exclude a significant share of GHG emissions associated with cities. As a result, important opportunities for local action to shape and tackle GHG emissions – which are crucial to achieve EU’s ambitious mitigation goals and targets – may be overlooked. A shift toward more comprehensive GHG inventories at city level in GHG accounting and mitigation action is needed.

Typically, GHG accounting at city level in the EU has mostly relied on relatively simple process-based modelling, and the availability of activity data and emissions factors that are representative of the local context already poses significant challenges to many cities, which have hindered regular (annual) compilation of inventories and monitoring of GHG mitigation progress (Melica et al. 2024). The development of more comprehensive GHG inventories including out-of-boundary emissions of global supply chains can significantly increase the complexity and data requirements of GHG accounting. At this stage, and with the currently available tools and data, widespread application of process-based methods to develop comprehensive GHG inventories appears unfeasible in the short term.

In this context, top-down approaches (IO-based or downscaling from global GHG databases) can offer important opportunities: they may provide a faster and more comprehensive overview of GHG emissions associated with cities. However, these approaches typically offer limited disaggregation and detail, which are essential to support local action, and steps toward disaggregation often come with very high uncertainty. However, recent and regular IO data availability may also be a challenge for many EU cities.

While the different methods, tools and data were described separately, combining them may offer important opportunities to leverage their advantages and strengths, and to overcome their (individual)

limitations, including complexity, time and data requirements. Moreover, some approaches offer limited coverage, e.g., only household consumption in the case of IO methods using household expenditure, and in the case of the consumption footprint.

To overcome limitations of IO-based accounting, researchers have proposed combining IO models with process-based LCI data in hybrid approaches (Balouktsi 2020). They may be combined with different levels of integration. IO-based methods and data may be used for screening and to provide the overall context, and the efforts of more detailed process-based modelling can then focus on some sectors, activities or components of GHG inventories. For example, if a city has significant GHG emissions associated with residential buildings, a detailed process-based LC inventory can be developed for this sector, but the overall GHG emissions of the city can be estimated with a IO approach, to provide an overall understanding of how significant this sector is, and the relative potential of actions targeting this sector within a wider comprehensive perspective.

6 Good practices: Boosting GHG mitigation across the EU

This section provides examples from the Cities Mission where cities included in their Climate City Contracts (CCC)¹⁷ an ambition to go beyond common practice, taking a step further to address trans- and out-of-boundary emissions that have been typically excluded in city-level GHG inventories and mitigation action. Such examples demonstrate the motivation and interest of cities across the EU, and the feasibility of implementing effective actions, beyond common practice.

As mentioned, Mission cities have typically focused on scope 1 and 2 emissions, and to a certain extent on scope 3 emissions associated with the treatment of waste generated in the city (downstream emissions). Nonetheless, many cities have included actions that may reduce scope 3 emissions, such as circular economy actions that aim at increasing resource efficiency, promoting the use of lower emission materials, and preventing waste generation, for example. Some of these cities have already started developing consumption-based GHG inventories – in some cases these are included in their CCCs, in other cases they are mentioned but not included. Many practitioners among Mission and CoM EU cities have mentioned challenges related to the lack of accounting guidance, indicators and tools to monitor the impacts of actions tackling scope 3 emissions.

6.1 Climate change mitigation action

This section illustrates examples of GHG mitigation actions addressing trans- and out-of-boundary emissions from the Cities Mission. Virtually, all climate change mitigation actions undertaken by cities might affect out-of-boundary emissions, as cities are highly linked and dependant on other regions. Any change in demand, production or use phases in urban systems is likely to affect upstream or downstream processes that occur outside the city boundaries. We focus on advanced practices and initiatives that have the potential to significantly reduce GHG emissions that have seldom been tackled in climate change mitigation action at city level. Sectors that can be particularly important to tackle out-of-boundary emissions include, for example, food, construction (including buildings and civil construction) and transportation.

For *food*, the relative contribution of the supply chain of food products can dominate their life-cycle GHG emissions. Recent research has shown how changes in diets, supply chains, and agricultural practices can significantly reduce impacts associated with food consumption in France by 2050 (Deteix, Sarlou and Loiseau, 2025).

In relation to *buildings*, actions tackling energy efficiency and RES electricity generation have significantly reduced the GHG emissions associated with their use phase, which has been the dominant LC phase in typical buildings in the EU building stock. However, such actions tend to increase the relative significance of embodied GHG emissions. Construction material requirements are often associated with significant (and increasing) GHG emissions in urban areas, and the potential of CE in this sector can be an important area of intervention at urban and regional level.

Transportation differs from food and buildings, as its significance in terms of out-of-boundary emissions is mostly related to the transboundary nature of transportation activities. In other words, while food and construction can have significant embodied (upstream) emissions, increasing ambition and action in relation to transportation may be significant because of the demand associated with cities taking place outside the territory – a significant share of direct emissions from transportation may take place outside cities, as it is the case in inter-city, regional and international travel (e.g., commuting, shipping, rail and air travel).

¹⁷ 2030 Climate Neutrality Action Plans referenced can be accessed online through the Knowledge Repository function of the NetZeroCities Portal (<https://netzerocities.app>), in the cities' Climate City Contracts (CCC).

6.1.1 Bergamo

Bergamo's climate change mitigation actions are strengthened by the city's CE action plan, which builds on three main areas:

- Construction, including the recovery and re-purposing of existing property, new buildings with special attention on those undergoing de-construction and demolition, as well as on the design and choice of materials and in situ technologies;
- Food, addressing prevention and management of waste, reduction of upstream losses, and maximised downstream circularity;
- Consumer goods, promoting recovery, reuse, repair and resale of products.

Drawing on its CE action plan, Bergamo proposed several GHG mitigation actions to reduce scope 3 emissions, for example:

- tackling the reduction of disposable plastic and promoting biodegradable materials;
- promoting behavioural changes in reusing, recovering and recycling practices through awareness actions;
- increasing shares of vegetarian food in school menus, in particular vegetable sources of protein to partially replace animal protein sources; and
- developing energy efficient buildings in 'bio-districts' that integrate energy efficiency and RES, and promote wood as the primary construction material.

With these actions, the municipality can potentially reduce upstream and downstream GHG emissions, associated for example with the supply chain of construction materials and products, from raw material extraction and processing, to packaging and transport, and of food, for example, by reducing the consumption of food products that have particularly GHG intensive supply chains.

Notably, the Municipality has engaged a network of companies and stakeholders who operate within or in partnership with the city, but are physically based outside municipal borders. These partners are estimated to offer a reduction of roughly 9 kt CO₂-eq. The city highlighted the lack of data and guidance as a critical barrier to implement and monitor CE actions.

6.1.2 Gävle

Gävle's stands out for its ambitious target of achieving climate-neutrality of consumption-based emissions by 2035, including air travel. Its action plan prioritizes two lines of intervention:

- in the transport sector: strengthening the transition to sustainable modes of travel such as public transportation, cycling, walking, and low-emission vehicles.
- in the construction sector: tackling emissions originating from steel, cement, and transportation of materials. The municipality aims to introduce mass management, construction material logistics, and set higher standards for fuel, materials, and recycling in construction.

The action plan considers a comprehensive consumption perspective. Consumption-based emissions were estimated with the Swedish Consumption Compass (see section 6.2.1): approximately 6 t CO₂-eq per person, of which around 60% are associated with household consumption, and 40% from the public sector and investments. Public consumption consists of goods and services, such as those purchased by schools, hospitals, and authorities to conduct their operations. Investments encompass emissions related to the purchase of buildings, machinery, computers, valuables, and inventory investments. Consumption-based emissions are dominated by Transport (41%), Food (20%) and Housing (18%), followed by Restaurants, hotel and other recreational activities (11%) and by Clothing and footwear (4%).

Concerning construction, the Action plan highlights that a significant share of GHG emissions is currently occurring beyond city boundaries (scope 3), in particular associated with production of building materials. To tackle these emissions, the city calls for regulatory actions and legal requirements to lower GHG emissions. All new construction projects should aim for climate-neutral buildings by 2035 – which is particularly important in a city that is currently undergoing significant development – building on life-cycle-based requirements to support material selection in new construction and refurbishment projects. Incentives and collaborative projects are needed to engage stakeholders from the private sector and to develop a strong market for used building materials.

The city also adopts a range of actions tackling final consumption and promoting CE. However, it highlights that more ambitious GHG mitigation actions can be developed when adequate indicators for monitoring consumption and air travel are available. Lastly, the action plan highlights (i) the need to increase accountability in relation to resource efficiency and the circular economy, (ii) the potential contribution of technological developments to reduce embodied GHG emissions, and (iii) the importance of raising the political priority to address consumption-based emissions at national and EU level.

6.1.3 Helsinki

Helsinki was the first city in Finland to introduce, in 2023, a limit value for GHG emissions of new residential construction with a life-cycle perspective. This requirement reflected the city's ambition to tackle GHG emissions associated with residential construction. In the future, the aim is to set limit values also for other sectors/categories.

The process was carried out by first researching over 60 buildings to determine what determines and contributes to GHG emissions of buildings (e.g., materials, heating systems). The city then held a competition for a low-emission residential building, judged 50% for architectural merits and 50% for low carbon footprint. The three winning buildings reached a very low carbon footprint through various combinations (wood frame/low emission concrete frame, solar panels, heat pumps, green roofs, among others). The three will be built in Helsinki. The competition engaged many companies and sparked dialogue and collaboration, and the results informed the new limit, which was set to 16 kg CO₂-eq/m²-year, in a 50-year timeframe.

6.1.4 The Hague

The Hague proposed several actions to tackle scope 3 emissions, including:

- Transboundary travel: collaborating with employers to incentivise alternative commuting modes, to reduce congestion on regional highways by 5%.
- Circular economy: efforts to reduce the demand for new materials and fossil fuels, increasing biotic and reused materials in the construction and industry sectors. These include developing circular wood chains to reuse and recycling of wood materials, creating a hotline for resource sharing to encourage collaboration and reduce waste, and building a coalition to foster eco-friendly practices in the textile industry.

The city underscores that to strengthen the alignment of circular economy measures with the Coalition Agreement 2023-2026's goals, the benefits and value added by these actions would need to be analysed in detail. The intention to include CE indicators in the future is identified as the next step to broaden the scope of their climate-neutrality commitment and action.

6.1.5 Kranj

Kranj is proactively addressing scope 3 emissions and extending action to neighbouring municipalities and the wider NUTS 3 Gorenjska region.

- Transboundary travel: the city's action plan considers strategic infrastructure projects aimed at improving traffic flows in the region, reducing congestion and emissions associated with idling and longer commuting travel. By shortening travel distances and times, a significant reduction of GHG and air pollutant emissions could be achieved in the region, benefitting both Kranj and surrounding areas. The city underscores the importance of integrated planning, involving urban development decision-makers, but also regional and national governments, in achieving environmental and transport efficiency objectives. Moreover, the city's smart multimodal public transport system, the "One Car by Household" initiative, and complementary actions (i.e., free city bus, free city bike) aim to reduce reliance on personal vehicles, thus impacting the indirect emissions associated with local and regional travel. Key stakeholders have been involved in the city's ambitious integrated approach, such as neighbouring municipalities, major business parks in Kranj, and the National Airport.
- Construction sector: there is a multi-objective approach to building retrofits, considering GHG emissions across value chains. By complementing energy efficiency with measures to improve buildings' lifespan, the city can reduce demand for new construction materials, reducing GHG emissions associated with manufacturing and transport of materials.
- Circular economy: the action plan also includes a zero-waste programme, which aims at minimising waste generation but also material and energy demand. Actions that can reduce scope 3 emissions include for example the promotion of local purchases with minimum or no packaging, banning printed advertisement, the implementation of environmental standards and zero waste events to reduce also emissions associated with tourists in the city. The creation of a one-stop-shop for waste reduction and resource management to reduce demand for new raw materials and waste generation, through initiatives including re-use workshops, tools exchange, and a car cleaning facility using recycled water from the nearby wastewater treatment plant.
- Food consumption: Kranj's urban agriculture program aims to promote local food consumption (e.g., from small suburban farms and urban green spaces). A "Farm to Fork" program includes important initiatives, e.g., daily local food distribution and improving farmer skills in vegetable production.

6.1.6 Porto

The city of Porto shows strong commitment to CE action, supported by EU-funded R&I projects. A Centre for Circular Economy of the City of Porto is being created. Overall, the city considers addressing consumption-based emissions (i.e., reducing resource consumption and promoting circular practices) in terms of goods and services (such as food, clothing, electronic equipment, building construction, transboundary travel journeys) by proposing actions targeting emissions reductions in related sectors. For example, the city's actions in the waste sector, including the City Loops project and ReBoot Porto, target an increased re-use of products.

In transport actions, the city stands out for reflecting on the out of boundary impact of its ambition to electrify the freight fleet, including heavy long-distance road intercity transport of passenger and freight operations.

6.1.7 Milan

Milan's commitment to CE principles is evident throughout its action plan, with the intention to address supply chain emissions and consumption practices, to promote sustainability beyond direct municipal control. The city targets the reduction of raw materials consumption across diverse sectors, such as food, urban construction, and packaging for home delivery and e-commerce.

The action plan includes measures to tackle GHG emissions beyond common practice, for example:

- the CE action plan considers green criteria for public procurement and events, as well as launching a pilot project to develop an environmental and social multi-label for Hotel, Restaurant, and Catering (HoReCa) operators.
- the C40 Clean Construction Accelerator promotes sustainable buildings, through renovation over new construction, incentivising circular design, zero-emission machinery, and low-carbon materials in procurement contracts;

The action portfolio also addresses energy-related emissions concerning air travel, associated with the Milano Malpensa airport, which is outside the city boundaries. There is commitment from SEA Airporti SpA, the company managing Milan's airports to lead GHG emissions reduction efforts building on sound stakeholders' engagement.

6.1.8 Gothenburg

Gothenburg is at the frontline of CE practices, with ambitious GHG emission reduction goals, including scope 3 emissions. For example, the city employs digital twin technology for future food system planning, the Smart Map platform to support circular economy efforts, and it applies the Swedish consumption compass (see section 6.2.1) to estimate citizens' GHG emissions with a consumption-based perspective.

The city proposed actions to enhance resource efficiency, reduce consumption, and address emissions beyond direct municipal control and borders. To target hard-to-abate sectors like industry, refineries, port activities, and waste incineration, Gothenburg incorporates comprehensive CE strategies across various sectors, and it proactively engages in R&D and participatory projects. The city aims to reduce construction climate change impacts by up to 90% by 2030.

6.2 GHG emission accounting

6.2.1 The Swedish consumption compass

Swedish cities, such as Umea, Gävle, Helsingborg and Gothenburg, have complemented their territorial-based GHG inventories with insight on GHG emissions associated with household consumption, drawing on the Swedish consumption compass.

The Swedish consumption compass¹⁸ is an excel-based tool of the Stockholm Environment Institute (SEI), which provides data on GHG emissions associated with household consumption at national, city and postal code level. Consumption-based GHG emissions are calculated for more than 100 activities grouped in: food, clothing, housing, health, transport services, air transport, communication, recreation, education, restaurants and hotels, vehicles, electricity, district heating, house heating, and "other".

¹⁸ <https://www.sei.org/features/consumption-compass-impact-households/>

The tool builds on methods and data for the consumption-based emission model at national level developed under the PRINCE¹⁹ research project, and on the UNLOCK²⁰ research project, which examined Swedish municipalities' consumption at municipal level.²¹ GHG emissions associated with investments and the public sector are excluded.

The project is recognized as an essential step to reducing consumption-based household emissions: by mapping emissions at postcode level, municipalities and other stakeholders are better informed and equipped to design targeted effective policies and actions. Sweden's consumption-based GHG emissions average 9 t per person,²² but the consumption compass shows how unevenly distributed these are among households, ranging from 3.5 to 18 t CO₂-eq per person.

6.2.2 Porto and Kranj: accounting for transboundary transport emissions

Porto and Kranj have each taken their territorial-based GHG inventories beyond common practice, by including associated with transboundary transport. Both cities employed bottom-up methodologies to capitalised on local transport data (from surveys, traffic counts).

Porto has estimated the emissions from journeys that occur due to commuting outside the city boundary, including from passenger and freight activities, using data from the Porto's Metropolitan Area Mobility Survey and the Portuguese Directorate-General for Energy and Geology (DGEG). The survey helped to first differentiate between trips made in private vehicles within and outside the city and subsequently between scopes (scope 1: emissions from fuel combustion that occur within the city; scope 2: grid-supplied energy consumed in the city for on-road transport; scope 3: emissions from transboundary journeys that occur outside the city). Additionally, DGEG provides detailed annual data on electricity, natural gas consumption, and fossil fuel sales at the municipal level, segmented by sector. This comprehensive public database enables the assessment of energy consumption and GHG emissions in the transport sector, enabling also an account of residual consumption of electricity and oil for waterborne navigation and aviation purposes.

Kranj has considered aircraft operations at the airport, which is located outside the city boundary, using publicly available data from the Slovenian Infrastructure Agency's on key variables. The inclusion of emissions from airplanes during their landing and take-off cycles both in the inventory and in the city's climate neutrality target reflects an understanding of the airport's significant role in the region's transport dynamics and its impact on overall emissions.

6.3 Learning from Mission cities

The examples provided in this section are not exhaustive, they are a small selection of illustrative actions that can serve as inspiration in the pathway toward more comprehensive GHG accounting and mitigation action at city level. Nonetheless, these and other examples across the Cities Mission and the CoM show (i) an increased awareness of the significance of scope 3, trans- and out-of-boundary emissions among EU cities; (ii) the ambition to pursue more comprehensive GHG mitigation action; and (iii) the challenges that cities have identified, and in particular the need for guidance and data. While significant challenges need to be overcome, many cities and stakeholders have been pushing towards

¹⁹ Policy-Relevant Indicators for National Consumption and Environment (PRINCE): <https://www.sei.org/projects/prince/>

²⁰ Understanding local government drivers for sustainable consumption (UNLOCK): <https://www.sei.org/projects/unlock-sustainable-consumption/>

²¹ the approach and methods are linked also to the USDN CBEI tool: <https://sustainableconsumption.usdn.org/climate/cbei-guidebook/cbei-prioritization-tool#overview>

²² <https://www.naturvardsverket.se/data-och-statistik/konsumtion/vaxthusgaser-konsumtionsbaserade-utslapp-per-person>

more comprehensive and integrated GHG mitigation efforts at all levels, from individual and local, to national and global scales.

The expansion of scope and boundaries in climate change mitigation action, and in sustainable development in broader terms, is clearly reflected in the increased recognition of the circular economy as key to reduce mitigate environmental impacts, beyond energy efficiency and direct operational emissions. Cities across the EU have developed and implemented Circular Economy Action Plans aiming at high resource efficiency, low material demand and waste prevention, among other goals. While these are closely related to upstream and downstream processes and emissions, cities need tools, data and indicators to support and monitor these actions.

While cities across the EU have proactively started to act on reducing GHG emissions and other environmental impacts of their activities beyond borders, their efforts must be supported by evidence. Cities need clear, harmonised and consistent data and guidance to support their efforts and enable effective action.

7 Main takeaways and recommendations

The state-of-the-art shows an increased acknowledgement of the relative significance of out-of-boundary, transboundary and trade-related emissions, and of the important opportunities for climate change mitigation that more comprehensive approaches provide. While typical territorial-based GHG accounting frameworks have provided critical insight to inform local action across EU cities, they often exclude out-of-boundary emissions, for example, associated with products' supply chains and transboundary travel, overlooking important GHG mitigation opportunities.

A shift to more comprehensive and relevant GHG inventories has been observed in recent years across research and practice at multiple levels, including national and city-level accounting, but also at organizational and product levels (Marcu et al. 2021; TCFD 2021). However, limited guidance and data is currently available for EU cities to inform their actions. There is a need for consistent GHG accounting frameworks supporting the development of more comprehensive city-level GHG inventories (WMO, 2022).

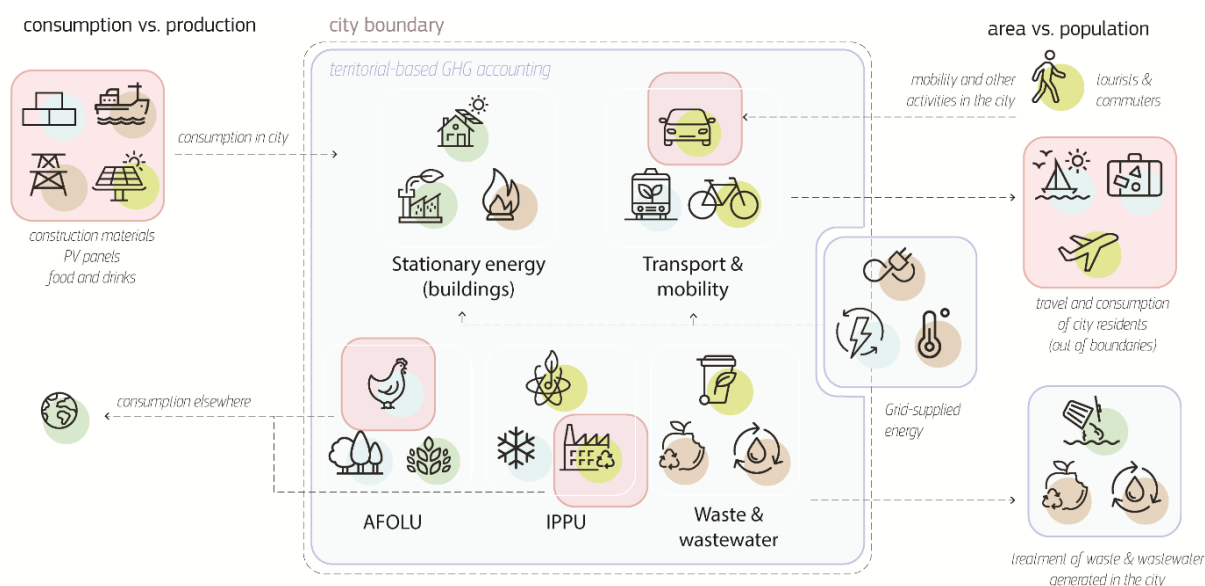
The development of more comprehensive GHG inventories including, for example, upstream supply chain GHG emissions associated with cities, can be associated with increased methodological complexity, higher data requirements, and subjective responsibility and emission allocation choices (Hung, Hsu, and Cheng 2019). Different methods, approaches and data sources are available, all with specific strengths and limitations, and cities need support to navigate through them. In particular, clarifications and consistent guidance are needed regarding methodological aspects such as scope and boundary definition, categorisation, and allocation of emissions (Balouktsi 2020). The shift to more comprehensive inventories involves methodological choices and data requirements that must be aligned with cities' needs, priorities and resources.

Drawing on this state-of-the-art, key methodological aspects should be considered to develop guidance on more comprehensive city-level GHG inventories. First, the shift from territorial- to activity-based GHG accounting, entails a separation between production and consumption activities and processes. GHG emissions from activities and processes associated with the supply of goods and services used in a city, can be allocated both to the consumption of that city and to the production emissions of the region of origin. Similarly, GHG emissions from activities and processes occurring in a city that are associated with exported goods or services, which are typically included in territorial-based inventories, can be accounted in the consumption-based inventories of other cities. Local activities and imports include emissions associated both with production and consumption, and the separation of data and emissions might bring challenges.

Second, in a consumption-based perspective, GHG emissions may be allocated and accounted for with two approaches: area- or population-based. An area-based approach considers GHG emissions associated with activities that take place in the city, including those related to tourists and commuters, while a population-based approach considers GHG emissions associated with activities of city's resident population, including travel and activities in other regions and countries, for example. This choice affects also scope 1 and 2 emission accounting. Emission allocation issues also arise in transboundary emissions associated with road travel and aviation for example.

Third, consumption-based classification and grouping of activities, processes and emissions follows a different structure than that typically used in territorial-based GHG inventories. Consumption-based data and inventories may not be easily divided into scopes, and consumption areas do not correspond to IPCC sectors. For example, waste is generated across all consumption areas, and reducing demand or consumption of food, or clothes, would reduce GHG emissions upstream and downstream, associated with production, supply and waste collection and treatment.

Figure 5. Towards more comprehensive approaches to city-level GHG accounting and action.



Source: JRC elaboration.

Fourth, a shift to consumption-based GHG approaches may be perceived as a shift in responsibility, ‘a push toward final consumers’. The IPCC Sixth Assessment Report (IPCC 2023) highlights that changing consumption patterns and lifestyles is crucial for achieving the climate change mitigation key targets. Significant opportunities for effective and prompt GHG reduction are linked in particular to behavioural changes in wealthier economies and high-income socio-economic groups, for example, to tackle overconsumption. Consumption-based emission accounting may be linked to these opportunities, as it can inform and support targeted actions in this context. However, consumption and the potential of behavioural changes are not a specific challenge of consumption-based approaches. They apply to all scopes of GHG emissions: for example, significant GHG mitigation can be achieved in many cities through the shift from private to public, or to active transportation modes. In other words, changing from territorial-approaches focusing on scope 1 and 2 emissions in city-level GHG inventories to consumption-based approaches should not be associated with a shift in the approach to tackle GHG emissions, nor in the responsibility or power of national, regional and local authorities, other stakeholders or civil society to collaboratively achieve climate change mitigation targets.

Other methodological aspects related to scope, coverage and allocation of emissions arise with the selection of methods and data. For instance, IO-based approaches using household expenditure data may provide adequate estimates of GHG emissions for household consumption, but exclude the public sector. Process-based LCA approaches also have limited coverage. On the other hand, burden shifts and trade-offs may also occur in relation to other environmental issues, as well as social and economic levels. More comprehensive inventories with a life-cycle perspective can ease integrated environmental impact assessment to inform integrated action, and in the future it can also promote the integration of social and economic dimensions.

Lastly, more comprehensive GHG accounting comes with double-counting, and limited aggregation and comparability risks. Scope 3 GHG emissions of a city are scope 1 or 2 emissions of another city or region; thus, double-counting issues and losing the ability for aggregation is an intrinsic limitation of more comprehensive GHG inventories. Perhaps more important in the context of supporting GHG mitigation action, is the risk of different organizations and regions claiming responsibility or credit for GHG emissions and their reduction. It may happen that more than one actor claims credit for the same reductions across a supply chain, for example (Marcu et al. 2021). Consistent guidance on scope and boundary definition and emission allocation in city-level consumption-based GHG inventories can improve transparency and enable effective action and monitoring.

There are approaches accounting for the total of transboundary activities, allocating emissions of a trip between two cities to both cities, therefore double-counting these emissions. There are also inventories including both production- and consumption-based emissions (Balouktsi 2020). The rationale of prioritising comprehensive and complete accounting of emissions that can be influenced/tackled by cities, at the expense of overlapping and double-counting emissions or impeding aggregation is valid, and it may simplify data and methodological requirements (e.g., not needing to distinguishing imports for final consumption and for processing and exporting of products consumed elsewhere). Balouktsi (2020) provides the example of energy storage, whose emission allocation to a production- or consumption-based perspective remains undefined. Nonetheless, we recommend that frameworks developed for EU cities enable consistent allocation and separation of these emissions, if possible.

Box 8. Inventory structure: from IPCC sectors to consumption areas - example from the buildings' sector

Buildings' GHG emissions include direct and indirect emissions: direct emissions occur during their use or operational phase, and they are primarily associated with fuel combustion for space heating and domestic hot water, and for cooking. Indirect emissions include operational emissions, associated with use of grid-supplied electricity, heating or cooling, and emissions embodied in construction materials, building products and building components. Embodied emissions include those associated with raw material extraction, product manufacturing and materials transport, for example. They may also include emissions associated with building end-of-life (e.g., demolition and waste disposal).

In the IPCC, emissions associated with buildings' operation are typically included in the 'stationary energy' sector, while emissions embodied in building materials and products, such as cement, should be included in the 'IPPU' sector, and emissions associated with waste treatment at the end-of-life should be accounted for in the waste sector. Moving away from a territorial perspective, production- and consumption-based perspectives brings challenges in relation to the sectoral structure and allocation of emissions in city inventories.

To support cities, it may be adequate (under a consumption-based perspective) that GHG emissions across the service life of buildings are all allocated within the same sector, as it may better and more directly inform on the impacts of GHG mitigation action (Huang et al. 2024). For example, energy-efficiency measures for buildings are likely to reduce GHG emissions associated with the operational stage, while increasing embodied emissions. The effective result of these actions may be clearer if these emissions are all in a 'buildings sector'.

In the longer term, a consistent and robust framework should be developed for EU cities to account for consumption-based GHG emissions. The Swedish consumption compass is a valuable example of a tool developed to provide consumption-based GHG inventories at city level, consistent and comparable across the whole country. A similar coordinated effort could be pursued at EU level – the development of a single multi-scale GHG accounting tool would be a major contribution to the support of effective and integrated climate change mitigation action at national, regional and city level.

7.1 How should EU cities move forward?

Drawing on the state-of-the-art, and on the main opportunities and challenges summarised in this section, we provide some initial reflections and recommendations on steps toward more comprehensive GHG accounting and action in EU cities.

Should cities move away from territorial- to consumption-based GHG accounting?

Both territorial- and activity-based (production/consumption) approaches provide important complementary insight to inform GHG mitigation action. Together, they support the identification of GHG hotspots and mitigation opportunities, increasing choices and helping the design effective strategies to leverage cities' climate change mitigation potential, involve all relevant actors in climate action planning, and promote sustainable production and consumption practices (Balouktsi 2020). Consumption-based GHG accounting alone may lose important insight and information currently captured in territorial-based inventories and moving away from territorial-based inventories brings significant challenges.

As such, we recommend that, until a complete, consistent and accurate consumption-based GHG accounting framework is developed, cities consider and use territorial- and consumption-based inventories in complementary manner, to adequately estimate and monitor emissions associated with inbound emissions, as well as those associated with imported goods, construction materials, food supply chains, and transboundary transportation, for example. This will provide more a complete understanding, inform on potential burden-shifts across sectors and regions, and support more equitable and effective climate change mitigation strategies, especially in relation to sectors with significant upstream emissions.

Should cities develop both production- and consumption-based inventories?

While both perspectives offer opportunities for GHG mitigation, EU cities may prioritise a consumption-based perspective. This separation may affect emission accounting across all three scopes: imports of energy and intermediate goods that may be used in production processes, or transport within city boundaries associated with the production and supply of goods and services that will be used elsewhere should, in theory, be excluded. The separation of these emissions and processes may be challenging and unpractical, depending on the type of data and method adopted. For instance, methods based on household expenditure data focus on household final consumption and exclude imports and in-boundary activities associated with exports, while methods using material flow accounting and considering all flows going into a city would need additional data and effort to distinguish flows associated with intermediate consumption that can be associated with exports, and final consumption.

How should cities manage resource, time and data requirements in GHG accounting?

While aiming for comprehensive and relevant GHG inventories, we are aware these may require significant time and resources, and that flexibility is crucial to enable prompt and effective climate change action at local level. As such, processes and sources potentially associated with significant GHG emissions may be prioritised, and a gradual improvement in terms of scope, coverage and quality can be achieved, as more and better data and knowledge become available.

A phased or tiered system of GHG accounting can be adequate to address the wide range of challenges that cities across the EU may face. A simple methodological approach, with low resource and data requirements can be adopted when local, context-specific, granular data is unavailable. IO-based methods with lower detail at levels with higher disaggregation may be used for screening, to identify priority areas of intervention, and then partial bottom-up inventories with more accuracy and detail can be developed for those areas (e.g., specific sectors or activities). GHG inventories can be expanded and improved over time, as more detailed data and information becomes available.

What sectors or areas should be prioritised?

While screening is recommended to identify city-specific hotspots and priorities in GHG mitigation, buildings, transportation and food can be generally identified as priority areas for intervention. In buildings, actions to reduce scope 1 and 2 emissions can increase upstream emissions associated with the supply chain of construction materials, for example; and in food products the relative contribution of the supply chain can dominate their life-cycle GHG emissions). Other relevant aspects to increase the comprehensiveness of city-level GHG accounting include transboundary transportation emissions. This step into a more comprehensive and complete GHG accounting is important to avoid overlooking significant GHG emissions associated with cities, and to identify and manage potential trade-offs and burden shifts.

Criteria for cities to select priority sectors for which more comprehensive and detailed GHG inventories should be developed include (i) their potential significance in terms of GHG emissions, (ii) the interest and power of cities (incl. perception of public interest and collaboration with relevant stakeholders), (iii) the need to identify potential burden shifts and trade-offs (e.g., in actions tackling GHG emissions from buildings).

What can we learn from cities that are already addressing scope 3 emissions?

Many cities across the EU have started to account for and tackle out-of-boundary emissions. Rather than seeing this ambitious step as a burden, it has been identified as an opportunity: an increased range of actions and room for improvement in their climate change mitigation strategy.

Cities can have a significant effect in reducing emissions of all products and goods associated with urban activities, by considering their entire value chain, acknowledging the implications of local action on increasing globalised economies. As GHG methods and data continue to improve, they can support the development of tailored and context-specific actions to tackle life-cycle GHG emissions in priority sectors, such as buildings (construction), transport and food.

7.2 Concluding remarks

Researchers and practitioners, in particular among EU cities, have increasingly acknowledge the importance of trans- and out-of-boundary GHG emissions in climate change mitigation actions. Currently, there is a need for integration and alignment to navigate through available approaches, methods and data, to develop more comprehensive inventories, and to support ambitious and effective action.

As highlighted by the IPCC, relevant GHG accounting should ‘reduce uncertainties as far as is practical’ (IPCC guidelines on Good practice guidance). While current GHG inventories rely on bottom-up process-based models, the construction of a consumption-based inventory fully based on process-based LCA is not considered practical at the city scale – currently, it may be feasible for smaller spatial scales, such as neighbourhoods, or for specific urban systems or consumption categories. While more comprehensive inventories can add important insight, excessive time and resource requirements may hinder climate change mitigation action.

In this context, it might be preferable to combine a screening phase to identify key sectors and sources of emissions, and then invest in detailing data, knowledge and indicators on those sectors (Balouktsi 2020). Together with methodological guidance, cities need representative, useful and easily applicable data (Balouktsi 2020). Harmonization of GHG accounting methods and data at multiple scales would allow exploiting synergies. An alignment with data provided in global emissions datasets (e.g., EDGAR), or in the context of emission regulation schemes (e.g., ETS) could ease and improve the development of GHG inventories at national, regional and urban level. It is worth noting, however, that several databases provide data only for a subset of relevant direct GHG emissions to be monitored through city-level inventories.

Although some flexibility should be allowed to account for GHG emissions so that cities can focus on their relevance for local policymaking, it is essential to increase the harmonisation and consistency of inventories across the EU, to ease transparency, benchmarking and communication.

The development of methodological frameworks should build on the engagement of city representatives and practitioners to understand needs, priorities, resources and challenges. With the objective of advancing current practice and developing guidance toward more comprehensive GHG accounting and action, several activities in the Cities Mission have been organized engaging city representatives and practitioners. Recently (March 2025), an online webinar gathered 17 city representatives who discussed challenges and needs of cities. Challenges included ambiguous terminology and understanding of scope 3 emissions, variety and complexity of methodologies, lack of representative data, and the different capabilities, priorities and resources of EU cities, which place them at different stages of development in this shift toward more comprehensive GHG accounting and action. In this context, the Cities Mission foresees the creation of two working groups: a taskforce where cities that have particular experience, resources or interest engage with the JRC in the development of methodological guidance and data; and a peer-to-peer exchange group facilitated by NetZeroCities.

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List of abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
CB	Consumption-based
CBA	Consumption-based approach
CCC	Climate city contract
CDIAC	Carbon Dioxide Information Analysis Center
CE	Circular economy
CEDS	Community Emissions Data System
CHP	Combined heat and power
CoM	Covenant of Mayors
CO ₂ -eq	CO ₂ equivalents
CRF	Common reporting framework
CoM	Covenant of Mayors for Climate and Energy
CoM EU	Covenant of Mayors for Climate and Energy Europe
DGEG	Directorate-General for Energy and Geology
DPSC	Direct plus supply chain (PAS 2070 approach)
EC	European Commission
EDGAR	Emissions Database for Global Atmospheric Research
EE-IO	Environmentally extended input-output
EE-IOA	Environmentally extended input-output analysis
EIA	Ecodesign impact accounting
EIO	Economic input-output
EU	European Union
FFDAS	Fossil Fuel Data Assimilation System
GCoM	Global Covenant of Mayors for Climate and Energy
GHG	Greenhouse gas
GPC	Global Protocol for Community-scale greenhouse gas emission inventories
GTAP	Global Trade Analysis Project
GWP	Global warming potential
IG3IS	Integrated Global Greenhouse Gas Information System
IO	Input-output
IOA	Input-output analysis
IOT	Input-output table
IPCC	Intergovernmental Panel for Climate Change
IPPU	Industry processes and product use
JRC	Joint Research Centre
LC	Life-cycle
LCA	Life-cycle assessment
LCI	Life-cycle inventory

LEGGI	London Energy and GHG inventory
MRIO	Multi-regional input-output
ODIAC	OpenData Inventory for Anthropogenic CO ₂
OECD	Organisation for Economic Co-operation and Development
PBA	Production-based approach
SECAP	Sustainable energy and climate action plan
SRIO	Single-region input-output
SUT	Supply-use table
RME	Raw material equivalents
RoW	Rest of the world
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

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