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

State of the art in greenhouse gas accounting and mitigation, including scope 1, 2 and 3 emissions – Final report

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Contents

Abstract

The European Green Deal and the European Climate Law set ambitious climate change mitigation targets, and cities play a key role in achieving them. Initiatives such as the EU Covenant of Mayors and the EU Mission 'Climate-neutral and smart cities' have brought together thousands of cities committed to reducing their greenhouse gas (GHG) emissions. Through these initiatives, cities have developed 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, additional challenges in data collection and subjective methodological choices. Limited guidance and data are currently available to support EU cities, which need consistent GHG accounting frameworks and data, aligned with their needs, priorities and resources.

This report provides a review of the state of the art in GHG accounting and action in the EU, including current practices and 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 prepare relevant, comprehensive and consistent GHG inventories at the city level.

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[1] At the time of publication of this report, the working group had held two online meetings where parts of the preliminary version were discussed, and several participants had provided further feedback by email.

Executive summary

This report provides a review of the state of the art in greenhouse gas (GHG) accounting and mitigation 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, frameworks and practices to account for GHG emissions at the city level in the EU, and on state-of-the-art methods, tools and data to discuss potential opportunities and steps forward.

Policy context

The European Green Deal and the European Climate Law have set ambitious targets regarding climate change mitigation, and cities play a key role in achieving them. Initiatives such as the EU Covenant of Mayors (EU CoM) and the EU Mission 'Climate-neutral and smart cities' (Cities Mission) have brought together thousands of cities committed to reducing 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 (i) direct emissions occurring within local territories and (ii) indirect emissions associated with local energy use. While the increase in the urban population and consumption across the EU, together with the globalisation of supply chains, has resulted in a growing significance of GHG emissions occurring beyond city boundaries, GHG accounting frameworks often exclude a significant share of upstream and downstream emissions associated with urban activities. Increasingly ambitious mitigation targets call for advances in GHG emission accounting: more comprehensive inventories are needed to adequately account for, tackle and monitor GHG emissions associated with cities.

Main findings

In recent decades, the path towards developing more comprehensive GHG inventories at the city level has mostly built on a shift from territory- to activity-based emission accounting, and in particular to consumption-based accounting. Research and practice have mostly adopted input-output modelling for more comprehensive accounting, often focusing on household consumption alone (e.g., estimated using expenditure data). At the same time, however, bottom-up process-based accounting has been used to complement such inventories, or to detail and inform targeted mitigation actions for specific consumption areas, sectors or systems (e.g., buildings, transport and food).

While top-down input-output-based accounting may provide an adequate and relatively easy approach to estimating GHG emissions associated with urban (consumption) activities, its application to cities is limited by assumptions that result in significant uncertainty at high levels of disaggregation (e.g., by urban sector or subsector) and by the limited availability of up-to-date data, which are critical to inform local climate action. On the other hand, bottom-up process-based approaches have been considered unpractical to develop comprehensive inventories, due to the complexity of cities and the required modelling resources, including detailed context-specific data, time and expertise.

Key conclusions

A wide range of methods, tools and data are available that provide opportunities to expand the scope and boundaries of GHG emission inventories, enabling the development of more comprehensive and relevant data at the city level. Since the various approaches offer different strengths and limitations, they can be applied in different contexts, in a complementary manner, and used for screening or in a tier-based system, for example, depending on the resources, needs and priorities of cities.

Important developments in life-cycle approaches and data in recent years have improved their applicability to cities; however, significant advances are still needed to develop a widely applicable framework and to provide relevant data at the city and regional levels across the EU.

This review of the state of the art in GHG emission accounting and action in EU cities could support the development of a more comprehensive accounting framework. It provides insight on current opportunities, recommendations and steps forward that are useful for organisations and people accounting for GHG emissions associated with cities, including local, regional and national governments, researchers, practitioners and consultants.

Related and future Joint Research Centre work

This report builds on the Joint Research Centre's work supporting cities in GHG accounting under the EU CoM and the Cities Mission. It lays the groundwork for further developments in methodological guidance and data provided by the Joint Research Centre for more comprehensive GHG emission accounting at the city level.

Quick guide

The report is structured in seven chapters. Chapters 1 and 2 provide an introduction to and context on GHG accounting and mitigation under the EU CoM and the Cities Mission. Chapter 3 summarizes reference GHG accounting frameworks at the city level, currently applied to the European context, including an overview of key concepts. Chapter 4 describes the motivation for advancing common practice, to develop more comprehensive GHG inventories. Chapter 5 provides insight on available methods, tools and data sources that can be used in this context, and Chapter 6 illustrates some examples of good practices associated with the Cities Mission, accounting for or tackling GHG emissions beyond common practice. Lastly, Chapter 7 briefly concludes the report, providing several recommendations and next steps.

1. Introduction

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 European Green Deal (COM(2019) 640) established ambitious goals and introduced the roadmap for achieving climate neutrality by 2050, in line with the EU's commitment to global climate action under the Paris Agreement. In this context, the European Climate Law (Regulation (EU) 2021/1119) established a GHG reduction target of 50-55% of the EU's net GHG emissions by 2030, relative to 1990. Recently, in July 2025, the European Commission proposed an amendment to the European Climate Law to set the new EU climate target for 2040: reducing emissions by 90% (COM(2025) 524).

Initiatives such as the EU Covenant of Mayors (EU CoM) and the EU Mission 'Climate-neutral and smart cities' (Cities Mission) have brought together thousands of cities committed to reducing their GHG emissions. As part of these initiatives, cities develop GHG inventories to inform decision-making and to monitor progress. The European Commission's Joint Research Centre (JRC) provides scientific and technical support to the EU CoM and to the Cities Mission, developing guidance, tools and data to accelerate the transition to climate neutrality throughout EU cities.

City-level GHG accounting frameworks in the EU have typically focused on (i) direct emissions occurring within the local territory and (ii) indirect emissions associated with grid-supplied energy (for local energy use), excluding a significant share of upstream and downstream emissions associated with urban activities. However, the increasing urban population and consumption trends, together with the globalisation of supply chains, have resulted in a growing significance of GHG emissions occurring beyond city boundaries. Increasingly ambitious climate change mitigation targets call for advances in GHG accounting: more comprehensive inventories are needed to adequately account for, tackle and monitor GHG emissions associated with cities.

This report aims to provide insight on the state of the art in accounting for and tackling the GHG emissions associated with cities ([2]), to support the future development of more comprehensive and holistic GHG inventories and action at the city level. It provides a scoping review of current and state-of-the-art practices adopted in cities to tackle and account for GHG emissions, beyond the typical scope and boundaries. In particular, this report provides insight on:

- current guidance and frameworks on GHG accounting at the city level, in the European context;
- the potential significance of GHG emissions 'beyond common practice';
- methods, tools and data that can be used for more comprehensive GHG accounting;
- good practices and examples of instances in which cities accounted for or tackled emissions in a way that went beyond common practice and the usual scope in GHG mitigation action.

[2] The terms 'city' and 'urban' are used throughout this document with a generic meaning, including subnational geographical areas such as municipalities, metropolitan areas, towns and communities.

Concerning GHG accounting, we first provide a summary of existing guidance and frameworks, from reference organizations and relevant to the EU context, to account for GHG emissions at the city level. Drawing on this overview, we establish a reference for *common practice*. Next, we discuss the motivation for developing more comprehensive GHG inventories, including the potential significance of GHG emissions that have been typically excluded from city-level GHG inventories and climate action plans, and the increased opportunities they provide for cities to contribute to climate change mitigation. We then review state-of-the-art methods and tools – and potential data sources – that can be used to account for GHG emissions at the city level, beyond common practice. The review includes a brief discussion of potential features, advantages and limitations of available methods, quality and suitability of 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 the cities involved in the Cities Mission (hereinafter Mission cities). While these examples are non-exhaustive, they illustrate actual steps already taken by cities and demonstrate the ambition to go beyond common practice.

This report draws on scientific research publications and local climate action plans. It is important to advance common practice by identifying and prioritizing the next steps to support more relevant, holistic and consistent GHG accounting, which can ultimately support more effective and significant climate action. The report serves as a basis for the future development of concrete methodological guidance and data to account for GHG emissions associated with EU cities in a comprehensive manner. Comprehensive and detailed knowledge and monitoring of GHG emissions are paramount to inform and to track progress of local climate action.

The review provided in this report is not meant to be comprehensive or systematic. As mentioned, it is a scoping review focused on potentially relevant frameworks, methods, data and actions in the context of EU initiatives to mitigate climate change at the city level.

2. Tackling GHG emissions associated with EU cities

Cities play a key role in achieving the EU's climate change mitigation targets. 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 are home to 70-75% of the population (EEA, 2019; Marelli et al., 2025; World Bank Group, 2018). At the same time, the proximity of local governments to citizens enables the development of a good understanding of local needs and contexts, and effective and responsive policy implementation, giving cities a unique opportunity to shape and drive climate change mitigation efforts.

To date, cities have mostly focused their actions to mitigate climate change on (i) local GHG emissions, occurring within their geographical boundaries (territorial emissions), and (ii) GHG emissions associated with the generation of grid-supplied energy used locally (i.e., emissions associated with energy used within their geographical boundaries, which may occur elsewhere) (Balouktsi, 2020). However, GHG emissions and other environmental pressures and impacts associated with urban activities go well beyond this scope and boundaries.

Consumption continues to grow across Europe and supply chains have become increasingly global. In addition, the extraction and processing of natural resources have drastically increased in recent decades. The United Nations Environment Programme's 2024 global resources 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 has had significant environmental implications: the extraction and processing of natural resources is estimated to account for over 60% of our climate change impacts (UNEP, 2024). The sixth assessment report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) highlights that, while ambitious and prompt mitigation efforts could reduce urban consumption-based GHG emissions between 2020 and 2050, the projected trend with low or moderate effort is for emissions to continue to grow (IPCC, 2022).

To effectively tackle climate change and achieve climate neutrality targets, adopting a narrowed 'local emission' or 'local energy use' perspective is no longer enough. Ambition and action need to be stepped up, and cities need to advance current practices to tackle significant GHG emissions associated with their activities that occur beyond their geographical or administrative boundaries, in a comprehensive and integrated manner, with a life-cycle perspective. In fact, in recent years, a growing number of cities across the EU have started promoting, for example, circular economy and green procurement practices, which can strongly affect upstream GHG emissions associated with local activities.

Comprehensive action to mitigate GHG emissions needs to be supported by accurate and relevant data. The relevance, quality and consistency of city-level GHG inventories is crucial to support effective local climate action. Consistent, reliable and transparent GHG inventories are also important to increase trust and uptake, and to enable comparability and benchmarking, which in turn facilitate knowledge sharing and collaboration. To ensure the consistency, reliability and credibility of GHG inventories, accounting frameworks at the city level across the EU have typically followed internationally recognized GHG accounting principles and guidelines, such as those of the IPCC. Such frameworks provide systematic approaches to accounting for a city's GHG emissions over a reference year.

In recent years, scientific research has advanced methods and increased the availability of good-quality data for quantifying and monitoring GHG emissions, including territory-based but also activity-based accounting approaches (see Section 3.1). Putting these advances into practice can help increase the scope, accuracy and relevance of GHG inventories at the city level.

Challenges related to data availability, to scope and boundary selection, and to the allocation of emissions have prevented more comprehensive GHG emission accounting and mitigation action at the city level. Among these challenges, GHG inventories have often excluded potentially relevant and significant GHG emissions associated with urban activities. Emissions that are typically excluded from cities' GHG inventories include, for example:

- transboundary transport emissions, beyond (or across) city boundaries (e.g., from road, shipping and air transport);
- upstream supply chain emissions of construction materials;
- management of waste beyond municipal solid waste and waste water (e.g., construction and demolition waste).

Across the EU, cities have been actively engaging in climate change mitigation, and important initiatives, such as the EU CoM and the Cities Mission, have been established to support them. The following sections summarise the context, objectives and scope of GHG mitigation in these two initiatives.

2.1. EU Covenant of Mayors

The EU CoM 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 EU CoM, cities voluntarily commit to developing and implementing a sustainable energy and climate action plan (SECAP), which includes the compilation of GHG inventories (Davide et al., 2025).

In the EU CoM framework, climate change mitigation focuses mainly on reducing local energy use and its associated GHG emissions (Bastos et al., 2025). As such, GHG emission accounting focuses mostly on energy-related activities under the direct control or influence of cities (local authorities). In terms of scope and coverage, SECAPs and their GHG inventories should cover at least four CoM activity sectors (referred to as 'key activity sectors'), which essentially correspond to the Buildings (Stationary energy) and Transport sectors. Nonetheless, the inclusion of emissions associated with waste and waste water treatment is recommended, along with those from any other activity sectors with significant GHG emissions that can be addressed through local climate change mitigation action, so that the impact of local climate action can be adequately evaluated and monitored.

2.2. EU Mission 'Climate-neutral and smart cities'

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

The Cities Mission ([3]) has two key objectives:

- to deliver 100 climate-neutral cities by 2030;
- to ensure that these cities act as experimentation and innovation hubs to enable all European cities to follow suit by 2050.

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

GHG emissions that occur outside the geographical boundaries of cities (upstream and downstream) are generally not covered in the Cities Mission (under its definition of climate neutrality), except for GHG emissions associated with waste and waste water treatment, which should be accounted for, regardless of where they occur ([4]), i.e., whether they are scope 1 or 3 emissions (see Section 3.1). Nevertheless, several highly ambitious cities have showed clear intention to start systematically monitoring and tackling consumption-based, upstream and/or downstream GHG emissions. In fact, several cities have already accounted for and addressed in their climate city contracts (CCC) – at least partially – scope 3 emissions, beyond the waste and waste water sector.

The JRC has recently engaged advanced and interested Mission cities in the form of a task force, facilitated through the EU Cities Mission platform, to collect additional good practices, along with inputs on the cities' priorities, available methodologies and data. The main aim of the work is to tailor upcoming guidance on GHG accounting to cities' needs, co-developing a consistent and comprehensive GHG accounting framework.

[3] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en#what-are-eu-missions

[4] See Cities Mission information kit (http://ec.europa.eu/mission-cities) for further details.

3. GHG emission accounting at the city level: current practice

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

GHG inventories provide estimates of GHG emissions and removals from a range of sources and sinks, for a given geographical area and period. Under the United Nations Framework Convention on Climate Change (UNFCCC), countries develop annual national GHG inventories, which are paramount to inform policymaking, to monitor progress and to communicate – in transparent manner – the status of GHG emissions, along with associated targets and trends. Since cities play a key role in climate change mitigation, ensuring the availability of accurate and consistent activity and GHG data at the city level is crucial.

City-level GHG inventories are needed to inform decision-making, to ensure transparency and credibility and to promote the uptake and success of effective action to mitigate GHG emissions at the local level (Balouktsi, 2020; Turnbull et al., 2022). Research has shown that European cities that account for and monitor GHG emissions are more likely to have achieved emission reductions, and limited GHG emission data have been identified as the primary challenge in evaluating cities' performance (Hsu et al., 2022).

Different reference organizations, initiatives and experts have proposed frameworks and guidance on GHG emission accounting at the city level, typically in line with the IPCC guidelines for national GHG inventories (IPCC, 2006, 2019). However, frameworks and guidance are often dispersed and fragmented, building on different assumptions and methodological choices, and chosen to align with specific objectives, scope and context, which can make their application, interpretation and comparison difficult (Balouktsi, 2020). Typically, GHG accounting frameworks, including those commonly used by the EU CoM and Cities Mission, have categorised and allocated emissions using a territory-based approach.

This section first provides an overview of key concepts and definitions commonly used in GHG emission accounting (Section 3.1). Then, it provides a brief description of city-level GHG accounting frameworks and/or guidance, relevant in the EU context, focusing on their comprehensiveness and emission coverage (Section 3.2). This overview establishes a reference for current, common or typical practice in GHG emission accounting to support climate change mitigation at the 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.

Box 1. Guiding principles for city-level GHG inventories

To effectively inform policymaking, city-level GHG inventories should be 'decision-useful' – that is, 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 the following (Bastos et al., 2025; European Commission, 2021a; IPCC, 2006, 2019; TCFD, 2021; Turnbull et al., 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-level GHG inventories should be consistent over time, comparable among cities and complementary to national accounting systems, tools and methodologies. Consistency in methodological aspects, choices and assumptions across inventories is particularly important to ensure adequate interpretation and comparability.

— **Flexible and action oriented.** GHG emission accounting to inform city-level action calls for simplicity of use and application, and flexibility to suit various regional and local contexts; to accommodate the needs and resources of different cities, reflecting their specific characteristics and challenges; and to take into account cities' policymaking priorities, resources, capacities and regulatory contexts.

— **Complete and accurate.** City-level GHG inventories may not be exhaustive, but they should cover all relevant sectors and GHG emission sources to provide meaningful data and insight. Complete and relevant GHG inventories are key to supporting the design, implementation and monitoring of effective local action and to monitoring progress. GHG inventories should be as accurate as possible, and should represent a reasonable estimate of real urban activities and their 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 the availability of reliable data across time. Transparent and detailed data are important for inventories' reliability, credibility, comparability, interoperability and validation.

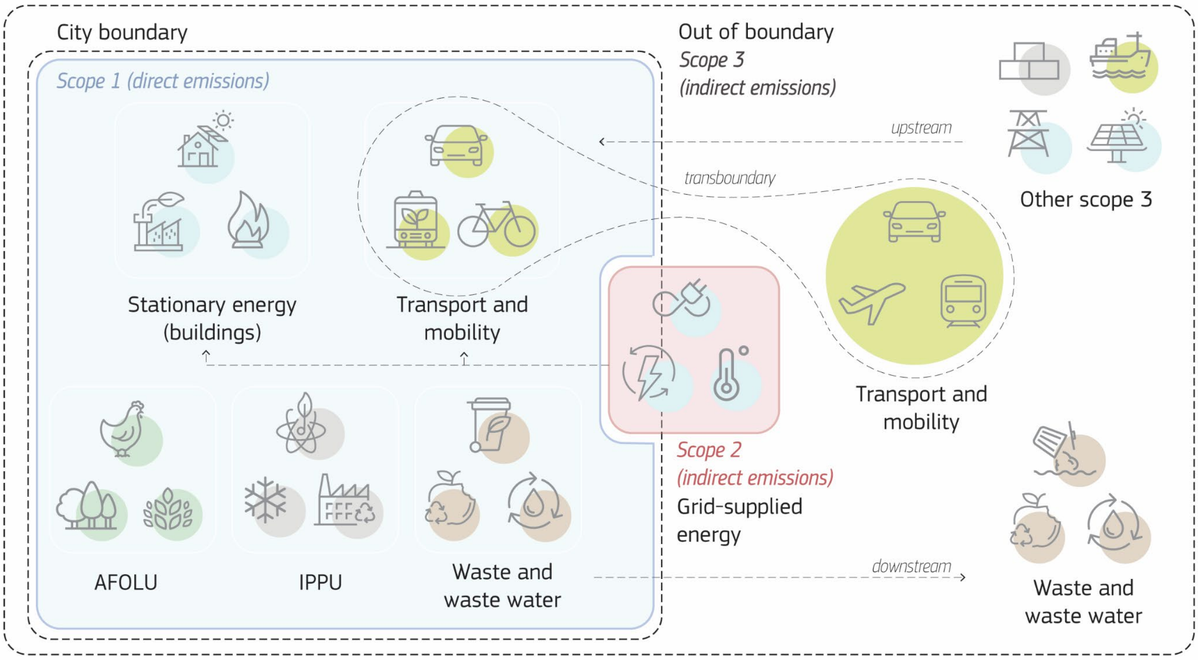
3.1. Scope and boundaries: key concepts

The definition of adequate scope and boundaries in GHG inventories is key to informing and supporting effective climate action strategies (Peters, 2008). Scope and boundaries generally define what activities and emissions an inventory covers – that is, what should be included or excluded. The selection of scope and boundaries depends mostly on the purpose of the inventory. Selection involves identifying the GHGs, emission sources (from a range sectors and activities), geographical area and period that is covered by the inventory. Thus, scope and boundary definition has implications for the comprehensiveness, usability and comparability of GHG inventories.

Figure 1 illustrates the definition of and relationships between concepts, sectors and emissions commonly associated with city-level GHG emission accounting. Definitions of the concepts related to GHG emission accounting may vary by reference organization, guidance document, and object or system of application. This section briefly describes key concepts and definitions to support the clear and unambiguous interpretation of the terminology used in this report.

It is important to highlight that some of the concepts and definitions presented here are not universal, and that other sources provide different definitions, particularly if they focus on other levels of GHG emission accounting (e.g., national, organisational).

Figure 1. City-level GHG emission accounting: definitions and links between key concepts, sectors and boundaries



NB: AFOLU, agriculture, forestry and other land use; IPPU, industrial processes and product use.

Source: JRC, based on C40 Cities Climate Leadership Group (2018).

3.1.1. Inventory year

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

3.1.2. Geographical area

Geographical boundaries in cities' GHG inventories often correspond to administrative (geopolitical) boundaries (e.g., a municipality or a group of municipalities). Inventories are developed to support the action of local authorities, and therefore are closely linked to their geographical area of governance – that is, where they have the (direct) power to intervene (Bastos et al., 2025). Using administrative boundaries also makes it easy to communicate with many relevant stakeholders, as they are known, transparent and well-established (Balouktsi, 2020). Moreover, these usually correspond to the local administrative units (LAU) in the NUTS (nomenclature of territorial units for statistics) ([5]) classification, for which good-quality statistical data may be readily available.

It is important to note, however, that cities may go beyond the municipality scale to consider for example metropolitan or functional boundaries ([6]) in GHG emission accounting and mitigation action. Drawing on the coordinated efforts of different municipalities and public administrative organizations in a metropolitan area, among other spatial and administrative levels, can offer synergies and significantly increase the effectiveness and impact of climate action.

3.1.3. Emission sectors and activities

GHG inventories are generally structured in sectors, which group categories of activities and/or emission sources. City-level GHG inventories are typically built on four main sectors used in national GHG inventories, in accordance with IPCC guidelines (IPCC, 2006, 2019).

— **Energy.** Two main types of emission sources are associated with the energy sector: (i) fuel combustion activities and (ii) fugitive emissions associated with the production and distribution of fossil fuels. Fuel combustion activities cover all sectors of the economy that use primary energy sources (fuels) to produce heat or power (e.g., energy industries, manufacturing and construction industries, transport, agriculture, housing, services), which emit mainly carbon dioxide (CO_2) and methane (CH_4). Within the energy sector there are stationary and mobile emission sources. Stationary emission sources generally include buildings, equipment and infrastructure, while mobile emission sources include freight and passenger transport, across water, road, air and rail modes, but also off-road vehicles and machinery.

  City-level GHG inventories have often adopted urban sectors and subsectors, such as **Buildings**, including Residential buildings, Municipal buildings and Commercial buildings, or **Transport**, including Public transport, Municipal transport and Private transport, for example. In this case, emissions associated with electricity generation and supply, for instance, are usually allocated based on the final electricity use in the corresponding sector.

  GHG emissions associated with residential buildings include, for example, (i) use-phase direct emissions associated with local energy use (e.g., biomass stoves, natural gas heating), (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 occurring outside city boundaries. In GHG inventories, these emissions are categorized as scope 1, 2 and 3, respectively, described later in this section.

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5 http://ec.europa.eu/eurostat/web/nuts/overview

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

- **Industrial processes and product use (IPPU).** The IPPU sector includes processes and product use that may emit non-energy-related GHGs (mainly CO_2, nitrous oxide (N_2O) and fluorinated gases (F-gases), as by-products and as fugitive emissions). These include industrial processes involving chemical reactions, for example in the production of chemicals and metals, or using mineral compounds and chemicals (e.g., production of cement, some food and beverages, and aluminium); and the use of products such as electronics equipment, air conditioning systems and aerosols.
- **Agriculture, forestry and other land use (AFOLU).** AFOLU includes emissions from (i) agriculture, land-use change and forestry (e.g., N_2O and CH_4) 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.
- **Waste.** The waste sector focuses on emissions from treatment of waste and waste water generated within the city, including, for example, municipal solid waste and industrial waste, for example. Types of treatment include disposal in landfill, organic waste treatment, composting and solid waste incineration, among others. Waste treatment processes with energy recovery are excluded from this sector (they may be considered in the energy sector).

3.1.4. Direct and indirect emissions

According to the Contribution of Working Group III to the AR6 of the 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';
- 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'.

Essentially, the classification of emissions as direct or indirect depends on the scope and boundaries considered or, more specifically, on the relationship between the source – where and when emissions physically occur – and the sector, system or activity under analysis. City-level GHG emissions typically consider sectoral boundaries and geographical boundaries.

If we analyse the residential buildings sector, emissions associated with small-scale heating systems based on local combustion of fuels, for instance wood stoves or natural gas boilers providing heating to apartments or multifamily buildings, are direct emissions. In the case of combustion emissions from a power plant using wood-based biomass to generate and supply heat to residential buildings, two sectoral boundaries can be considered: in the analysis of emissions from *energy industries*, these are direct emissions – that is, when accounting for organisation or industry emissions, these would be considered direct emissions of the industry, organisation or system under analysis; while in the analysis of emissions associated with *residential buildings* these are indirect emissions.

If we consider geographical boundaries, the definition of direct and indirect emissions in city-level GHG inventories may be generally established based on the 'point of emission' being within or beyond geographical boundaries. In this context, the classification of emissions from a district heating plant may depend on the location of the plant – that is, the emissions would be direct if they occurred within the city's boundaries, and indirect if they occurred outside. In both cases, GHG emissions associated with the generation of heat to be used in a city are typically included in its GHG inventory.

It is worth noting that the Greenhouse Gas Protocol has established a distinction between direct and indirect emissions based on ownership or control of emission sources (WBCSD et al., 2015). This is associated with the primary purpose and nature of the protocol, which focuses on accounting for GHG emissions of an organization, as 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).

3.1.5. Scope 1, 2 and 3 emissions

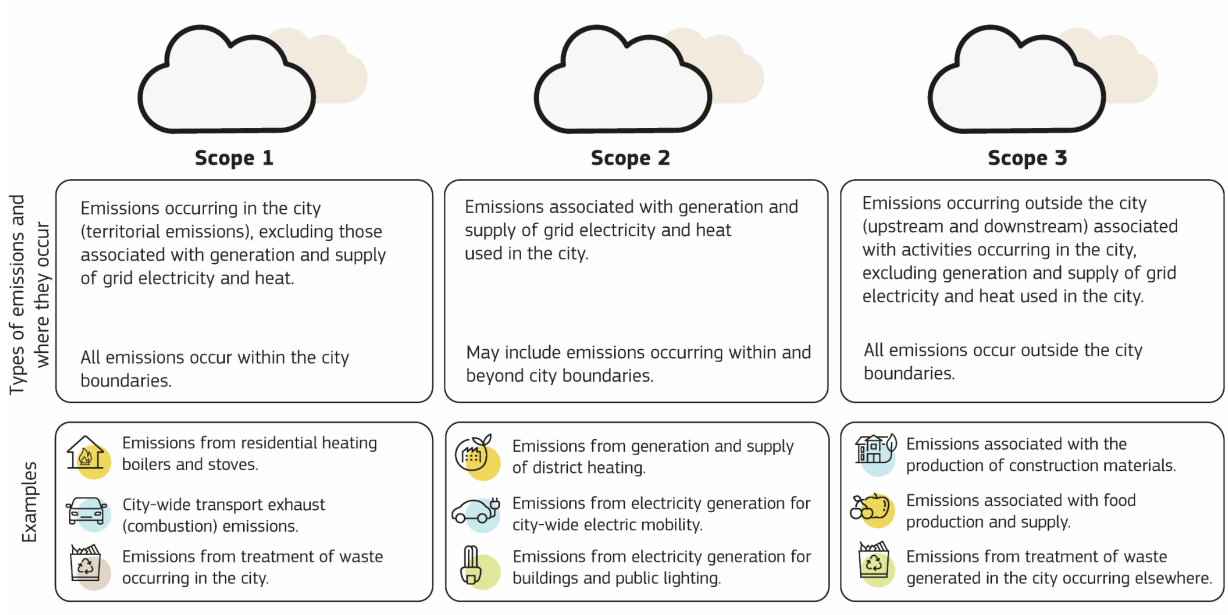
GHG emissions are typically categorized as scope 1, 2 or 3. The categorisation of emissions into scopes is mainly linked to where emissions occur and the control or influence of the inventorying/acting body on the emissions. As such, the classification of emissions into scopes is broadly related to the definition of direct and indirect emissions (summarized above).

In general, scope 1 emissions are direct emissions (they occur within the space and/or control of the acting body, and typically in the same place and at the same time as the related activity), scope 2 emissions are energy-related indirect emissions (i.e., emissions associated with upstream energy generation, in particular with energy conversion processes, which occur in a different place and/or at a different time from energy use) and scope 3 emissions are other (non-energy-related) indirect emissions (e.g., upstream and downstream emissions associated with the life cycle of materials and products). Figure 2 provides a summary of the types of emissions associated with scope 1, 2 and 3 in city-level GHG emission accounting.

With regard to cities, the classification of emissions into scopes is directly linked to their spatial/geographical boundaries and to where emissions generally occur.

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

Figure 2. Types of GHG emissions in city inventories by scope.



Source: JRC.

The relationship and linkages between the classification of GHG emissions as direct or indirect and as scope 1, 2 or 3 (from a territorial 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 3 in city-level inventories, depending on whether treatment activities take place within or outside the city's geographical boundaries.

Other terminology may be used related to direct and indirect, or scope 1, 2 and 3, emissions, including '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 usually include emissions associated with raw material extraction, processing, production, manufacturing, transport and packaging, for example. In some cases, they may also include downstream emissions (e.g., associated with waste treatment).

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

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

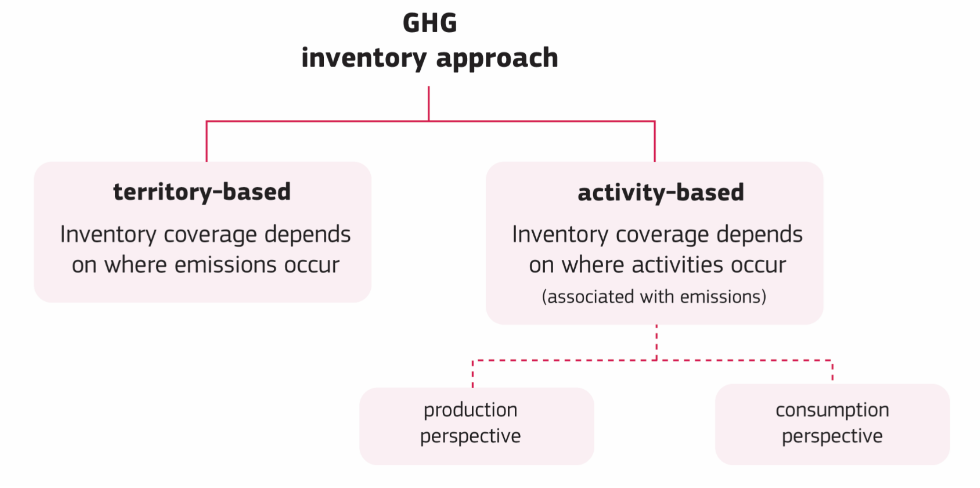
As previously mentioned, GHG inventories at the national, regional and city levels has been typically bound by and based on territorial boundaries, accounting for emissions that occur within a territory, or associated with energy generation and supply to the territory (Tukker et al., 2016). GHG inventories often include emissions from both production and consumption processes; for example, inventories include emissions from passenger transport, which is a consumption-related activity, along with energy-related emissions associated with the manufacturing and transport of products that may be exported and used elsewhere, in which case the activities are related to production – that is, they are part of the supply chain of products to be used or consumed outside a city's boundaries.

Cities could, in principle, follow a strictly 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 consider a territory-based ([7]) approach including scope 1 and 2 emissions. This approach draws on IPCC standard methodologies, and depends mostly on local knowledge. It makes accounting, monitoring and aggregation among inventories easier, and improves comparability, at the city level and on other spatial scales, while avoiding risks of double-counting (Tang, 2025). 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 elsewhere. It determines multiple supply chains, which may span several cities, regions and countries (Tukker et al., 2016).

In this context, GHG emission accounting frameworks may adopt an activity-based approach (Heinonen, 2025). 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 from energy use in the territory, regardless of where these GHG emissions occur. Activity-based approaches typically adopt one of two perspectives of the allocation of activities and GHG emissions: a production-based or a consumption-based perspective (see Figure 3). As the name suggests, a production-based approach generally accounts for emissions associated with production, while a consumption-based approach accounts for emissions associated with final consumption (Allan et al., 2023; Balouktsi, 2020; Lin et al., 2017).

[7] Territory-based GHG emission accounting has also been referred to as 'production-based', 'domestic' or 'sector-based' accounting (Jakob et al., 2014; Peters, 2008; Tang, 2025). While the boundaries of territory-based GHG inventories reflect where emissions are produced, they often include emissions from both production and consumption activities occurring in the territory, for example, emissions from energy generation or industrial processes, and emissions from the combustion of fuels in private car travel. For the sake of clarity, production-based emission accounting in this report refers to the accounting of emissions associated with production processes only, as opposed to consumption-based emission accounting (which is also an activity-based approach), not to territory-based accounting (i.e., addressing scope 1 and 2 emissions). Territorial emissions are emissions occurring in the territory (scope 1). Lastly, the term 'sector-based' is not applied in this report: both territory-based and activity-based approaches can be applied to develop GHG inventories structured by sector.

Figure 3. Schematic diagram of GHG inventory approaches: territory- and activity-based accounting



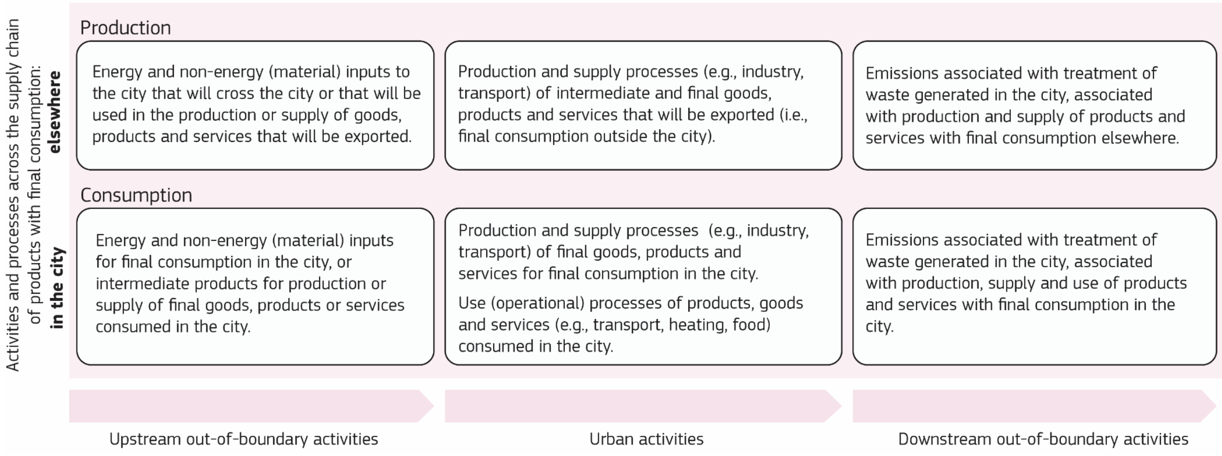
Source: JRC.

In principle, a production-based inventory includes all GHG emissions associated with the production and supply of goods occurring in a city, regardless of whether the goods are used within the city or exported. A consumption-based inventory instead, accounts for GHG emissions associated with consumption in a city, or by its population, regardless of where goods are produced (see Figure 4). In other words, emissions from the 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-based and consumption-based accounting approaches are valid and useful to support action to mitigate GHG emissions. These two perspectives provide relevant complementary insight on GHG emissions associated with trade, and on GHG emissions associated with the whole value chain, which both producers and consumers can influence and tackle (Allan et al., 2023; Balouktsi, 2020; Hung et al., 2019) ([8]).

Since EU cities have become increasingly significant hotspots of consumption, heavily relying on other territories that produce and supply goods, consumption-based analyses and inventories have gained traction in the last couple of decades, and they have been increasingly adopted in GHG accounting frameworks and practices across the EU (Balouktsi, 2020; C40 Cities Climate Leadership Group, 2018). Consumption-based approaches aim to capture GHG emissions of goods and services across the value chain (from raw material extraction, to manufacture, processing, distribution, use and disposal) that are associated with the city's activities – that is, used in the city or by its population – regardless of where these emissions occur (C40 Cities Climate Leadership Group, 2018).

[8] This is also observed at the country level, where production- and consumption-based approaches are outlined as providing complementary information on the emissions associated with production and consumption.

Figure 4. Schematic diagram of production and consumption perspectives in activity-based accounting



Source: JRC.

As such, consumption-based GHG inventories should, in principle, (i) include life-cycle emissions associated with final products and services used within a city's boundaries (or by the city population, as explained next), and (ii) exclude any emissions occurring within city boundaries (or upstream) associated with the life cycle of any products or services that are consumed elsewhere, including emissions associated with the production and/or supply of goods exported from the city (C40 Cities Climate Leadership Group, 2018). 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 throughout its life cycle (Wright et al., 2014).

Consumption-based (CB) accounting can be population- or area-based (Heinonen, 2025). Population-based CB inventories account for emissions associated with the activities of a city's population for a given year, regardless of where they occur – that is, including out-of-boundary activities such as work travel or the city's residents' engagement in tourism abroad. 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 the 'daytime population'). [9] Further details of differences and application of territory-based and emerging activity-based approaches to GHG emission accounting at the city level are provided by Balouktsi (2020).

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

[9] Per capita metrics (e.g., GHG emissions) based on the daytime population are related to the concept of a 'population equivalent' (Mirabella et al., 2018), which considers not only residents but people who use urban services and live elsewhere (e.g., tourists, commuters).

Other approaches, variants or denominations have been used for GHG emission accounting at the city level, such as community-wide supply chain, household or personal consumption footprints. It is also worth noting that activity-based inventories typically aggregate GHG emissions across scopes, and therefore do not categorise emissions by scope.

3.2. Current frameworks and guidance

While there is no single established methodology for GHG emission accounting at the 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 emission accounting guidance and practice in the EU CoM, the Cities Mission, the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) and the British standard PAS 2070. For each, it provides insight focusing on the scope and boundaries of GHG inventories. It summarizes their guidance in relation to (i) GHG coverage, (ii) scope and boundaries (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 emission accounting in Europe.

The frameworks draw on principles and guidelines of the IPCC regarding national GHG inventories. This provides transparency, consistency and – to a certain extent - comparability across cities and other geographical scales. The objectives of the IPCC's national GHG inventories programme included the development of internationally agreed-upon methodologies and tools for estimating and reporting national GHG emissions. It also aimed to encourage widespread uptake of methodological principles and methods to 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 (IPCC, 2006, 2019).

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

The development of city-level GHG inventories to support local climate action typically follows a bottom-up approach, in which GHG emissions are calculated by multiplying activity data for a reference year (e.g., on energy use, distance travelled and waste generation) by corresponding GHG emission factors ([10]). For aggregation, GHG emissions are converted using their specific global

[10] Examples of activity data include annual fuel consumption in municipal road transport (e.g., in l of diesel) or electricity used in residential buildings (e.g., in kWh). Emission factors express a rate of emission per unit of activity; for example, a power plant emission factor expresses the mass amount of CO_2 or CO_2-eq per kWh of grid electricity generated/supplied.

warming potential (GWP), with a 100-year time horizon (GWP100 metric), to tonnes of carbon dioxide equivalent (t CO_2-eq).

Table 1 presents an overview of the sectors and subsectors generally covered in city-level GHG inventories, including a brief description of their activities and emission sources. Most city-level GHG accounting frameworks adopt a sectoral structure and definition in line with IPCC guidelines, while providing some degree of flexibility by setting minimum requirements and recommendations. This section focuses on a restricted set of alternatives within those frameworks. It is worth noting that, while the table focuses on sectors and subsectors covered in common, current city-level GHG inventories, consumption-based inventories already used by some EU cities follow a different structure, mostly based on urban consumption groups/categories, as mentioned in Chapter 7.

Transboundary and out-of-boundary (scope 3) emissions that are typically excluded from GHG inventories at the 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).

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, for example g of CO_2 or CO_2-eq emitted per litre of diesel used, or per kilometre travelled by a vehicle. While the methodological aspects and scope of these emission factors are not covered by this report, they are worth noting. For example, the use of generation emission factors versus supply/consumption emission factors, which take into account international trade (imports and exports) of energy, affects scope 2 emission estimates, and is linked to the scope and comprehensiveness of city-level GHG inventories.

Table 1. GHG inventory structure: typical sectors and subsectors used, and their definitions, activities and emission sources

Sectors and subsectors	Brief definition, activities and emission sources
Stationary energy (or Buildings)	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 local energy use through fuel combustion (e.g., biomass, natural gas, diesel, coal and heating oils), and indirect emissions associated with the generation of grid-supplied energy used within the city's boundary, including electricity, district heating and cooling.
Residential buildings	GHG emissions associated with final energy use in residential buildings (e.g., final energy use by households).
Commercial and tertiary buildings	GHG emissions associated with final energy use in commercial/tertiary buildings (e.g., final energy use in offices).
Institutional buildings	GHG emissions associated with final energy use in public buildings and facilities, and buildings of institutional, governmental or administrative organizations, such as schools, hospitals and government offices.
Public lighting	GHG emissions associated with energy use for 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 from 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 (other) industrial buildings, including in the energy industries. Emissions associated with the generation of energy to be supplied and used beyond city boundaries are often excluded (to avoid double-counting), along with 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 transport of fuels	Any intentional and unintentional GHG emissions associated with the extraction, processing, storage or transport of fuels in the city, including coal, oil and natural gas. 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.

Sectors and subsectors	Brief definition, activities and emission sources
Transport and mobility	GHG emissions from transport of goods and people within the city's boundary (road and rail as a minimum), often disaggregated by, for example, municipal fleet (or government travel), public transport, private (or personal) travel or commercial transport. Transport vehicles and mobile equipment or machinery are associated with direct GHG emissions by combusting fuel, and indirect, by consuming grid-supplied electricity.
On-road	On-road vehicles for transporting people and goods on common or public roads, streets or highways, including buses, cars, taxis, trucks, motorcycles and waste collection vehicles.
Railway	Railway transport typically uses diesel or electricity. Railways can be divided into urban railway systems including tramways and subways, regional commuter rail, and national and international rail. Each can be classified as passenger or freight.
Waterborne navigation	Water transport includes ships, ferries and other boats operating in the city, along with 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 transport (occurring within the geographical boundary of the city, e.g., via helicopter) and emissions from trips departing from airports that serve the city.
Off-road	Off-road vehicles are typically designed or adapted for travel on unpaved terrain. This category includes, for example, airport ground support vehicles and equipment, all-terrain vehicles, and landscaping and construction vehicles and equipment.
Waste management	GHG emissions associated with disposal and treatment of waste and waste water generated within city boundaries (including solid waste disposal/landfill and biological treatment, through aerobic or anaerobic decomposition, or incineration). Scope 2 emissions associated with energy use in waste management and emissions from waste treatment with energy recovery are accounted for in the Stationary energy (or Buildings) sector.
Solid waste disposal	Solid waste may be disposed of at managed sites (e.g., sanitary landfill), or 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 involving energy recovery (in such case reported under stationary energy). Open burning is an uncontrolled, often illicit, process with direct emissions and can typically only be estimated based on collection rates.
Waste water treatment	Waste water can be treated aerobically or anaerobically. It can generally be categorized as domestic or industrial, and both should be included in city-level GHG inventories.

Sectors and subsectors	Brief definition, activities and emission sources
Industrial processes and product use (IPPU)	GHG emissions resulting from non-energy-related industrial activities and product use. These include all GHG emissions occurring from industrial processes, product use and non-energy-related use of fossil fuels, along with chemical processes associated with products and by-products.
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 the 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, that can release GHG emissions with significant global warming potential.
Agriculture, forestry, and fishing activities (AFOLU)	GHG emissions associated with agriculture, forestry, fishing and other land uses. GHG emissions from a variety of pathways, including land-use changes that alter the composition of the soil, methane (CH_4) production during the digestive processes of livestock and nutrient management for agricultural purposes (including emission sources and removal/sinks).
Livestock	Livestock emissions, for example of CH_4 through enteric fermentation, and of CH_4 and N_2O through the management of manure.
Land use	Emissions and removal of CO_2 are based on changes in ecosystem carbon (C) stocks and are estimated for each land-use category. Carbon 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.

Sources: JRC, based on European Commission (2021a), Ridoutt et al. (2016), Kean Fong et al. (2021) and PAS 2070:2013+A1:2014.

3.2.1. EU Covenant of Mayors

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

- Municipal buildings, equipment and facilities;
- Tertiary (non-municipal) buildings, equipment and facilities;
- Residential buildings;

— Transport ([11]).

The framework also recommends including emissions associated with the treatment of waste and waste water generated in the city, and any other sectors and activities that may be addressed in local actions to mitigate climate change, so that the results of those actions can be adequately evaluated and monitored. CoM inventories typically exclude non-energy-related emissions associated with the AFOLU and IPPU sectors, which are generally considered of limited relevance in an urban context.

The CoM framework provides two approaches that can be adopted to calculate GHG emissions: the activity-based and life-cycle-based (LC-based) approaches. 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 typically estimated based on the carbon content of the fuels used. This approach builds on IPCC guidelines, and is aligned with national reporting practices set out in the 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 and supply (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 long-lived reference GHGs should be considered in CoM inventories – carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O); and the minimum requirement is to account for CO_2 only.

3.2.2. EU Mission 'Climate-neutral and smart cities'

The Cities Mission is characterised by setting more ambitious targets to be achieved within a shorter time frame, and having a smaller number of cities involved, than other frameworks: it gathers 112 cities (100 EU and 12 non-EU), committing to significantly reducing 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 EU CoM, GPC or other reliable GHG accounting approaches for reference.

The scopes, sectors, activities, GHGs and emission sources to be included in GHG inventories are mainly established through the Cities Mission's 'climate neutrality definition', and the Mission's Info kit provides general guidelines and recommendations (European Commission, 2021a). In brief, GHG emission sources in the Stationary energy, Transport, Waste and waste water, IPPU and AFOLU sectors should be included. GHG emissions may be excluded when sectors, activities or sources are considered negligible; and the overall share of excluded GHG emissions should not exceed 5% of the city's GHG emissions.

[11] Transport is both a macro-sector and a key activity sector, while the other key activity sectors are subsectors of the buildings macro-sector.

Mission cities should account for emissions of the following reference GHGs: CO_2, CH_4, N_2O, fluorinated gases (F-gases) (hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The minimum requirement is to account for CO_2, CH_4 and N_2O, if emissions from the IPPU sector are excluded (i.e., if emissions from this sector are considered negligible). These have been the main GHGs targeted since the first commitment period of the UNFCCC's Kyoto Protocol.

3.2.3. Global Protocol for Community-scale GHG emission inventories

The Global Protocol for Community-scale GHG emission inventories (GPC) provides guidance by the World Resources Institute, ICLEI and the C40 Cities Climate Leadership Group. 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+ (Kean Fong et al., 2021).

— The BASIC level comprises sectors and sources that dominate GHG emissions in most cities, including in-boundary stationary energy and transport sources, and in-boundary emissions from locally generated waste.

— The BASIC+ level includes the sectors of the BASIC level and emissions associated with IPPU, AFOLU, transboundary transport, 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 under the GPC framework cities should account for emissions occurring within city boundaries separately, so that they can be used to aggregate multiple city inventories.

In the GPC framework, cities should include all reference GHGs regulated under the Kyoto Protocol: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3.

3.2.4. PAS 2070

The PAS 2070 ([12]) is a standard of the British Standards Institution that specifies requirements for the assessment of GHG emissions of a city or an urban area. Published in 2013 and amended in 2014 (PAS 2070:2013+A1:2014), it was the first framework including guidance on consumption-based GHG emission accounting in the European context (Balouktsi, 2020). In fact, it provides guidance on two alternative methodologies, both beyond common practice in terms of scope and coverage.

— The direct plus supply chain (DPSC) methodology covers direct GHG emissions from activities within city boundaries and indirect emissions from large supply chains serving cities, namely grid-supplied energy (electricity, heating and/or cooling), transboundary travel (e.g., airline and commuter travel) and supply chains of key goods and services, including water supply, food and

[12] https://www.en-standard.eu/

drinks and construction materials. As such, it covers scope 1 and 2 emissions, and a selection of scope 3 emissions. This methodology builds on the GPC framework.

— The consumption-based (CB) methodology covers direct GHG emissions from the combustion of fuels in residential buildings and private (residents') vehicles and life-cycle GHG emissions associated with the residents' final consumption of all goods and services. It accounts for GHG emissions associated with the final consumption of city residents, and excludes impacts of production of goods and services within the city that are exported for consumption elsewhere, visitor activities, and goods and services provided to visitors.

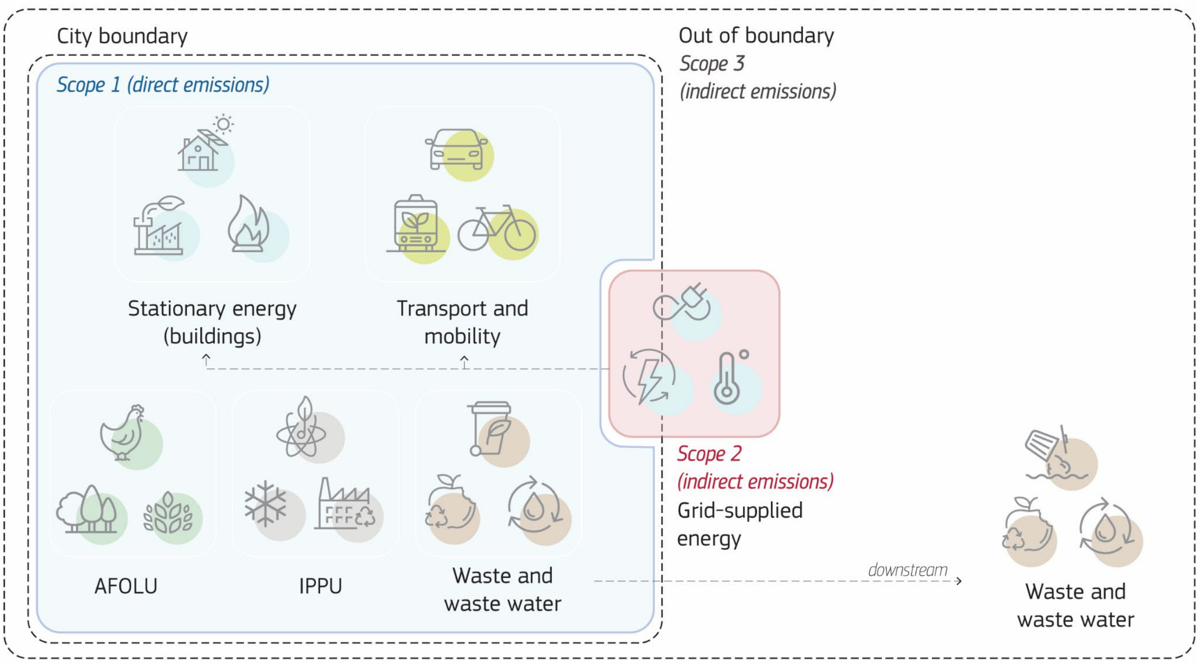
The DPSC methodology is broadly equivalent in scope to the GPC BASIC+ guidance and to the LC-based approach of the EU CoM. The CB methodology uses input-output (IO) data to estimate the consumption of goods and services, in opposition to all other reference frameworks mentioned in this section, which use bottom-up process-based methods.

In both methodologies cities should include all reference GHGs regulated under the Kyoto Protocol: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3.

3.2.5. Overview: what is 'common practice'?

A summary of the activity sectors and scopes typically covered in GHG inventories under the Cities Mission, EU CoM, GPC and PAS 2070 frameworks is provided in Table 2. Figures 5 and 6 illustrate what can be considered as common practice.

Figure 5. Common practice in GHG emission accounting: typical boundaries, sectors and scopes used by European cities



Source: JRC.

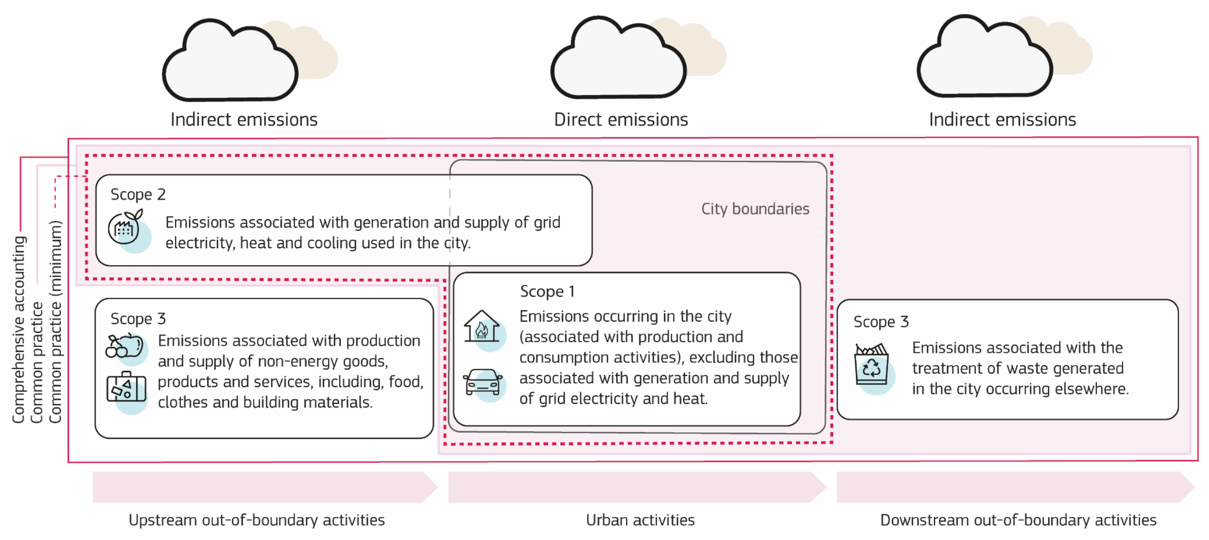
Table 2. Summary overview: activity sectors and scopes included in city-level GHG accounting frameworks

Sector	Cities Mission	EU CoM	GPC	PAS 2070	Remarks
Stationary energy (or Buildings)	1, 2	1, 2*	1, 2	1, 2, 3	This sector focuses on energy use in buildings. The local generation of energy that is supplied to the grid should be excluded or treated separately to avoid double-counting. Emissions associated with local energy generation (conversion) within city boundaries may be incorporated in EU CoM inventories through an emission factor that is applied to all sectors using energy (not reported under a specific sector). PAS 2070 includes emissions associated with the transmission and distribution of grid-supplied energy (separating them from generation emissions), along with emissions from upstream activities associated with the supply of fuels and other materials. Scope 1 fugitive emissions should be included in the GPC and in PAS 2070, and may be included in the Cities Mission and in the EU CoM. In GPC's BASIC+ framework recommends the inclusion of scope 3 emissions.
Transport and mobility	1, 2	1, 2*	1, 2	1, 2, 3	Emissions associated with the share of 'in-city' transboundary trips should be accounted for; however, this is challenging, and transboundary travel is often excluded or simplified. Crossing flows may be excluded (e.g., a highway crossing the territory with no access/exit points for the city) in the EU CoM framework. While the most significant mobile source of emissions in EU cities is typically road transport, most frameworks recommend the inclusion, if relevant, of scope 1 and 2 emissions for waterborne navigation, aviation and off-road transport sources. PAS 2070 specifies that GHG emissions associated with air transport and the shipping of people and goods to the city should be included, even if the airports or ports serving the city are not within its boundaries. The Cities Mission and GPC's BASIC+ framework recommend the inclusion of scope 3 emissions.
Waste	1, 3	—	1	1, 3	The EU CoM recommends the inclusion of GHG emissions associated with the treatment of waste and waste water generated within the city, but it is not common practice. The GPC BASIC+ recommends inclusion of scope 3 emissions associated with waste treatment.
IPPU	1	—	1	1, 3	—
AFOLU	1	—	1	1	—
Goods and services	—	—	—	1, 3	The PAS 2070 DPSC methodology includes goods and services that are 'of exceptional importance to life in cities' or 'known to account for a significant share' of cities' GHG emissions. These include water provision, food and drinks, construction materials and any other goods and services with significant GHG emissions, identified, for example, based on previous assessments, publicly available data or screening analyses.

* The life-cycle-based approach of the EU CoM framework includes upstream GHG emissions associated with the energy supply chain; however, it is not commonly used among cities.

Sources: JRC based on Bastos et al. (2025), European Commission (2021b) and Kean Fong et al. (2021).

Figure 6. Coverage of city-level GHG inventories and types emissions by scope



Source: JRC.

4. Why should we advance common practice?

The brief overview of frameworks and guidance in Chapter 3, provides a baseline – a reference for common GHG emission accounting practice at the city level in the European context. To date, GHG accounting frameworks and GHG mitigation actions at the city level have mostly focused on scope 1 and 2 emissions, while scope 3 emissions have often been excluded (Wang et al., 2018). However, research has demonstrated that scope 1 and 2 emissions provide an incomplete picture of the overall GHG emissions associated with cities. Moreover, as a result of the current trends of increasing urban population and final consumption and globalisation of supply chains, it is likely that the relative share of out-of-boundary emissions associated with urban consumption will continue to 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, with higher-income economies being the main source of this increased demand (IRP, 2019).

Currently, a large share of current final consumption (goods and services) in European cities relies on global value chains (Allan et al., 2023; Cabernard et al., 2021). In global value chains, raw materials are often imported by a producer, to then be processed and sold as an intermediate product to another producer elsewhere and eventually sold as a product for final consumption. GHG emissions are generated at each step and location across the supply chain (Cabernard et al., 2021). The United Nations Environment Programme's International Resource Panel (UNEP IRP) published a report on the carbon, water stress and biodiversity loss footprints of global material production. The report 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 (Cabernard et al., 2021a). The concentration of population and activities in cities offers a unique opportunity to reduce material demand and associated GHG emissions, by increasing the efficiency of systems' and products' supply, for example through shared infrastructure and services (IPCC, 2022).

Comprehensive inventories provide a holistic systems overview of GHG emissions associated with cities, which is important to inform decision-making. They allow for the identification of hotspots, priorities and improvement opportunities, as they provide important insight on the significance of key emission sources and of opportunities for improvement across urban systems and along supply chains. Moreover, they also contribute to identifying potential risks, trade-offs and burden shifts that may occur, for example, between sectors or regions (e.g., carbon leakage). Consistent comprehensive GHG inventories also promote transparency, benchmarking and peer-to-peer learning.

As previously mentioned, territory-based approaches excluding scope 3 emissions may overlook potential burden shifting and carbon leakage (Balouktsi, 2020). For example, burden shifting may occur when tackling GHG emissions associated with buildings. While the use or operational phase of typical or conventional buildings can account for over 80% of overall life-cycle GHG emissions (Huang et al., 2024; Nemry et al., 2008; Sartori et al., 2007), state-of-the-art construction solutions (e.g., zero-energy buildings) have sharply reduced GHG emissions associated with the operational phase. However, typical measures related to energy efficiency and renewable energy in new construction along with building retrofits, are often associated with increased material demand (e.g., for insulation or photovoltaic panels). Without a life-cycle perspective, stakeholders and policymakers may not be aware of an overall reduction in emissions; and, in some cases, a tipping point may eventually be reached, beyond which reducing operational GHG emissions may result in increased overall emissions (Ipsen et al., 2019; Rodrigues et al., 2014). Lastly, consumption-based, scope 3 and transboundary GHG emission accounting can inform, encourage and facilitate cooperation among stakeholders, and across cities and regions.

Box 3. London case study: application of PAS 2070

A case study of London (GLA, 2013) compares the following three approaches.

— The London Energy and Greenhouse Gas Inventory (LEGGI) covers scope 1 and 2 CO_2 emissions (only) from the combustion of energy within city boundaries to provide transport, power and heat. It broadly represents common (minimum) practice in city-level GHG inventories.

— The Direct Plus Supply Chain (DPSC) approach covers direct GHG emissions from activities within city boundaries and indirect emissions from grid-supplied energy, transboundary travel and supply chains of key goods and services, for example, water supply, food and building materials. The approach therefore includes scope 1 and 2 emissions and a selection of scope 3 emissions.

— The Consumption-based (CB) approach covers direct and life-cycle GHG emissions for all goods and services consumed by residents of a city. It excludes impacts of the production of goods and services within a city that are exported for consumption elsewhere, visitor activities, and goods and services provided to visitors.

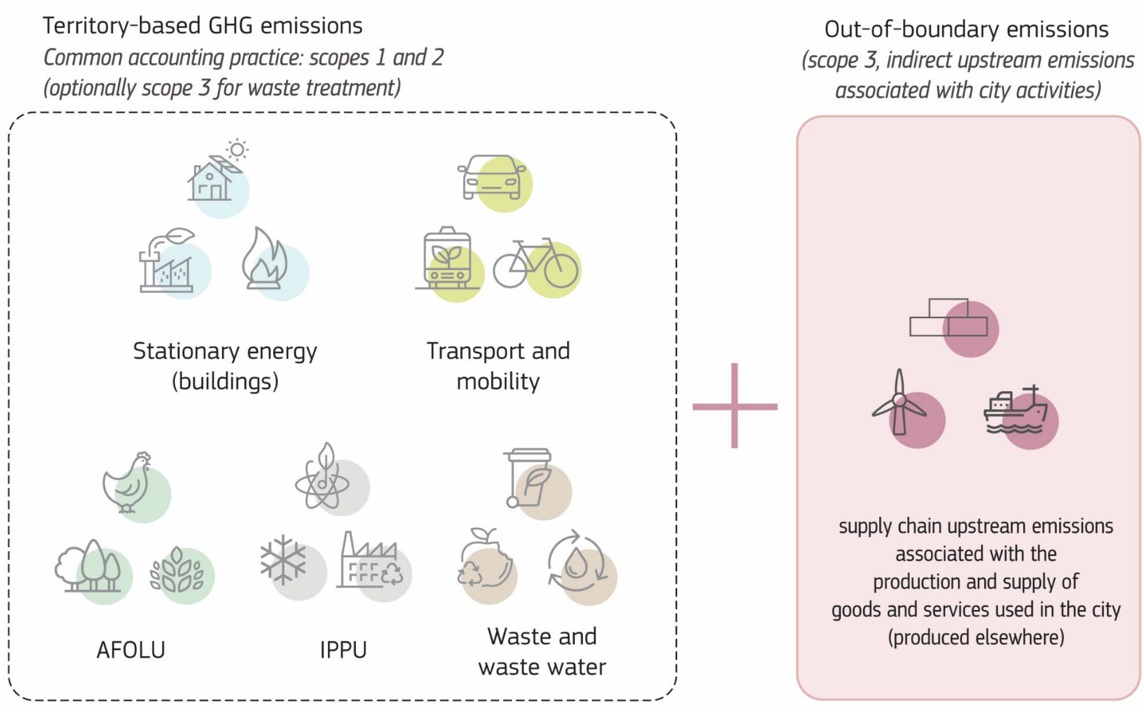
The DPSC and the CB approaches draw on the PAS 2070 (see Section 3.2.4), which aims to provide a robust and transparent method for consistent, comparable and relevant quantification, attribution and reporting of city-scale GHG emissions. It encourages more holistic GHG assessments, greater disclosure 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.

Results highlights. GHG emissions calculated using the CB approach are 40% higher than those calculated using the DPSC approach, and 157% higher than those calculated based on the LEGGI (114 Mt CO_2-eq, 81 Mt CO_2-eq, and 44 Mt CO_2-eq, respectively). The case study highlights the relevance of the DPSC methodology to future planning of measures and infrastructure addressing water, energy and material use, and waste management in cities.

Another important contribution of more comprehensive GHG inventories come from their ability to inform on and monitor actions that promote the circular economy (CE). In recent years, many cities across the EU have developed CE action plans, and CE measures are increasingly considered in local climate action. A significant potential of CE actions lies in 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).

Overall, research and practice have consistently showed that the majority of GHG emissions associated with cities fall under scope 3, originating outside the geographical boundaries of cities. The significance of upstream emissions — embedded in the goods, services and infrastructure used in urban areas— underscore the critical need to adopt consumption-based accounting methods or, at least, to add supply chain emissions to current territory-based inventories (see Figure 7), in urban climate strategies (Moran et al., 2018; Wiedman, Chen, et al., 2015).

Figure 7. GHG emissions associated with cities:
adding upstream emissions associated with urban consumption



Source: JRC.

In summary, current GHG inventories provide limited insight on (i) overall GHG emissions associated with urban areas and activities, and (ii) potential opportunities for mitigation of GHG emissions through local climate action (Wang et al., 2018). The focus on territory-based GHG emission accounting has been criticized in inventories aimed at informing and monitoring reductions in GHG emissions, in particular for not including international transport and trade and for overlooking carbon leakage. Transboundary and out-of-boundary emissions are difficult to include due to challenges related to data availability and barriers related to what is perceived as assigning responsibility (Peters, 2008; Heinonen, 2025). 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 compiling more comprehensive, relevant and complete inventories.

To capture the actual GHG emissions from final consumption occurring along global value chains, research and practice have increasingly adopted consumption-based (CB) accounting (Balouktsi, 2020; Hung et al., 2019; Lin et al., 2017; Peters, 2008; Peters et al., 2008) ([13]). In recent years, CB approaches have been applied to countries, organizations and products, but also at the city, district and household levels (Balouktsi, 2020).

[13] The remainder of this report focuses mostly on consumption-based GHG emission accounting. While it does not correspond to scope 3 emission accounting (and other approaches can be adopted to estimate transboundary and/or out-of-boundary GHG emissions), it is the most common approach – used in research and practice – to developing GHG inventories at the city level with more comprehensive scopes and boundaries, including scopes 1, 2 and 3.

As mentioned, CB accounting typically covers 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, this type of accounting addresses supply chain choices and management (Cabernard et al., 2021; Hung et al., 2019). CB accounting provides key insight to inform local climate action (Larsen et al., 2010). CB accounting is typically structured in three domains: personal/private consumption, governmental consumption, and capital production (Heinonen, 2025). It is important in tackling GHG leakage and supporting more effective climate action, and it can provide useful metrics to inform residents, and help public administrations, organizations, companies and households make better-informed decisions on their choices (Lin et al., 2017; Wang et al., 2018).

Box 4. The C40 Cities Climate Leadership Group's analysis of consumption-based GHG emissions of 79 cities

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

In an analysis of 79 C40 cities, consumption-based (CB) emissions were estimated to be on average 60% higher than territory-based emissions (C40 Cities Climate Leadership Group, 2018). Overall, territory-based emissions of the 79 cities were 2.2 Gt CO_2-eq. CB emissions added another 2.2 Gt CO_2-eq and excluded 0.9 Gt CO_2-eq of territory-based emissions associated with exports. Cities in Europe, North America and Oceania had strong consumer profiles, with CB emissions more than three times larger than the estimated territory-based GHG emissions. CB emissions per capita showed large variability across the world, from 1.8 to 25.9 t CO_2-eq/capita. European cities' emissions ranged mostly from 10 to 15 t CO_2-eq/capita (C40 Cities Climate Leadership Group, 2018).

Looking at GHG emissions by consumption area (or sector), more than 60% of CB GHG emissions in European cities were associated with (i) utilities and housing (including water, electricity and gas consumption), (ii) capital (including physical assets such as infrastructure, construction and machinery), (iii) transport (including purchase and operation of vehicles) and (iv) food, beverages and tobacco. These sectors accounted for over 90 % of consumption-based emissions when taken together with clothing, furnishing and household equipment; government; and restaurants, hotels and other recreational activities (C40 Cities Climate Leadership Group, 2018).

Advantages of CB inventories also include accounting for international trade and thus covering more emission sources, increasing mitigation options and encouraging cleaner production and supply chains. However, CB inventories also have disadvantages and barriers. For example, they may involve more data, calculations, assumptions and uncertainties; they may be seen as shifting responsibility to consumers, rather than promoting and supporting shared responsibility between producers and consumers; and they may go beyond the geographical area of influence and power of geopolitical administration/authorities (Peters, 2008; Heinonen, 2025). Moreover, it is important to highlight that the quality and reliability of CB inventories are inherently dependent on the availability of good-quality data on urban activities (i.e., city-level activity data), which should cover more sectors and processes than current territory-based inventories (e.g., food consumption), but also on the supply chains and trade of goods and services (often global data).

5. Methods, tools and data for more comprehensive GHG accounting

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

Typically, GHG emission accounting in European frameworks has mostly relied on bottom-up process-based modelling where input activity data are collected and multiplied by GHG emission factors to estimate overall emissions by sector. GHG emission modelling can range 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 aims to support cities and practitioners, and to provide the basis for the development of consistent and easily applicable GHG accounting frameworks for European cities, it focuses on relatively simple approaches using commonly accessible, reliable (and regularly updated) input data sources and methods.

Research on GHG emission accounting at the city level has increased in recent years. Due to the complexity and diversity of activities, systems and emission sources in cities, analyses on consumption-based or holistic emission accounting have often used top-down methods, in particular input-output (IO) models. Such approaches typically downscale IO data on economic flows between industries and sectors, and between production and consumption, from the national to the regional or city level, and combine them with environmental data to develop environmentally extended input-output (EE-IO) models (Allan et al., 2023). These can include GHG emissions and other environmental impacts associated with economic activities at the local level. Conversely, bottom-up methods, have had limited application in more comprehensive GHG inventories, including scope 3 emissions, at the city level. This is probably related to the lack of a consistent bottom-up framework and to the significant data collection and modelling requirements associated with the methods. Some examples of this kind of GHG accounting have used statistical data on consumption, obtained for instance through household consumption surveys at the local level, combined with GHG emission data (Allan et al., 2023).

Box 5. Types of methods for developing GHG emission information based on guidelines of the Integrated global greenhouse gas information system (IG^3IS)

A set of urban good practice guidelines, based on established and evolving scientific GHG emission accounting methodologies, were published in the World Meteorological Organization's (WMO) integrated global greenhouse gas information system (IG^3IS). Since the first version of this guidance, entitled *IG^3IS urban greenhouse gas emission observation and monitoring good research practice guidelines* (Turnbull et al., 2022), was published, several technical areas have matured or expanded. Recently, the guidance was updated to reflect state-of-the-art research (WMO, 2025). The document highlights the increasing adoption and integration of alternative methods for GHG emission accounting in research and practice.

The IG^3IS guidelines identify three main types of methods for developing GHG emission data.

— Process models leverage emission data such as activity and process information (e.g., traffic counts, vehicle characteristics, fuel consumption) to estimate and map time-specific and sector-based emissions. They often provide estimates at the source level, and thus include details, for example, on fuel, technology and sometimes ownership.

— Direct atmospheric observation methods, depending on the technique, may offer emission information at various levels of detail. Direct observational methods can be particularly important for validating results, and 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.

The IG^3IS guidelines provide 'Extended technical discussions' dedicated to specific methodologies or techniques, which are intended for use as a resource to guide researchers and practitioners in implementing methods.

5.1. Process-based methods

As mentioned, European frameworks for city-level GHG emission accounting have typically adopted process-based bottom-up approaches. These models use statistical and observational data to describe urban activities (e.g., building floor areas, electricity use in buildings, distances travelled by car, traffic counts, fuel sales, population/demographic data), and multiply that data (referred to as activity data) by GHG emission factors.

The main advantage of process-based methods is that they build directly on the link between activities and emissions, which is important 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), along with spatial and temporal details, which are also relevant to policymaking (Fong et al., 2021). The availability of activity data at the city level is often limited, however, and data may have to be downscaled from national- or regional-level data (e.g., using proxy data to break down and/or adjust inputs), which can introduce significant uncertainty. Developing detailed bottom-up emission inventories can also be resource intensive (in terms of time, labour, expertise and data). Lastly, since bottom-up models tend to be more context-specific (e.g., using local data and making methodological choices that reflect the local context), they may, in some cases, be less transparent and result in limited comparability among cities.

Extending the scope and coverage of GHG emission accounting to provide more comprehensive inventories, including transboundary and out-of-boundary emissions, is likely to exacerbate the challenges associated with process-based methods by (i) increasing data and resource requirements, (ii) increasing uncertainty associated with the downscaling and extrapolation of data and other calculations, and (iii) affecting the interpretation of data and comparability among cities. As a result, researchers and practitioners developing more comprehensive inventories, including scope 3 emissions, have considered bottom-up modelling unpractical and burdensome for whole-city GHG emission accounting.

5.1.1. Process-based life-cycle approaches

Life-cycle assessment (LCA) is a standardized methodology for quantifying potential environmental impacts associated with a product, system or service throughout its entire life cycle, from raw material extraction to end of life (ISO 14040:2006; ISO 14044:2006). It has been widely applied to a variety of research areas, and can be particularly important to support decision-making because of its function-oriented and holistic nature, which can help identify environmental hotspots and potential burden shifts and trade-offs (Barkhausen et al., 2023). Process-based life-cycle approaches have been widely applied in GHG emission accounting for products and companies, for example, and have become increasingly relevant to EU policymaking (Sala et al., 2021).

LCA has been combined with urban metabolism (UM) and material flow analysis (MFA) (Goldstein et al., 2013; Ipsen et al., 2019; Lavers Westin et al., 2019), to account for flows (and resulting consumption) associated with urban areas and then estimate their environmental impacts (through process-based LCA). MFA systematically models and quantifies flows (inputs and outputs) and stocks of materials associated with systems, defined by spatial and temporal boundaries, building on mass balance principles (Brunner et al., 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 et al., 2017; Graedel, 2019). MFA has gained particular attention in recent years, with the increasing importance of the 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 the national level – for example, Member States report their economy-wide material flow accounts (EW-MFA) yearly – however, its application at the regional and city levels is still limited, mostly due to a lack of a standardized methods and data at the 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 et al., 2021), which have been increasingly applied in specific sectors, such as buildings and 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 geographical levels, such as regional and urban areas, to provide increasingly comprehensive assessments would be a valuable advancement and research contribution to support policymaking in relation to sustainable development (Barkhausen et al., 2023; Graedel, 2019). Life-cycle-based approaches have also been combined with the use of expenditure data at the household level, for example in the distributional consumption footprint assessment developed by Ciccolini et al. (2024).

Life-cycle-based approaches offer important advantages over IO approaches (discussed in Section 5.2). Firstly, LCA models have a high level of granularity and disaggregation, providing insight on the linkages between activities, processes and GHG emissions. Secondly, process-based LCA enables the compilation of a comprehensive inventory of GHG emissions and the simultaneous assessment of multiple environmental impacts (Castellani et al., 2019). This information can support the identification of environmental hotspots, co-benefits and trade-offs; guide targeted policy action; and enable detailed policy scenario analysis (Sala et al., 2022).

However, the application of process-based life-cycle approaches to develop city-level GHG inventories has high resource requirements – namely in terms of data, time and expertise/knowledge. Its wide application to promptly support GHG mitigation action across European cities is challenging. Two crucial steps to improve the application and uptake of these approaches to support local climate action are increasing the availability of good-quality life-cycle inventory (LCI) data that are representative of the specific context and supply chains of European cities, and developing a consistent framework, widely applicable by practitioners. The accuracy and quality of holistic bottom-up LCA-based GHG inventories is highly dependent on the quality and representativeness of LCI data.

5.1.2. EU Consumption footprint

The EU Consumption footprint (CF) model estimates life-cycle environmental impacts of household consumption at the EU and at the national level, considering not only direct impacts (associated with the use of products and services), but also impacts taking place in other regions of the world (e.g., emissions associated with products imported for consumption in a country), by considering ‘apparent consumption’ – that is, local production plus imports minus exports (Sanyé-Mengual et al., 2025). The Consumption footprint Platform hosted by the JRC provides annual data on the domestic and consumption footprints of the EU and its Member States.

The CF model considers five areas of household consumption: 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 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 (with a selection of representative products of the consumption area) and process-based LCA models were developed for each representative product and consumption area (Sala et al., 2019).

In brief, the CF model is structured in four steps:

— selection of representative products by consumption area;

— compilation of apparent consumption data by representative product for the year under assessment using statistical data;

- modelling of LCI datasets for the selected products representative of the products consumed in the EU (including representative use conditions and end-of-life treatment) combining both foreground and background data ([14]);
- calculation of environmental impacts per consumption area, country or person through the application of life-cycle impact assessment (LCIA) models.

For the LCIA, the CF employs the Environmental Footprint method (Andreasi Bassi et al., 2023), as recommended by the European Commission for the assessment of environmental impacts of products and organisations ([15]). In the case of GHG emissions, the climate change impact category is currently based on the GWP from the AR6 of the IPCC (Forster et al., 2021).

Recently, the CF model has been applied to the city of Turin, Italy (Genta et al., 2022). The adaptation of the model to the city level included: (i) identification of data sources with suitable geographical resolution and product granularity; (ii) alignment of local data with the CF structure in terms of consumption, product group and representative product, and (iii) identification of the potential need for unit conversion (e.g., translating monetary terms (EUR) into mass-based units (kg)). LCIs for representative products modelled for the EU have been applied to city-level consumption data. These factors consider the environmental impact throughout the entire life cycle of each representative product.

While Genta et al. (2022) employed EU-average LCIs from the CF model (and thus GHG emission factors), JRC researchers have developed another set of emission factors for EU Member States with improved temporal and geographical representativeness (Sanyé-Mengual et al., 2023). The learnings from Genta et al. (2022) and recent developments could be the basis for a new GHG accounting framework that facilitates the application of LCA approaches at the city level. When discussed with stakeholders, the CF model was considered promising for monitoring the implementation of the circular economy in cities with the potential for improvement, namely by refining and adapting data to local conditions (e.g., by adding representative products) (Genta et al., 2025).

5.2. Input-output and expenditure-based methods

Input-output (IO) analysis is a commonly used methodological approach in economic and environmental assessments at the macro level (e.g., macro-regions, the national level). IO analysis emerged as a field in the 1930s, driven by the work of economist Wassily Leontief, who was awarded the Nobel prize in economics for his contributions. The approach draws on the

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[14] LCAs rely on background databases that provide a detailed life-cycle inventory (LCI) of technological processes and their emissions, for example, electricity production, transport or other manufacturing processes. LCI databases typically allow the combination of background and foreground data (i.e., primary, context-specific data collected by researchers and practitioners) to build comprehensive and representative LCIs. Background databases combine measured and modelled data.

[15] Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the environmental footprint methods to measure and communicate the life cycle environmental performance of products and organisations (OJ L 471, 30.12.2021, p. 1, ELI: http://data.europa.eu/eli/reco/2021/2279/oj).

quantification of flows of goods and services between sectors in an economy, through production and consumption of intermediate outputs (Leontief, 1951, 1966, 1970).

IO-based approaches have been increasingly used for GHG emission accounting on a national scale in recent decades, as they provide a consistent top-down methodological framework for estimating GHG emissions and other environmental impacts associated with final demand or consumption, including international trade (Miller et al., 2009; Wiedmann, 2009) ([16]).

IO analysis is based on input-output tables (IOTs), which describe monetary transaction flows (e.g., intersectoral 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 with 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 as a 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 countries' national accounts.

Essentially, IOTs provide tabular representations of how much the various sectors of the economy supply and use (in monetary units) of various goods and services, and how much of each sector's outputs are sold (i) as intermediate inputs to other sectors, (ii) as goods for final consumption by households or governments, or (iii) 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 index column, while the cells in the table describe monetary flows (inputs and outputs) between them (i.e., purchases and sales), along with sales to final consumers (e.g., households).

The fundamental principle in IO analysis is that the accounts of how much each sector purchased from all other sectors over the year describe the direct requirements to produce the sector's own outputs. This allows the assessment of economic activity of a given demand by tallying the direct input requirements from all sectors and then carrying out the same procedure to these inputs, and continuing this process upstream to eventually describe the total (overall) requirements – inputs and outputs – of each sector. However, the linkages between monetary transactions, flows of physical goods and services, and related environmental impacts in IO approaches are associated with significant constraints and limitations, in particular due to homogeneity assumptions and sectoral aggregation (Wang et al., 2018).

Over the past few decades, there has been a growing interest in applying IO-based methods to assess the environmental impacts associated with final demand and different economic flows, sectors and goods. In this context, IO data can be combined with data from environmental accounts, to provide insight on GHG emissions and other environmental aspects. Environmentally extended input-output (EE-IO) models add, for example, GHG emissions associated with production (using GHG emission factors per economic sector) (Tukker et al., 2016).

In this report, we distinguish single- and multiregional IO analyses, each with different capabilities and limitations. In a standard single-region input-output (SRIO) model, an important issue is how to

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

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 and impacts as domestically produced goods (Wiedmann, 2009). As supply chains have become increasingly complex and global over the years, the implications of this assumption have become more important.

To address this issue, a multiregional input-output (MRIO) model combines IO models for several regions into a single modelling framework, thus allowing the analysis to explicitly model imports from other countries (Wiedmann, 2009). In principle, a MRIO model is constructed similarly to a single nation's IOTs, tabulating flows between different sectors in different regions (countries) of the world. MRIO models can capture regional differences in production efficiency and track the supply chain, providing information on where GHG emissions associated with consumption occur. This is relevant for understanding international flows and their associated GHG emissions, and for understanding the relative contribution of economic sectors and geographical linkages, which is important in supporting action to mitigate GHG emissions (Xu et al., 2023). However, MRIO databases and analyses involve higher data requirements and modelling complexity than SRIO. They consider detailed import and export data, which are generally not available in national accounts.

As computational power has become increasingly available, several environmentally extended multiregional input–output (EE-MRIO) databases have been developed in recent years (see Section 5.2.2 for an overview). Using these, researchers have been able to perform various consumption-based environmental analyses for various countries or regions of the world (Alsamawi et al., 2014; Hertwich et al., 2009; Steen-Olsen et al., 2012; Wiedman, Schandl, et al., 2015), and several countries, such Sweden ([17]) and the United Kingdom ([18]), publish annual national carbon footprint accounts based on EE-MRIO frameworks.

Several analyses have applied, extended and/or modified MRIO databases to allow for more tailored environmental assessments.

- By combining MRIO tables at the national level with detailed data on household consumption at the local level, for example from consumer expenditure surveys, several studies have provided more detailed household carbon footprints with emission contributions, broken down by specific products or activities (Ivanova et al., 2017, 2020). However, consumption-based approaches based on household expenditure data alone (i.e., estimating GHG emissions associated with private final consumption) may exclude significant emissions associated with governments, public buildings, infrastructure and capital goods, and services/investments (i.e., government final consumption and business capital) (Balouktsi, 2020).

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[17] https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/environmental-accounts-and-sustainable-development/system-of-environmental-and-economic-accounts/

[18] https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/ukenvironmentalaccounts/2025

— Some MRIO databases feature a wide range of extensions, for example including different types of labour, land use, water use and primary energy requirements. Drawing on these, researchers have been able to show how consumption activities in one region may contribute to a wide range of effects across the world – including effects such as threatening endangered species, exacerbating poor working conditions or increasing water demand in water-stressed regions of the world.

— IO methods and data can be combined with LCA or other process-based methods in hybrid analyses, so that the benefits of both approaches are reaped: using LCA to analyses specific activities or processes in detail and give accurate process-specific results, while drawing on a background IO model to capture upstream effects that are often outside the system boundary of an LCA model (Hagenaars et al., 2025).

5.2.1. Application to cities

IO models have been increasingly applied to build consumption-based GHG inventories at the regional and city level (Lin et al., 2017; Peters, 2008; Wang et al., 2018). Since IO tables are generally compiled at the national level, they are not readily applicable to cities. As such, several approaches have been proposed to disaggregate national IOT data, using regional or local statistical data or by constructing a regional (or city-level) IOT and combining this context-specific data with a national IOT or an MRIO database.

MRIO models have been increasingly used in this context (Cabernard et al., 2021b; Lin et al., 2017; Xu et al., 2023). MRIO models can describe the 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. (2017) proposed a city-centric global MRIO model that focuses on final consumption in individual cities, using sectoral products from a diversity of countries and geographical regions worldwide. Wang et al. (2018) proposed an IO-LCA carbon accounting framework to quantify sectoral indirect upstream supply chain emissions at the city level, including direct emissions, energy-related upstream emissions (scope 2) and complete supply chain emissions (scope 3). The results showed that scope 1 and 2 emissions accounted for 28% of total supply chain and use emissions for the city of Chongqing, China.

Other approaches have combined IO data on economic flows, value of goods and GHG emission factors at the national level with household expenditure data at the local level. By combining MRIO data with detailed local data on household consumption, for example from consumer expenditure surveys, several studies have provided detailed household carbon footprints, with emission contributions broken down by specific sectors, products or activities. 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 also alternative approaches on how to share allocation of emissions among producers across supply chains (Peters, 2008).

Globally, China has published the highest number of IO-based carbon footprint studies of cities, followed by Finland, Australia and the United States (Heinonen et al., 2020). In China, studies have frequently combined MRIO models with municipal or provincial IOTs to quantify both territory-based, transboundary and out-of-boundary emissions (Lin et al., 2017; Zheng et al., 2019).

Similarly, in Japan, Hasegawa et al. (2015) applied non-survey techniques using single-region IO tables and regional (inter-prefectural) trade data to estimate city carbon footprints.

When city-level data are not readily available, researchers often rely on proxy indicators — such as population statistics or income distributions — to downscale national IO tables to the city level. This approach has proven especially useful in cross-country studies, such as the work by Moran et al. (2018), who analysed urban emissions across European and other global cities using these downscaling techniques.

In the European context, a range of methodological frameworks have been applied, mostly depending on data availability and spatial scope and resolution. Luxembourg is a notable example, where a hybrid IO model was used to integrate process-based LCI data with IO tables (Caro et al., 2015). Other European cities have combined IO models with household expenditure data to estimate consumption-based emissions. For example, London's GHG inventory incorporates average household expenditure across different goods and services, using publicly available data from the UK government ([19]). In Finland, Ala-Mantila et al. (2013) employed household expenditure surveys to develop carbon footprints of cities. Minx et al. (2013) developed a hybrid MRIO-based method for analysing UK cities, combining household expenditure and lifestyle survey data. Their methodology expanded on household-survey–based approaches by integrating MRIO models with data on government services and capital investments, downscaled from national statistics to the local level. This hybrid method aligns with the principles of the PAS 2070 standard, which promotes a consistent and comprehensive framework for assessing city-level carbon footprints.

In Australia, Wiedman, Chen, et al. (2015) conducted a high-resolution study on Melbourne, combining detailed household surveys with IO data. Their work highlights the importance of harmonizing heterogeneous data sources (e.g., differing sector classifications and spatial scales), which, if not carefully managed, can introduce significant uncertainties in city carbon footprint analyses.

[19] https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/ukenvironmentalaccounts/2025

Box 6. The C40 Cities Climate Leadership Group's analysis of consumption-based emissions for 79 cities: methods in a nutshell

> The C40 Cities Climate Leadership Group's analysis of consumption-based emissions for 79 cities draws on PAS 2070 and uses household expenditure data on goods and services, government-provided services and business capital investment. To calculate supply chain emissions, PAS 2070 recommends using an EE-IO model, which can estimate the spending (final demand) of households and governments, along with business capital expenditure. The model builds on financial flow data from national and regional economic accounts, which are combined with average GHG emission factors for each sector/consumption area, depending on the origin of goods and services (local, national or rest of the world) (C40 Cities Climate Leadership Group, 2018).
>
> The analysis used data from the Global Trade Analysis Project (GTAP) (Carrico et al., 2020) - a global MRIO database (see Section 5.2.2) –to calculate GHG emissions associated with the resident population (excluding visitors).

5.2.2. Multiregional input-output databases

Several MRIO databases exist, with various characteristics, strengths and weaknesses. Due to the complexity and resource requirements involved, such databases are typically developed by research consortiums over several years. An MRIO database for GHG emission 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 geographical regions (Cabernard et al., 2021). EXIOBASE 3 and Eora26, for example, are databases with harmonized country and sector disaggregation, covering a large set of environmental pressures over an extended time series (Cabernard et al., 2021). However, the development and updating of MRIO databases is data and resource intensive, which can result in limited availability of recent data, and limit their applicability to monitoring progress of GHG mitigation action at the city level. Typically, these databases are updated with a two- to three-year lag (i.e., the most recent year available is usually at least two years old).

The Global Trade Analysis Project (GTAP) has developed a global trade database released in several versions over the years, from which an MRIO model can be constructed (Andrew et al., 2013). The Figaro database is a relatively recent MRIO dataset managed under Eurostat, the statistical office of the EU. Unlike many MRIO databases dependent on research funding, Figaro benefits from institutional support, allowing for annual updates. This ensures the availability of more timely and consistent data for environmental and economic impact analyses. Table 3 provides an overview of (well-known) reference MRIO databases developed over the years. The GTAP database, World Input–Output Database (WIOD), EXIOBASE and Eora have all been applied in city-level carbon footprint studies (Heinonen et al., 2020), and the recently published Figaro database is a promising candidate for city-level studies within the EU.

Table 3. Selection of MRIO databases and their main characteristics

Database	**Reference**	**Description**
GTAP MRIO	Carrico et al. (2020)	Version 10A of the GTAP MRIO database details 65 sectors for 141 countries and 19 aggregate regions. It has five reference years, with the latest being 2017.
EXIOBASE	Stadler et al. (2018)	Version 3.9 of EXIOBASE contains a time series of annual EE-MRIO tables from 1995 to 2020, along with nowcasted tables for 2021 and 2022. It details 43 countries (including all 27 Member States) and five aggregate regions to represent the rest of the world. Each region includes 200 products and 163 industries. A broad range of environmental extensions are included in the database.
Eora	Lenzen et al. (2013)	The Eora MRIO features a time series of MRIO tables from 1990 to 2022. It models 190 countries with varying numbers of sectors (in total 15 909 sectors, or an average of 84 per country, though many smaller countries are modelled with the minimum 26 sectors and other countries feature several hundred sectors), and a wide range of environmental extensions. A less detailed version, Eora26, features 26 sectors per region.
OECD-ICIO	Yamano et al. (2023)	The Inter-Country Input-Output (ICIO) MRIO database of the Organisation for Economic Co-operation and Development (OECD) models 45 sectors for 76 individual countries and 1 rest-of-the-world region, in a time series with annual tables from 1995 to 2020.
Figaro	Eurostat (2019)	Figaro is an MRIO database developed and maintained by Eurostat and the JRC. It details 64 sectors for 46 regions in a time series of annual tables for 2010 to 2022. It also includes GHG emissions as an environmental extension. The database is freely available on Eurostat's website.
WIOD	Timmer et al. (2015)	The WIOD was developed as part of a research project funded by the European Commission, and is currently hosted by the University of Groningen. The latest database release, from 2016, covers 44 regions and 56 sectors, with annual tables up to 2014. It includes CO_2 emissions as an environmental extension.

NB: This overview of relevant EE-MRIO databases is non-exhaustive.

Source: JRC.

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

Several recent analyses can be found in the literature applying IO approaches to accounting for GHG emissions at the city level across the Europe.

— Allan et al. (2023) presented a framework for downscaling IO tables to the city level and for calculating production- and consumption-based carbon accounts, the latter from area- and person-based perspectives, simultaneously. The framework was applied to Glasgow, Scotland, for 2014, and the results highlight the importance of data quality and knowledge specific to the local context. The framework used the same data sources/inputs to produce two inventories – one from a consumption-based perspective and the other from a production-based perspective. The authors used WIOD's emission intensities of individual sectors at the national level, which were applied to represent the emissions intensities of the same sectors at the city level. The analysis also compared three ways to downscale national emission intensities to reflect the local context, while preserving overall national emissions, and showed how these approaches influenced the results. GHG emissions were 3 703 kt CO_2 for the production-based approach, 6 500 kt CO_2 (76% higher) for the area- and consumption-based approach, and 4 575 kt CO_2 for the person- and consumption-based approach. The latter used household final consumption, and excluded the final demand of the public sector.

— Dawkins et al. (2024) developed carbon footprints of consumption of goods and services at the municipal and postcode levels in Sweden. The authors adopted a top-down approach using EXIOBASE and downscaling national data to the municipal and postcode levels, focusing on residents (i.e., making this a population-based approach). The analysis also compared downscaling approaches, identified hotspot sectors/categories and explored variation across municipalities. Results showed high variability: the national average carbon footprint was 6.3 t CO_2-eq/capita, with cities' footprints ranging from 3.7 to 17.8 t CO_2-eq/capita. There was a strong correlation between income and carbon footprint.

— Ala-Mantila et al. (2013) estimated GHG emissions using a consumption-based EE-IO model based on expenditure data, including 'direct and indirect life-cycle greenhouse gas emissions either home or elsewhere, which are ultimately caused by consumption of products and services'. The analysis combined data from a Finnish household budget survey with the EE-IO model Envimat, based on the Finish economy. The annual average emissions per capita for the Helsinki metropolitan area were 13.5 t CO_2-eq, with individuals' emissions ranging from 12.6 to 14.3 t CO_2-eq.

— Tukker et al. (2016) performed a MRIO-based comparative analysis of EU and non-EU GHG emission footprints at the country level for carbon, water, land and materials and, through a hotspot analysis, concluded that final consumption of food, transport and housing should be prioritized in efforts to reduce emissions throughout the life cycle.

5.3. Other potential methods and data sources

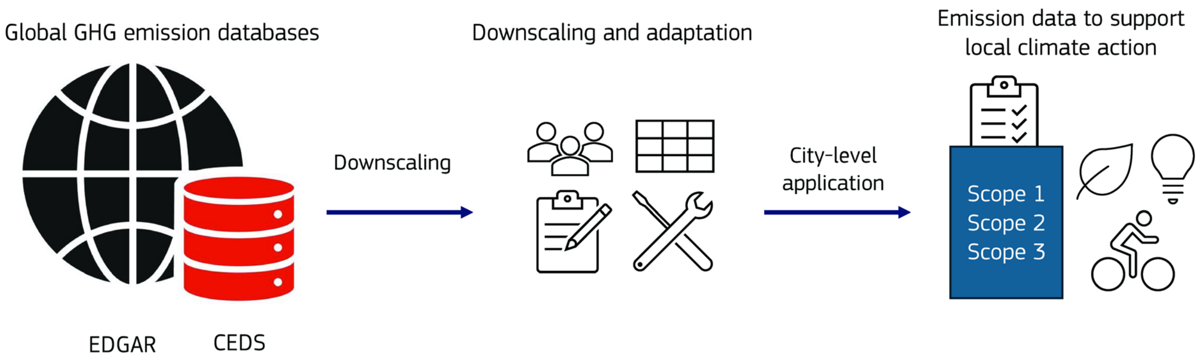
Global granular emission databases are typically developed using national-level GHG and activity data, which are downscaled to finer spatial resolutions (e.g., the region, city or grid-cell level), following a top-down approach. These databases may offer valuable resources for constructing city-level GHG inventories (Asefi-Najafabady et al., 2014; Crippa, Guizzardi, et al., 2021; Gilfillan et al., 2021; Hoesly et al., 2018; McDuffie et al., 2020; Oda et al. 2018; WMO, 2025). Reference databases include, for example, the Open-source Data Inventory for Anthropogenic CO_2 (ODIAC), the Fossil Fuel Data Assimilation System (FFDAS), the Emissions Database for Global Atmospheric Research (EDGAR), the Carbon Dioxide Information Analysis Center database (CDIAC) and the 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, along with 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;
— 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, 2025) 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 bridging the gap between global knowledge and consistency, with local action. Figure 8 illustrates this flow and sets the stage for a deeper look into two reference databases: EDGAR and CEDS.

Figure 8. Using global GHG emission databases to support local climate action



Source: JRC.

5.3.1. Emissions Database for Global Atmospheric Research

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

EDGAR can support city-level GHG emission 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° × 0.1°), which provide the possibility of overlaying cities' administrative boundaries with EDGAR's datasets to estimate territorial emissions (scope 1).

EDGAR serves as a benchmarking tool for estimating scope 1 emissions – that is, those that occur directly within the geographical boundaries of a city – such as fuel combustion in residential and commercial buildings, road transport and local industrial activities. These emissions are estimated using a globally consistent methodology based on the IPCC's Tier 1 methodology (along with some aspects of the Tier 2 methodology), ensuring comparability across regions and over time (Crippa et al., 2024). With regard to scope 2 emissions – that is, indirect emissions from the generation of electricity and heat used within the city — EDGAR provides data from power generation facilities, which can be combined with local consumption data to approximate a city's energy-related indirect emissions.

To date, EDGAR has not estimated scope 3 emissions. Ongoing developments within the EDGAR framework increasingly support the analysis of supply chain emissions. The EDGAR-FOOD approach (Crippa, Solazzo, et al., 2021, 2022), which focuses on emissions across the food supply chain, provides an example of how global emission inventories can be extended to include specific thematic domains. EDGAR-FOOD provides global, spatially explicit estimates of emissions across the food supply chain, covering agricultural production, processing, transport and distribution, and enabling the attribution of emissions to final food consumption rather than to the location of production alone. By integrating EDGAR emission inventories with food balance sheets, trade statistics and life-cycle emission intensities, EDGAR-FOOD supports the assessment of diet- and consumption-driven emissions.

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

Despite its strengths, EDGAR is not without limitations, particularly when applied at the city level. Its spatial resolution, while relatively adequate for a global dataset, can still be too coarse for smaller areas or for isolating emissions from adjacent cities. In addition, the disaggregation of national activity data to grid cells is associated with significant uncertainties. 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 bottom-up inventory.

As a result, EDGAR may be best used as a starting point for screening, or to validate city-level GHG inventory data. For example, Franco et al. (2024) used EDGAR 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 for evaluating the quality and usability of CoM datasets. This application supports greater transparency and improves the credibility of self-reported data.

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

5.3.2. Community Emissions Data System

CEDS ([20]) is a valuable open-access resource that provides a consistent time series of historical anthropogenic emissions. Designed to address gaps in long-term emission 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. Like EDGAR, CEDS combines national energy and industrial statistical data with GHG 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 subnational 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 insight into broader emission patterns. The system can be particularly valuable for cities lacking comprehensive local data, as it 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.

As emphasized by Smith et al. (2022), the coordinated development of emission inventories across pollutants and spatial scales is essential for producing consistent and reliable city-level GHG inventories. CEDS contributes to this effort by offering temporally and spatially resolved estimates that align local efforts with national and global reporting systems. Its methodological transparency and open-access framework can help cities to refine their inventories, monitor climate progress and simultaneously address GHG emissions and air quality co-benefits.

5.3.3. Ecodesign impact accounting

Ecodesign impact accounting (EIA) provides data on products regulated under the Ecodesign, energy labelling, energy star and tyre labelling schemes (European Commission, 2021b). 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), along with the associated energy consumption, GHGs, consumer expenses and business revenues for 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 (utility transformers). Bills of materials (BoMs) are defined for typical products, such as:

- building installation products (e.g., space and water heating systems, air conditioning systems and lighting products);
- electronic products (e.g., displays, computers);
- appliances (e.g., for refrigeration, washing and cleaning);
- industrial equipment and other products (e.g., fans, motors, pumps);

[20] https://www.pnnl.gov/projects/ceds

— other household consumption (e.g., sales and stock, energy consumption).

BoMs provide insight on the materials used in sold or installed products, which can be linked with material flows (i.e., connected to MFA or LCA approaches) to develop consumption-based inventories. By 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 can be calculated. District heating and very large appliances (e.g., boilers over 400 kW) are not covered.

5.3.4. Direct observation of GHG data

GHG emissions can be quantified based on direct observation (e.g., through the observation of atmospheric GHG concentrations at the ground level or from space-based platforms). Advances in observation tools for tracking GHG concentrations (and activity levels) have increased the accuracy and granularity of GHG inventories, adding local and sector-specific details (WMO, 2025).

Observational approaches add information that can be helpful for particular applications and targeted action. They can generate important insight with high geographical and temporal resolution, for example to identify key locations or emission sources, or insight on daily or seasonal activity and emission patterns (WMO, 2025). 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 for a wide range of stakeholders, and are visually impactful (WMO, 2025).

Atmospheric concentration measurements can offer reliable and accurate insight on concentrations, but their application to GHG emission accounting is challenging: the link between concentrations and emission sources needs additional modelling and data. Moreover, concentration measurements reflect mostly scope 1 or nearby emission sources, without distinguishing between production- and consumption-based emissions, for example. In addition, they do not correspond to administrative boundaries, and can include background sources (e.g., emissions from sources upwind). Background influence is a significant source of uncertainty in urban studies using observation data (WMO, 2025).

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 and uncertainty. Observation data can be used for validation, to a certain extent, to identify overlooked local emission sources, or to test potential GHG mitigation measures. For example, a municipality may test an action restricting traffic in an urban area for a short period (as a 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 wider civil society, increasing the acceptability and uptake of actions.

5.4. Strengths and limitations of available methods and data

As mentioned, developing comprehensive, accurate and detailed city-level GHG inventories is crucial to support effective local climate action; however, activity and GHG emission data at this level are limited. When good-quality real-world context-specific data are 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 action to mitigate climate change, a compromise needs to be found to provide robust and detailed data in a timely and transparent manner through reasonably accurate inventories.

This section presented a non-exhaustive overview of methods, approaches and data sources, relevant to European initiatives, such as the Cities Mission and the EU CoM, for modelling and developing more comprehensive GHG inventories. These methods include top-down, bottom-up and hybrid approaches, applying 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 with regard to resource requirements (including expertise, time, data). Table 4 provides a comparative overview of the available methods, approaches and tools.

As mentioned, GHG emission accounting approaches typically use bottom-up modelling with limited scope and boundaries – for example, including scope 1 and 2 of key sectors, such as buildings and transport. 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, the approaches may exclude an important share of GHG emissions and relevant information to support effective action to mitigate climate change.

As we aim to achieve a more comprehensive coverage of GHG emissions (e.g., including IPPU, AFOLU, transboundary transport, and upstream and downstream emissions), the availability and reliability of data may be very limited, and inventory modelling can become more complex and associated with higher uncertainties. Inventories with more limited coverage (i.e., focusing on scopes 1 and 2 of key sectors) may also be more easily interpreted by a wide range of stakeholders. Such inventories may also be more comparable, and they keep the potential to be aggregated with GHG inventories for other regions. In fact, only territorial inventories allow for the direct aggregation of multiple cities' inventories, consistent with GHG reporting at the regional, national and international levels.

Box 8. Data challenges related to modelling emissions associated with supply chains of imported goods

If GHG accounting practitioners know the place of origin (e.g., country) of imported goods, they may assume production took place there. This may be adequate for primary production (e.g., of agricultural products). However, for manufactured goods, it may be that a significant part of the production process took place upstream from the place or country of origin (Tukker et al., 2016).

Eurostat has developed coefficients (called 'raw materials equivalents' (RMEs), which use life-cycle inventories (LCIs) related to imported products to estimate life-cycle-wide material extraction (Schoer et al., 2012). Yet RMEs do not provide information regarding the countries of origin of the indirectly imported products (upstream flows).

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 emission accounting practices, and they provide a life-cycle perspective. They mostly rely on activity data and mass-based flows, potentially keeping a reasonable level of accuracy at high levels of disaggregation. 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, providing relevant information on potential burden shifts, trade-offs and co-benefits (Hellweg et al., 2023).

Nonetheless, bottom-up process-based LC methods have significant requirements for data and other resources, and given the complexity of cities, and the diversity of urban activities, systems and flows (urban consumption is linked to the whole world through global supply chains), their application in consumption-based city-level approaches has been considered unpractical. Moreover, these methods suffer from truncation errors, which result from the need to define limited system boundaries for bottom-up modelling, eventually cutting off processes and emission sources (Wang et al., 2018).

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

- aggregation errors (i.e., sectors with varying emission profiles are aggregated into one sector);
- assumptions of linearity of scale and product homogeneity;
- assumptions of technologies associated with the production of imported goods;
- limited frequency of data updates.

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

High levels of sectoral disaggregation and detail based on real-world data can improve the accuracy and relevance of IO-based GHG emission results; however, 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 et al. (2021) proposed an automated, transparent and time-efficient approach to improve the resolution, quality, and indicator coverage of EXIOBASE 3. 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 et al., 2021; Su et al., 2010; Xu et al., 2023), with a wide range of results. Research suggests that the limited spatial or sectoral detail of 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.

Table 4. Comparative overview of the available methods, approaches and tools

	Process-based bottom-up approaches	**Top-down approaches**
Examples	Consumption footprint, other LCA frameworks, potential combination with urban metabolism and MFA.	IO-based (MRIO), downscaling of emission data from global and regional GHG databases.
Strengths	Provide details on linkages between emissions and activities (and sources), for example activity data and process information on vehicles, fuel consumption and technology. Highly disaggregated and granular insight is important to inform action. A wide range of environmental impacts can be covered with the same activity data/assessment, valuable in addressing co-benefits and potential trade-offs.	Comprehensive/complete perspective, including services and other immaterial purchases such as software licenses (in final consumption of households and governments), along with capital production requirements. MRIO-based approaches are widely applicable, providing consistency and comparability among cities, and among different spatial scales.
Limitations	Lack of adequate activity data at the city level (often overcome using downscaled national or regional data, introducing significant uncertainty). Resource intensive (e.g., time, expertise and data). Context-specific data and methodological choices can hinder comparability.	Large uncertainties associated with aggregation, homogeneity and linearity (e.g., linear connection between emissions and prices, and equal emission intensities for all products from each IO model sector). Lack of detail on context-specific activity data and emission sources. MRIO databases have significant data requirements and high modelling complexity. Results can be hard to verify for non-experts. Recent and regular updates may not be available to enable monitoring by cities.
Data	Significant requirements for context-specific data: activity data must be collected and organized for the city/system in question. Various statistics and other data sources may be available, depending on the city. Emission factors are available. LCI databases can be used, with potentially limited representativeness.	EE-MRIO databases are available with global coverage, detailed at the national level. Databases are typically compiled on an annual basis, often with a two- or three-year time lag (nowcasted versions for current or previous year may be available).
Opportunities and gaps to overcome	Increasing the availability of good-quality LCI data, representative of EU cities, is an important step in improving application. The Consumption footprint can provide a basis for a consistent assessment framework. Its further development for application at the subnational level (regional and urban) to support local action would be a major step.	IO-based assessments are increasingly adopted at the national level. Obstacles to their application include the uncertainties and limited updates to databases. Eurostat now compiles and publishes the MRIO database Figaro, which may serve as a common framework for the EU. A lack of model detail remains a drawback; hence, MRIO-based assessments are useful for creating overviews and top-level analyses for a city, but may be less suitable to support local climate action.

Source: JRC.

Regarding global granular emission databases, until a reference database such as EDGAR develops data to account for scope 3 emissions – that is, through the multiscale allocation of global emissions, mapping not only where emissions occur, but the location of production and consumption activities driving them – their applicability in consumption-based (or scope 3) GHG emission modelling is limited. These sources remain valuable, together with observation-based data, for improving and validating territory-based approaches.

Box 9. Dealing with uncertainty

Uncertainty may be addressed in different ways. If input data include information on probability, for example, a Monte Carlo analysis can be performed to assess uncertainty. However, input data often lack this type of information. In such cases, expert judgement may help establish higher/lower bounds; and sensitivity analysis can provide insight on potential implications of uncertainty and variability in specific parameters.

5.4.1. Combining methods, tools and data

GHG emission accounting at the city level in Europe has mostly relied on relatively simple process-based modelling. Yet, the availability of activity data and emissions factors that are representative of the local context poses significant challenges to many cities, which have hindered the 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 emission accounting. At this stage, and with the currently available tools and data, the widespread application of process-based methods in comprehensive GHG inventories appears unfeasible in the short term.

In this context, top-down approaches (e.g., IO-based modelling) can offer important opportunities: they may provide a more comprehensive overview of GHG emissions associated with cities more quickly. However, these approaches typically offer limited disaggregation and detail, which are essential to support local action. In addition, steps toward disaggregation often come with high uncertainty. Recent and regular IO data availability may also be a challenge for many European 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, for example in the case of IO methods using household expenditure data and in the case of the Consumption footprint, which cover only household consumption.

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 emissions associated with residential buildings, a detailed process-based LC-based GHG inventory can be developed for this sector, while the overall emissions of the city can be estimated with an IO approach. Combining the two approaches can provide detailed activity data and emissions in the sector, to support targeted actions, along with an overall understanding of the city's GHG emissions. Knowing the relative contribution of the sector is important to understand the potential impact of targeted actions to mitigate GHG emissions.

The direct observation of GHG emission data (including remote sensing) can also be valuable in combination to process- and/or IO-based approaches. It can provide independent validation of GHG inventories, and can be used in screening, by providing an overview of the local context and helping to identify, for example, relevant sectors, systems or emission hotspots. Direct observation can also support the spatial and temporal disaggregation of GHG inventory data, or be used, for instance, to test the potential impacts and benefits of pilot actions in a short time frame. Lastly, it can help overcome data gaps, for example, when downscaling data, which may be particularly relevant if limited resources are available to compile detailed bottom-up inventories.

Box 10. Integrating GHG emission accounting methods: hybrid approaches

Hybrid approaches aim to integrate the advantages of bottom-up and top-down approaches and to overcome their shortcomings. Ideally, they seek a high level of detail and accuracy at the process level, while ensuring holistic and systematic accounting with relatively lower data requirements. However, the integration of different methods and data may introduce additional modelling complexity, and more sources of error and uncertainty. Analyses using hybrid approaches are still mostly tailored case by case, and there is a lack of widely applicable frameworks that can be used by non-experts.

Ramaswami et al. (2008) developed a hybrid LC-based methodology for developing GHG inventories at the city level, addressing the spatial allocation of travel (including surface and air travel) and the embodied energy of key urban materials, namely food, water, fuel and concrete. The methodology allows cities to separately estimate (i) energy-related scope 1 and 2 emissions (which is consistent with the common territory-based GHG accounting frameworks) and (ii) transboundary- and out-of-boundary (scope 3) GHG emissions associated with transport and material production. Hybrid approaches were also adopted by Caro et al. (2015) and Kyrö et al. (2012).

6. Good practices: boosting GHG mitigation across the EU

This section provides examples of cities and local climate actions reflecting an ambition to go beyond common practice, taking a step further to address transboundary- and out-of-boundary emissions that have been typically excluded from 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. These examples draw on the Cities Mission climate city contracts (CCCs) and related communications ([21]).

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 cities (downstream emissions). Nonetheless, many cities have included actions that may reduce scope 3 emissions, such as circular economy (CE) measures that aim to increase resource efficiency, promote the use of lower-emission materials and prevent waste generation.

Nordic cities have been at the forefront of tackling and accounting for consumption-based GHG emissions (SEI, 2024; Heinonen, 2025). Within the Cities Mission, we selected several examples of cities across Europe that have already started developing consumption-based GHG inventories and/or tackling scope 3 emissions. In some cases, consumption-based GHG inventories are included in their CCCs, and in other cases they are mentioned but not included. It is also worth highlighting that many practitioners among the Cities Mission and the EU CoM have mentioned challenges related to the lack of accounting guidance, and indicators and tools to monitor the impacts of actions tackling scope 3 emissions.

6.1. Climate change mitigation actions

This section provides examples from the Cities Mission of actions addressing transboundary- and out-of-boundary GHG emissions. Virtually all climate change mitigation actions undertaken by cities can 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 and/or downstream processes that occur outside a city's boundaries. We focus on advanced practices and initiatives with the potential to significantly reduce GHG emissions that have seldom been tackled in actions to mitigate climate change at the city level. Sectors that can be particularly important to tackling out-of-boundary emissions include, for example, food, construction (e.g., buildings and civil construction) and transport.

With regard to the food sector, 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 could significantly reduce impacts associated with food consumption in France by 2050 (Deteix et al., 2025).

[21] 2030 climate neutrality action plans of the cities referenced in this Chapter can be accessed online through the knowledge repository function of the NetZeroCities Portal (https://netzerocities.app).

In relation to buildings, actions tackling energy efficiency and renewable electricity generation have significantly reduced the GHG emissions associated with their use phase, which has been the dominant LC phase of typical buildings in the EU's 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 the CE in this sector can be an important area of intervention at the urban and regional levels.

The transport sector differs from food and buildings, as its significance in terms of out-of-boundary emissions is mostly related to the transboundary nature of transport activities. In other words, while food and construction can have significant embodied (upstream) emissions, increasing ambition and action in relation to transport may have particularly significant impact because of the travel taking place outside cities' territories. A significant share of direct emissions from transport may take place outside cities, e.g., in intercity, regional and international travel (e.g., commuting, shipping, rail and air travel). It is worth noticing that the electrification of road transport and the increasing demand of larger private vehicles is also likely to increase the relative shares of upstream (scope 3) emissions in this sector.

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 of new buildings, and the recovery and repurposing of existing property, with special attention to those undergoing de-construction and demolition, and to the design and choice of materials and technologies;
- food, addressing the prevention and management of waste, reduction of upstream losses and maximisation of circularity;
- consumer goods, promoting the recovery, reuse, repair and resale of products.

Drawing on its CE action plan, Bergamo proposed several 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 raising;
- increasing shares of vegetarian food on school menus, in particular to replace sources of animal protein;
- developing energy-efficient buildings in 'bio-districts' that integrate energy efficiency and renewable energy sources (RES), and promoting wood as the primary construction material.

With these actions, the municipality could 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. For food, scope 3 emissions could be reduced by decreasing 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 CO_2-eq per year. The city highlighted the lack of data and guidance as a critical barrier to implementing and monitoring CE actions.

6.1.2. Gävle

Gävle stands out for its ambitious target of achieving climate neutrality for 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 transport, cycling, walking and low-emission vehicles;
- in the construction sector, tackling emissions originating from steel, cement and the transport of materials. The municipality aims to introduce mass management and 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 using the Swedish Consumption Compass (see Section 6.2.1): approximately 6 t CO_2-eq per person, of which around 60% are associated with household consumption, and 40% with the public sector and investments. Public consumption includes goods and services, such as those purchased by schools, hospitals and authorities to conduct their operations. Investments encompass emissions related to the purchasing of buildings, machinery, computers, valuables and inventory investments. Consumption-based emissions are dominated by the transport (41%), food (20%) and housing (18%) sectors, followed by restaurants, hotels and other recreational activities (11%) and by clothing and footwear (4%).

Concerning construction, Gävle's action plan highlights that a significant share of GHG emissions currently occurs beyond city boundaries (scope 3), including, in particular, those associated with the production of building materials. To tackle these emissions, the city calls for regulatory actions and legal requirements to lower GHG emissions. All new buildings should be climate neutral 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 has also adopted a range of actions tackling final consumption and promoting the CE. However, it highlights that more ambitious actions to mitigate GHG emissions can be developed when adequate indicators for monitoring consumption and air travel are available. Lastly, the action plan highlights:

- the need to increase accountability in relation to resource efficiency and the circular economy;
- the potential contribution of technological innovation to reducing embodied GHG emissions;
- the importance of raising the political priority of addressing consumption-based emissions at the national and EU levels.

6.1.3. Helsinki

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

The process was carried out by first researching over 60 buildings to analyse what determined and contributed to their life-cycle GHG emissions (e.g., materials, heating). The city then held a competition to encourage companies to design low-emission residential buildings, scored partly (50%) based on architectural merit and partly (50%) based on their carbon footprint. The three winning proposals achieved a very low carbon footprint using various combinations of construction materials and systems (e.g., wood frame/low emission concrete frames, solar panels, heat pumps and green roofs). The three will be built in Helsinki. The competition engaged many companies and sparked dialogue and collaboration, and the results informed the new emission limit for residential building, which was set to 16 kg CO_2-eq/m^2-year over a 50-year time frame.

6.1.4. The Hague

The Hague proposed several actions to tackle scope 3 emissions, including the following.

- **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 promote the 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 highlights that to strengthen the alignment of CE measures with the 2023-2026 Coalition Agreement's goals, the benefits of these actions would need to be evaluated in detail. The intention to include CE indicators is identified as the next priority in broadening the scope of the city's 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 in GHG and air pollutant emissions could be achieved in the region, benefiting 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 several complementary actions (e.g., free city bus, free city bike) aim to reduce reliance on personal vehicles, thus affecting the direct and 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 extend buildings’ lifespan, the city could reduce demand for new construction materials, reducing GHG emissions associated with the manufacturing and transport of materials.

— **Circular economy.** The action plan also includes a zero-waste programme, which aims to minimise 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, the banning of printed advertisement, the implementation of environmental standards and the holding of zero-waste events to reduce 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 reuse workshops, tool exchanges and a car cleaning facility using recycled water from the nearby waste water treatment plant.

— **Food consumption.** Kranj’s urban agriculture programme aims to promote local food consumption (e.g., from small suburban farms and urban green spaces). The ‘farm to fork’ programme includes important initiatives, for example daily local food distribution and improvement of farmers’ skills in vegetable production.

6.1.6. Porto

The city of Porto shows strong commitment to CE action, supported by EU-funded research and innovation projects. The city is creating a centre for circular economy. Overall, the city considers addressing consumption-based emissions (for example by reducing resource consumption and promoting circular practices) for a range of goods and services (e.g., food, clothing, electronic equipment, building construction, transboundary travel). For example, the city’s actions in the waste sector, including the City Loops project and ReBoot Porto, aim to increase the reuse of products.

With regard to transport actions, the city stands out for the intention of addressing transboundary travel emissions through the electrification of vehicle fleets, including those for heavy long-distance intercity road transport of passenger and freight.

6.1.7. Milan

Milan’s commitment to CE principles is evident in 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 material consumption across diverse sectors, such as food, urban construction, and packaging for home delivery and e-commerce.

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

- considering green criteria for public procurement and events, and launching a pilot project to develop an environmental and social multi-label for hotel, restaurant and catering (HoReCa) operators;
- promoting sustainable buildings, through the C40 Clean Construction Accelerator, encouraging renovation over new construction, incentivising circular design, zero-emission machinery and low-carbon materials in procurement contracts.

The city's portfolio of actions also addresses energy-related emissions concerning air travel, associated with the Milano Malpensa airport, which is outside the city's boundaries. SEA Aeroporti SpA, the company managing Milan's airports (Milano Linate and Milano Malpensa), has committed to leading efforts to reduce GHG emissions, building on sound stakeholder engagement.

6.1.8. Gothenburg

Gothenburg is at the front line 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, and the Smart Map platform to support CE efforts, and applies the Swedish Consumption Compass (see Section 6.2.1) to estimate and monitor citizens' GHG emissions from a consumption-based perspective.

The city proposed actions to enhance resource efficiency, reduce consumption and address emissions beyond direct municipal control and geographical borders. To target hard-to-abate sectors like industry, refineries, port activities and waste incineration, Gothenburg incorporates comprehensive CE strategies and proactively engages in research and development and participatory projects. The city aims to reduce GHG emissions associated with construction by up to 90% by 2030.

6.2. GHG emission accounting

6.2.1. Swedish Consumption Compass

Swedish cities, such as Umeå, Gävle, Helsingborg and Gothenburg, have complemented their territory-based GHG inventories with insight on GHG emissions associated with household consumption, drawing on the Swedish Consumption Compass.

The Swedish Consumption Compass ([22]) is an Excel-based tool of the Stockholm Environment Institute (SEI), which provides a framework and data for calculating GHG emissions associated with

[22] https://www.sei.org/features/consumption-compass-impact-households/

household consumption at the national, city and postcode levels. Consumption-based GHG emissions are calculated for more than 100 activities grouped into the following categories: food, clothing, housing, health, transport, communication, recreation, education, restaurants and hotels, vehicles, electricity, district heating, house heating and 'other'.

The tool builds on methods and data for the consumption-based emission model at the national level, developed as part of the research project 'Policy-relevant indicators for national consumption and environment' (PRINCE) ([23]), and on the research project 'Understanding local government drivers for sustainable consumption' (UNLOCK) ([24]), which analysed Swedish municipalities' consumption at the municipal level ([25]). The tool estimates GHG emissions associated with five categories of household consumption, namely (i) transport; (ii) food and non-alcoholic beverages; (iii) domestic water, electricity, gas and other fuels; (iv) recreation, sport and culture; and (v) furnishings, household equipment and routine household maintenance. Investments and the public sector are excluded.

The project is recognised as an essential step in reducing consumption-based household emissions: by mapping emissions at the 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 CO_2-eq per person ([26]), but the consumption compass shows how unevenly distributed these are among households, ranging from 3.5 to 18 t CO_2-eq per person.

6.2.2. Copenhagen

Driven by high ambition, the city of Copenhagen has years of experience advancing GHG emission accounting beyond common practice. After analysing different state-of-the-art GHG accounting approaches, the city has started to consistently develop GHG inventories with both territory- and consumption-based approaches, used in a complementary manner, to effectively inform and monitor local climate action.

Between 2012 and 2025, the city reduced territory-based GHG emissions by 80%. By 2025, GHG emissions were estimated at 1 t CO_2-eq/capita and 10 t CO_2-eq/capita using territory-based and consumption-based accounting frameworks, respectively. While the city has significantly reduced its territory-based GHG emissions in the last decade, consumption-based accounting drawing on household consumption expenditure has revealed significant opportunities for mitigating GHG emissions.

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[23] https://www.sei.org/projects/prince/

[24] https://www.sei.org/projects/unlock-sustainable-consumption/

[25] The approach and methods are also linked to the Urban Sustainability Directors Network's consumption-based emissions inventory tool (https://sustainableconsumption.usdn.org/climate/cbei-guidebook/cbei-prioritization-tool#overview)

[26] https://www.naturvardsverket.se/data-och-statistik/konsumtion/vaxthusgaser-konsumtionsbaserade-utslapp-per-person

6.2.3. Amsterdam

Amsterdam has adopted an innovative approach to accounting for consumption-based GHG emissions, which combines IO-based emission data at the national level – specifically, MRIO sector–country emission factors – with a material flow accounting approach, based on logistics data. The approach provides insight on material flows, inputs and consumption for a wide range of materials and final goods consumed in the city. The accounting and monitoring of these flows is paramount to support effective GHG mitigation, and CE actions in particular.

In recent years, the city's efforts to promote a sustainable energy transition have contributed to a significant reduction in territory-based GHG emissions. In 2022, 86% of consumption-based emissions occurred outside the city's boundaries, mostly associated with the extraction of raw materials and production of goods.

6.2.4. Porto and Kranj: accounting for transboundary transport emissions

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

Porto has estimated the emissions from journeys that occur due to commuting outside the city's boundary, including from passenger and freight activities, using data from 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; and scope 3 – emissions from transboundary journeys that occur outside the city). Additionally, the 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, including for example the accounting of residual consumption of electricity and oil for waterborne navigation and aviation purposes.

Kranj has considered aircraft operations at its airport, which is located outside the city's boundary, using publicly available data from the Slovenian Infrastructure Agency 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 emission accounting and mitigation action at the city level. Nonetheless, these and other examples across the Cities Mission and the EU CoM show (i) an increased awareness of the significance of scope 3, transboundary and out-of-boundary emissions among EU cities; (ii) the ambition to pursue more comprehensive action to mitigate GHG emissions; 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 for 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 action to mitigate climate change, and in sustainable development in broader terms, is clearly reflected in the increased recognition of the circular economy as key to reducing environmental impacts, beyond energy efficiency and direct operational emissions. Cities across the EU have developed and implemented CE action plans aimed at ensuring high resource efficiency, low material demand and waste prevention, among other goals. While these actions are closely related to upstream and downstream processes and emissions, cities need tools, data and indicators to support and monitor them.

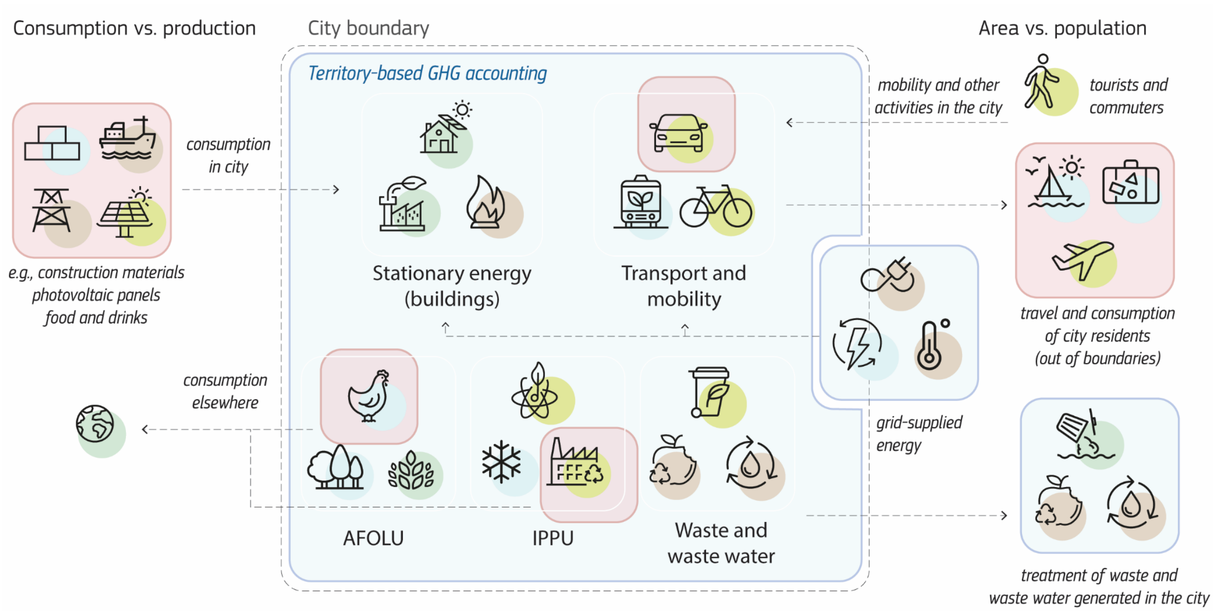
While cities across the EU have proactively started to act to reduce GHG emissions and other environmental impacts of their activities beyond borders, their efforts must be supported by evidence. Including indirect emissions associated with the supply chain of (non-energy-related) products provide insight on cross-scale resource efficiency. Cities need clear, harmonised and consistent data and guidance to support their efforts and enable effective action.

7. Key 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 territory-based GHG accounting frameworks have provided critical insight to inform local action across EU cities, they have often excluded out-of-boundary emissions, for example emissions 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 organisational and product levels (ERCST, 2021; TCFD, 2021). However, limited guidance and data are 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, 2025) (see Figure 9).

Figure 9. Towards more comprehensive city-level GHG emission accounting and mitigation action



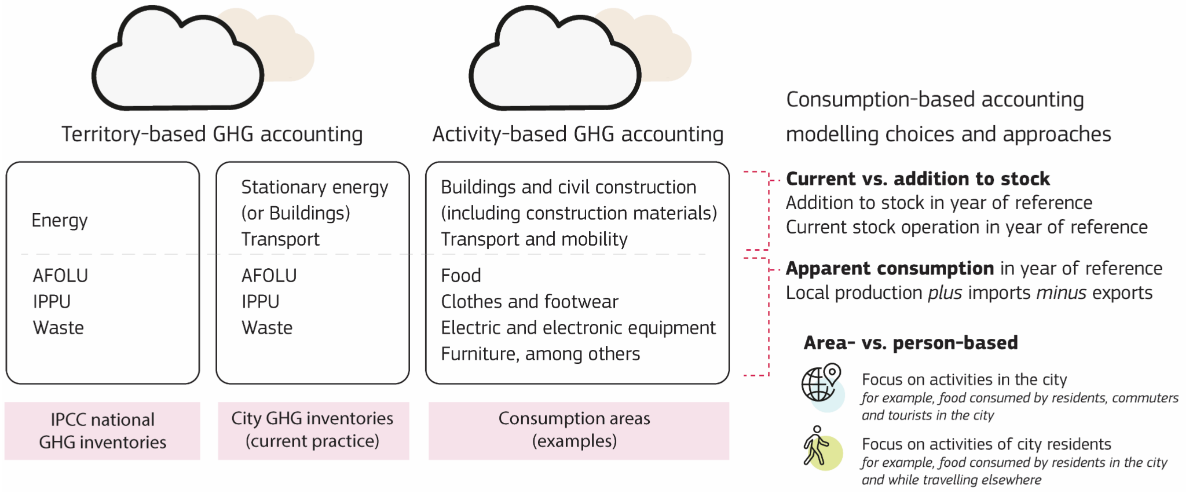
Source: JRC.

The development of more comprehensive GHG inventories including, for example, upstream supply chain GHG emissions can be associated with increased methodological complexity, higher data requirements and subjective emission allocation choices, which can be linked with attributing responsibility (Hung et al., 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 (see Figure 10).

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 territory-based to activity-based GHG emission accounting entails a separation between the activities and processes of production on the one hand and those of consumption on the other. 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 territory-based inventories, can be accounted for in the consumption-based inventories of other cities. Local activities and imports include emissions associated with both production and consumption, and the separation of data and emissions might bring challenges.

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

Figure 10. Towards more comprehensive approaches to city-level GHG emission accounting and action: methodological aspects related to structure and modelling



Source: JRC.

Third, consumption-based classification and grouping of activities, processes and emissions follows a different structure from that typically used in territory-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 associated with production, supply and waste collection and treatment processes. To pursue more comprehensive GHG inventories at the city level, some adjustments may be needed. In the PAS 2070, for example, GHG emissions associated with food production shall be accounted for separately from other AFOLU emissions, and they cannot be aggregated with the total GHG emissions to avoid double-counting, because the framework includes GHG emissions associated with the final consumption of food and drinks.

Fourth, a shift to consumption-based GHG approaches may be perceived as a shift in responsibility, with 'a push towards final consumers'. The IPCC AR6 (IPCC, 2022) highlights that changing consumption patterns and lifestyles is crucial for achieving the key climate change mitigation targets. Significant opportunities for effective and prompt GHG reduction are linked in particular to behavioural changes in wealthier economies and high-income socioeconomic 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 patterns and behavioural changes are not challenges specific to 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 transport or to active transport modes. In other words, changing from territory-based 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 or in the responsibility or power of national, regional and local authorities, other stakeholders or civil society to collaboratively achieve climate change mitigation targets. Just as territory-based GHG inventories do not attribute the sole responsibility of GHG emissions to local authorities, more holistic inventories such as those following CB accounting do not imply an increase in the responsibility of residents or final consumers. In both cases, successful effective action should build on co-participatory and collaborative efforts of public administrations, industrial and business stakeholders, research and innovation actors and civil society.

Box 11. 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 buildings' use or operation and are primarily associated with fuel combustion for space heating and domestic hot water supply, and for cooking. Indirect emissions include operational emissions, associated with the 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 transport of materials, for example. They may also include emissions associated with buildings' end-of-life processes (e.g., demolition and waste disposal).

With regard to 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, are included in the IPPU sector, and emissions associated with waste treatment at the end of a building's life are accounted for in the waste sector. Moving away from a territory-based (IPCC-based) perspective, production- and consumption-based perspectives bring challenges in relation to the sectoral structure and allocation of emissions in city inventories.

To support cities, it may be adequate (from a consumption-based perspective) to allocate GHG emissions across the service life of a building to the same sector, or consumption area, so that they may better and more directly inform the impacts of actions to mitigate GHG emissions (Huang et al., 2024). For example, energy efficiency measures for buildings are likely to reduce GHG emissions associated with their operation, while increasing embodied emissions. The overall impact of these actions may be clearer if the emissions are all allocated to the buildings sector.

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, while process-based LCA approaches have limited coverage due to their inherent truncation errors. On the other hand, burden shifts and trade-offs may also occur in relation to other environmental issues and in relation to the social and economic levels. More comprehensive inventories based on LCA approaches can improve integrated environmental impact assessment (and, they can include also social and economic impacts), thus supporting integrated action.

Lastly, more comprehensive GHG emission accounting comes with the risks of double-counting and limited aggregation and comparability. Scope 3 GHG emissions of a city are scope 1 or 2 emissions of another city or region; thus, double-counting issues and loss of ability to aggregate are intrinsic limitations of more comprehensive GHG inventories. Perhaps more important in the context of supporting GHG mitigation action is the risk of different organisations 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 (ERCST, 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.

7.1. Towards a more comprehensive GHG accounting framework

Of the approaches presented, IO-based ones have been the most adopted to develop consumption-based inventories, both by researchers and by EU cities taking ambitious first steps to tackle scope 3 emissions. IO methods offer a concise and consistent approach for complete GHG inventories with a reasonable degree of accuracy. MRIO databases are in continuous development – illustrated by the recent addition of Figaro to the family of MRIO databases. Figaro offers EU cities a good opportunity to use it as a foundation for MRIO-based carbon footprint assessments since it is freely available and reliably developed and maintained by Eurostat and the JRC.

Even though an MRIO model can be used for city-level analyses with only moderate adaptions, such analyses are only able to give aggregate indicative results. To obtain results at the more detailed level, or to be able to assess specific local climate actions, an MRIO model should be extended with more detailed data, or the analysis should be complemented by LCA or other assessments based on a bottom-up approach.

The further development of the EU Consumption footprint to provide consistent multiscale data (at the national, regional and city levels) would be a valuable contribution to support local action.

To have an application in more comprehensive GHG inventories at the city level (accounting for scope 3 emissions), global granular databases such as EDGAR need important developments, namely to provide a multiscale allocation of global emissions – that is, mapping not only where emissions occur but the location of production and consumption activities driving them. Until such data are developed, these databases and observation-based data remain valuable for improving territory-based approaches by supporting independent estimates and robust monitoring of GHG emissions, which can be used to validate GHG inventories.

Lastly, EU cities continue to face the major challenge of collecting accurate and reliable activity data, in particular to account for transport GHG emissions within their territory and for transboundary travel.

7.2. 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 reflections and recommendations on steps towards more comprehensive GHG emission accounting and mitigation action in EU cities.

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

Both territory- and activity-based (production/consumption) approaches provide important complementary insight to inform GHG emission mitigation action. Together, they support the identification of GHG emission hotspots and mitigation opportunities, increasing choices and contributing to the design of effective strategies to leverage cities' climate change mitigation potential, which should involve all relevant actors in climate action planning and promote sustainable production and consumption practices (Balouktsi, 2020). The use of consumption-based accounting alone may result in important insight and information currently captured in territory-based GHG inventories being missed, and moving away from territory-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 territory- and consumption-based inventories in a complementary manner, to adequately estimate and monitor scope 1 and 2 emissions, along with those associated with imported goods, construction materials, food supply chains and transboundary transport, for example. This will provide a more complete understanding, disclose 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, and within-city transport 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 methods 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 linked to exports or to local final consumption.

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

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

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

What sectors or areas should be prioritised?

While screening is recommended to identify city-specific hotspots and priorities in GHG mitigation, buildings, transport 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. For 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 emission accounting include transboundary transport emissions. This step into more comprehensive and complete 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 to tackle emissions in these sectors (including perception of public interest and collaboration with relevant stakeholders) and (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 to make use of an increased range of actions, revealing room for improvement in cities' climate change mitigation strategies.

Cities can have a significant effect in reducing emissions of all products and goods associated with urban activities, by considering their entire value chain and acknowledging the implications of local action on increasingly globalised economies. As GHG accounting 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.

7.3. Concluding remarks

Researchers and practitioners have increasingly acknowledged the importance of transboundary and out-of-boundary GHG emissions in climate change mitigation actions. To adequately inform local climate action, city administrations, practitioners and other stakeholders need good-quality data. GHG inventories provide cities with quantifiable and transparent insight that enables them to design their strategies and actions, based on identified drivers, risks and opportunities. They also enable adequate monitoring and prompt intervention in the implementation of GHG mitigation actions.

More holistic GHG inventories provide an overall assessment of GHG emissions that is crucial to understand the relative significance of city-related emission sources and to identify and evaluate hotspots, improvement opportunities and potential trade-offs and risks of burden shifting. However, there is a need for guidance and data to enable consistent, meaningful and credible GHG emission accounting. EU cities have started to consider a wider holistic scope in their climate action and to develop more comprehensive inventories that can adequately support ambitious and effective action. However, they lack alignment to navigate through available approaches, methods and data.

As highlighted by the IPCC (2000), relevant GHG emission accounting should 'reduce uncertainties as far as is practical'. While current GHG inventories rely on bottom-up process-based models, the construction of a CB inventory fully based on process-based LCA is not considered practical at the city scale in the near term. Currently, this may be feasible for smaller spatial scales, such as neighbourhoods, or for specific urban systems or consumption areas. While more comprehensive inventories can add important insight, excessive time and resource requirements may hinder climate change mitigation action.

A robust, transparent and consistent framework for holistic GHG emission accounting at the city level is needed. Together with methodological guidance, cities need representative, useful and easily applicable data. In the near term, however, it might be preferable to make use of a screening phase to identify key sectors and sources of emissions, before investing in detailing data, knowledge and indicators on those (selected) sectors.

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 facilitate transparency, benchmarking and communication. Harmonisation of GHG accounting methods and data at multiple scales would enable synergies to be exploited. An alignment with data provided in global emission datasets (e.g., EDGAR) and/or in the context of emission regulation schemes (e.g., the EU Carbon Border Adjustment Mechanism (CBAM) and the EU emissions trading system (ETS) could facilitate and improve the development of GHG inventories at the national, regional and urban levels. 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.

The development of methodological frameworks should build on the engagement of city representatives and practitioners to understand their needs, priorities, resources and challenges. With the objective of advancing current practice and developing guidance towards more comprehensive GHG emission accounting and mitigation action, several activities under the Cities Mission have engaged city representatives and practitioners. In March 2025, an online webinar gathered 17 city representatives to discuss the 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 towards more comprehensive GHG emission accounting and mitigation action. More recently, two working groups on scope 3 emissions were created: an expert working group (also referred to as a task force) through which 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 the EU Cities Mission platform, NetZeroCities.

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List of abbreviations and definitions

Abbreviation	Definition
AFOLU	Agriculture, forestry and other land use
AR6	IPCC's Sixth assessment report
BoM	Bill of materials
CB	Consumption-based
CCC	Climate city contract
CEDS	Community emissions data system
CF	EU Consumption footprint
CH_4	Methane
Cities Mission	EU Mission 'Climate-neutral and smart cities'
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CoM	Covenant of Mayors for Climate and Energy
DG	Directorate-General
DPSC	Direct plus supply chain
EDGAR	Emissions Database for Global Atmospheric Research
EE-IO	Environmentally extended input-output
EE-MRIO	Environmentally extended multiregional input–output
EIA	Ecodesign impact accounting
EU CoM	EU Covenant of Mayors
GHG	Greenhouse gas

Abbreviation	Definition
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
GTAP	Global Trade Analysis Project
GWP	Global warming potential
HFC	Hydrofluorocarbon
IO	Input-output
IOT	Input-output table
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use
JRC	Joint Research Centre
LCA	Life-cycle assessment
LCI	Life-cycle inventory
LEGGI	London energy and greenhouse gas inventory
MFA	Material flow analysis
MRIO	Multi-regional input-output
N_2O	Nitrous oxide
NF_3	Nitrogen trifluoride
PFC	Perfluorocarbons
SF_6	Sulfur hexafluoride

List of boxes

List of figures

List of tables

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