NET ZERO CITIES SGA2-NZC

# Scope 3 Emissions for cities

## Current landscape

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# Keywords

Scope 3 emissions, Consumption based emissions, Embedded emissions, Indirect emissions, European cities, Climate change, Greenhouse gas emissions.

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## Abbreviations and Acronyms

| Acronym | Description |
|---|---|
| ACF | Areal Carbon Footprint |
| AP | Action Plan (as part of the Climate City Contract) |
| CBE | Consumption-Based Emissions |
| CBEI | Consumption-Based Emissions Inventory |
| CCC | Climate City Contract |
| CDP | Carbon Disclosure Project |
| CO2 | Carbon Dioxide |
| CO2e | Carbon Dioxide Equivalent |
| EE-MRIO | Environmentally Extended Multi-Region Input-Output |
| EE-GMRIO | Environmentally Extended Global Multi-Region Input-Output |
| EU | European Union |
| GCoM | Global Covenant of Mayors for Climate & Energy |
| GHG | Greenhouse Gas |
| IE | Indirect Emissions |
| IO | Input-Output |
| IOT | Input-Output Table |
| JRC | Joint Research Centre |
| LCA | Life Cycle Assessment |
| MFA | Material Flow Analysis |
| MRIO | Multi-Region Input Output |
| NZC | NetZeroCities |
| PBs | Planetary Boundaries |
| PCF | Personal Carbon Footprint |
| SDGs | Sustainable Development Goals |
| SEI | Stockholm Environment Institute |
| SRIO | Single-Region Input Output |
| GPC | Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories. |



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# Summary

Scope 3 emissions, often referred to as consumption-based (CBE) or indirect emissions (IE), represent a critical but frequently overlooked aspect of urban greenhouse gas (GHG) accounting. These emissions originate from the entire life cycle of goods, services, and infrastructure consumed by a city, rather than those directly produced within its boundaries. Addressing Scope 3 emissions is crucial because they often constitute the largest share of a city's carbon footprint, encompassing supply chains, waste disposal, and outsourced activities. This report explores the efforts of cities participating in the EU's Mission for Climate Neutral and Smart Cities, showcasing insights on the drivers and barriers to adoption, as well as practical steps cities can take in the absence of inventories and comprehensive data. The recommendations in the report include strategies for building emissions inventories, leveraging existing mechanisms in the city to tackle emission reduction, and identifying key areas for intervention.

# 1. Introduction

Cities can play a pivotal role in addressing climate change, given their significant impact as centres of economic activity and resource consumption. While occupying just 3% of the Earth's land surface, cities account for 60–80% of global greenhouse gas (GHG) emissions and consume 75% of global resources (UN Environment Programme, n.d.), largely due to their reliance on goods and services produced outside of their geographic boundaries. European cities with primarily service-based economies may be underestimating their overall impact on climate change by only measuring and reducing emissions within their borders. Established approaches to emissions tracking, which focus on direct Scope 1 (S1) and energy-related Scope 2 (S2) emissions within and outside city boundaries, capture only part of the picture. Out-of-boundary emissions often classified as "**Indirect**", **"Scope 3 emissions" (Scope 3)** or '**consumption-based emissions' (CBE)** represent a significant and often overlooked share of a city's carbon footprint. These emissions can originate outside of city borders, from the creation of goods and services that cities import, as well as public investments. Understanding and addressing these emissions is critical for achieving net-zero goals and mitigating global climate impacts. Research by C40 Cities, Arup, and the University of Leeds in 2019, cautioned that urban consumption-based emissions must be cut by at least 50% by 2030 to maintain the possibility of keeping global temperature rise below 1.5°C (C40 Cities, Arup, & University of Leeds, 2019)

This report aims to explain the difference between different terms describing embodied emissions, the importance of tracking and acting on these emissions, the current state of what cities around the world and Mission Cities are doing already, and best practices for measuring and managing Scope 3 emissions in cities across urban, rural, and peri-urban contexts. Some highlights include:

- An examination of the efforts of cities participating in the European Union's (EU) Mission for Climate Neutral and Smart Cities, also known as "Mission Cities."
- Examples of innovative, city-led initiatives in key sectors such as waste, food, transport, and construction
- Information on existing approaches and barriers and challenges cities face in applying them—such as limited data availability, financial constraints, and a lack of technical expertise.

This report integrates insights from global initiatives and academic research to help cities identify practical entry points for further reducing indirect emissions, highlighting the urgency of adopting circular economy principles, transforming the food sector, promoting behavioural change, and leveraging policy tools, multi-level governance and collaborative actions to create a fair and climate neutral future.

# 2. Guide to Indirect, Scope 3, or Consumption-Based Emissions

## 1.1 Introduction to Terminology

The terms used in this report such as "Scope 3 emissions" "Consumption-based emissions", and "Indirect emissions" are closely related terms referring to the emissions associated with consumption within a city or region. These terms overlap but differ slightly in scope and are therefore not interchangeable. An overarching term we use to capture these and related terms for the same of brevity here is "embodied emissions". The term 'embodied emissions' encompasses the greenhouse gas emissions embedded in the life cycle of goods, services, and infrastructure that a city consumes, rather than those directly produced within its boundaries. Here is how the related terms fit under this umbrella:

**Scope 3 Emissions**

Scope 3 emissions, as defined in the Greenhouse Gas Protocol, refer to all indirect emissions that occur outside a city's geographic boundary but are a consequence of activities within a city. This includes emissions from the production of goods and services consumed in the city, out-of-boundary transportation, and treatment of waste outside city boundaries. These are a subset of consumption-based emissions, focusing on indirect contributions to global emissions that result from a city's supply chains and external activities.

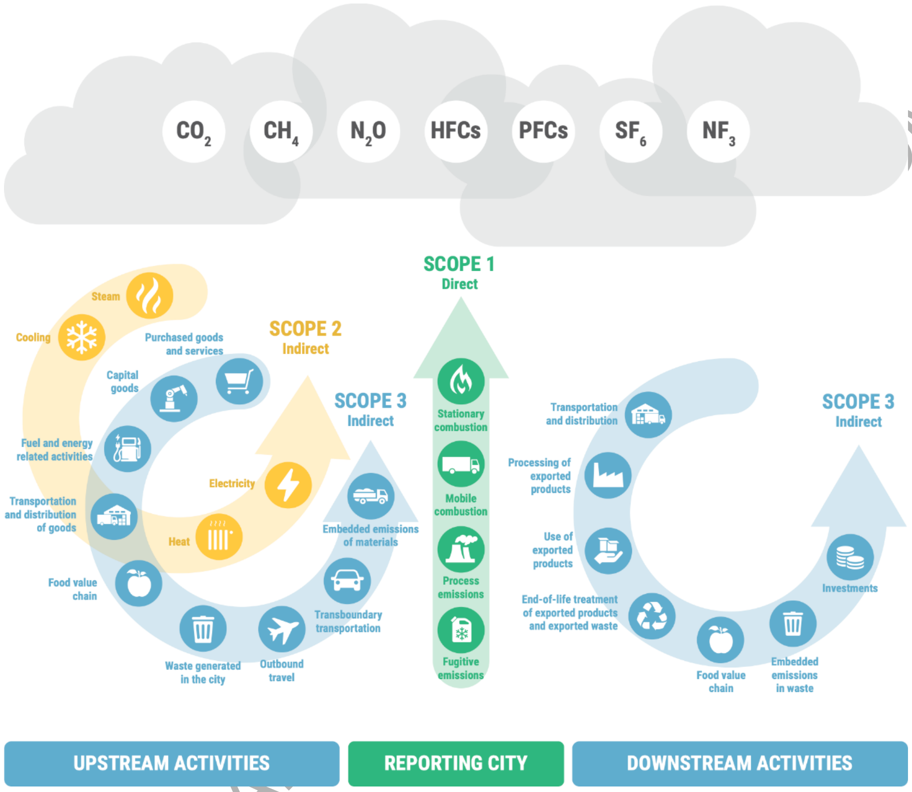


**Figure 1: Overview of the emissions sources displayed in a Sectoral-based approach (Adapted from WRI & WBCSD, 2013).**

**Consumption-based Emissions**

These are the total greenhouse gas emissions associated with all the goods and services consumed by people in the city, regardless of where those emissions occur. This approach allocates emissions to the end-user, accounting for the full supply chain, including production, transportation, and disposal, which often occur outside the city's geographical boundaries.

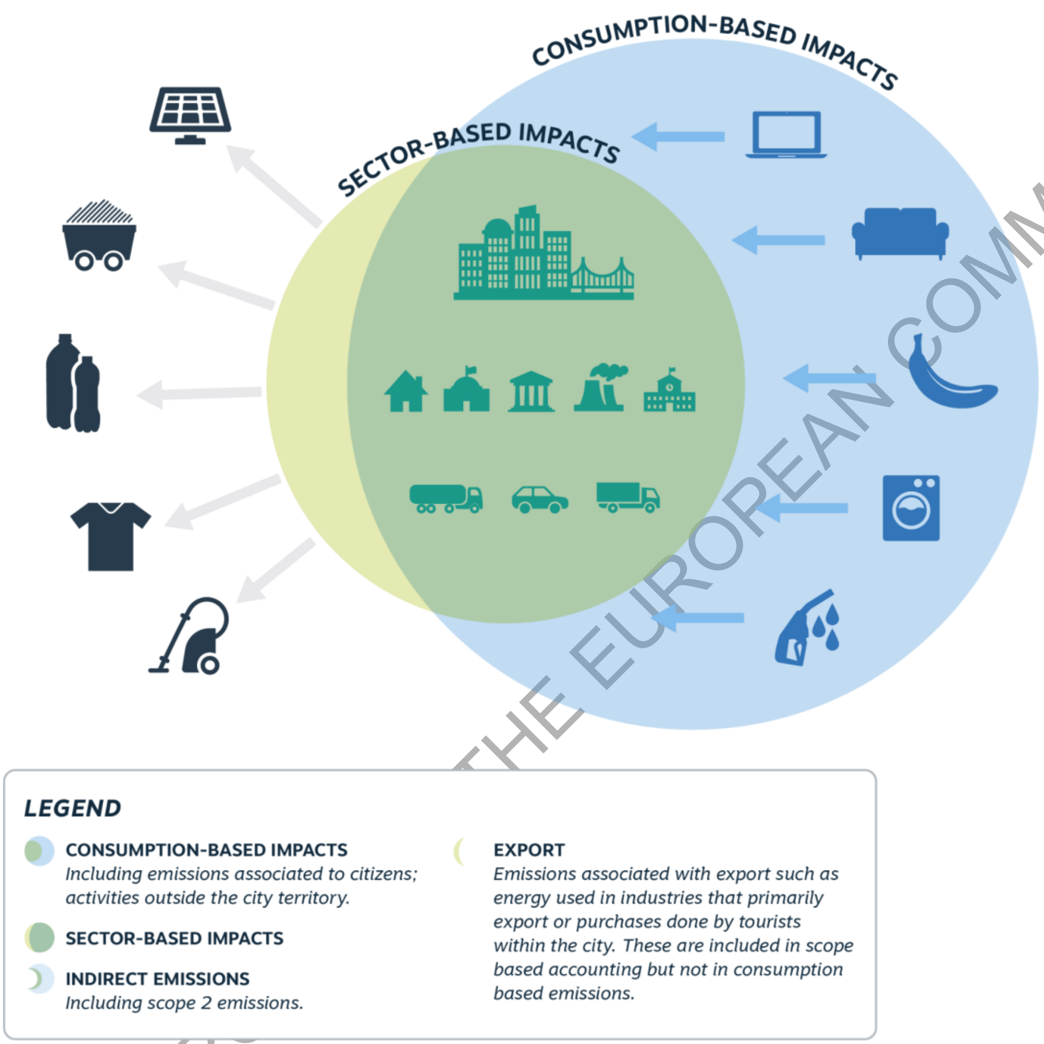


**Figure 2: Relationships between Sector based and consumption-based emissions (Adapted from (USDN, 2024))**

#### Indirect Emissions

This term broadly covers emissions that are a consequence of a city's consumption but occur outside its geographic boundary. Indirect emissions include Scope 2 (from purchased electricity, steam, heating, and cooling) and Scope 3 emissions. In the context of embodied emissions, it highlights the emissions occurring upstream (e.g., during the production and transportation of goods) and downstream (e.g., during the disposal of products).

## 1.2 Terms and Scope in The Mission Info Kit

When we speak of indirect emissions, we refer to emissions that are emitted outside of the city boundary but are directly caused by activities within the city boundary. The Info Kit for Cities also calls them "out-of-boundary" emissions for this reason. One exception is emissions due to electricity, which is usually generated at a power plant outside of the city. As emissions from electricity are regularly accounted for in city GHG inventories as "Scope 2 emissions" and are required by the Mission, these emissions are not addressed in this report.

According to the Info Kit for Cities, cities participating in the EU Cities Mission are expected to report their emissions inventories grouped by scope and sector (European Commission, 2021). The requirements call primarily for emissions accounting within the city boundary, including emissions from energy consumption within the boundary (Scope 2). The exception to this is in the case of waste generated within the city but managed outside the boundary "at point of disposal/treatment." This instance of Scope 3 emissions for the Waste sector is the only out of boundary emission *required,* however further Scope 3 emission types are laid out for cities' consideration.

In addition to requiring that Mission Cities account for emissions at point of disposal for waste generated within the city, the Info Kit also *recommends* that, by 2030, cities account for Scope 3 emissions from the transport sector. Scope 3 emissions from Transport refer to GHGs emitted outside of the city but because of activities which take place in the city. The primary example of this is transboundary commuting (to and/or from the city).

Other Scope 3 emissions sources for which the Mission will re-evaluate inclusion after 2030, when leading cities have achieved the current Mission definition of climate neutrality - include the following:

- Fugitive emissions and transmission losses from energy being delivered to the city
- Extraction/production of materials and products used/consumed in the city
- Production, processing and transport of food and drinks consumed by citizens within the city

| Field of action – Emission domain | Activities | | |
|---|---|---|---|
| | Scope 1 | Scope 2 | Scope 3 |
| Buildings | Energy consumption | Electricity supply, DH/C supply | Construction materials, demolition |
| Transport | On-road and rail transport | Electricity supply to charge EV | Life cycle of car stock |
| Waste | Waste generated and managed | Not applicable* | Waste generated by the city but treated outside city |
| IPPU | GHGs used in industrial processes and products | Not applicable* | Emissions from IPPU outside the city |
| AFOLU | Changes in emissions from changes in land use | Not applicable* | Land-use activities outside the city (e.g., agricultural products imported for consumption within the city boundary) |

**Figure 3: Emissions in the waste sector are the only required Scope 3 emissions in the CCC.**

Note that Scope 3 activities under other sectors are not required in the Climate City Contracts (CCCs). Scope 2 is not applicable for some sectors according to GHG protocol as the electricity required for supplying the buildings is included in the Stationary Energy/Buildings sector.



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# 2 Why Should European Cities Measure and Act on Embodied Emissions?

Accounting for indirect emissions gives a more complete picture of the GHG contributions from the city and its citizens. European cities are generally wealthier than the global average and therefore often consume more, resulting in a greater carbon footprint. This does not get reflected when only accounting for direct emissions. As a continent, the EUs carbon footprint is 15% higher using a consumption-based approach compared to a production-based approach (Eurostat, 2024b). For C40 cities, consumption-based emissions inventories (CBEI) were approximately 58% larger than the network's production-based emissions in 2017 (C40 Cities, Arup, & University of Leeds, 2019). Furthermore, a scientific study of 10 European cities, modelling emissions trajectories until 2050 using both production-based and consumption-based inputs, found that rising GDP and a corresponding increase in spending and consumption easily negated the local and global efficiency improvements (Harris et al., 2020). For a few Mission cities with publicly available CBEIs, the difference between an inventory covering Scope 1 and 2 vs an inventory with Scope 3 or a full CBEI was seen to be 3 to 13 times larger per capita (Figure 08).

Whether it is Scope 3 or CBE, accounting for a wider range of indirect emissions provides a more comprehensive measure of GHG emissions. It moves beyond a city's boundaries by adopting a global perspective to address what is fundamentally a global challenge.

## 2.1 Embodied Emissions Are Higher in High-income Regions

There are significant discrepancies between regions in terms of consumption demand and the resulting impacts. High-income regions consume far more resources than low-income ones. According to the International Energy Agency's Integrated Resource Plan (International Energy Agency, 2024), resource consumption in low-income countries averages just 2 tons per person annually, while an average person in high-income countries consumes approximately 27 tons a year – 13 times as much.

A report by Stockholm Environment Institute (SEI) highlights that between 1990 and 2020, global $CO_2$ emissions increased by 63%, while EU emissions decreased by 29% (Axelsson et al., 2024). However, this reduction fails to account for the EU's environmental footprint beyond its borders, due to the import of emissions-intensive goods and services to satisfy EU demand. Since 2015, the EU has been a net importer of $CO_2$ emissions (Figure 04): with over 30% of the imported emissions originating from outside the EU. Future projections suggest that without additional measures the environmental impact of EU consumption will rise further by 2030, underscoring the urgent need for alignment with global climate goals. Additionally, the separation between consumption and production geographies has a direct impact on the location of climate change impacts and human health impacts. Most notably, the Global North's consumption impacts air quality and health outcomes in the Global South.

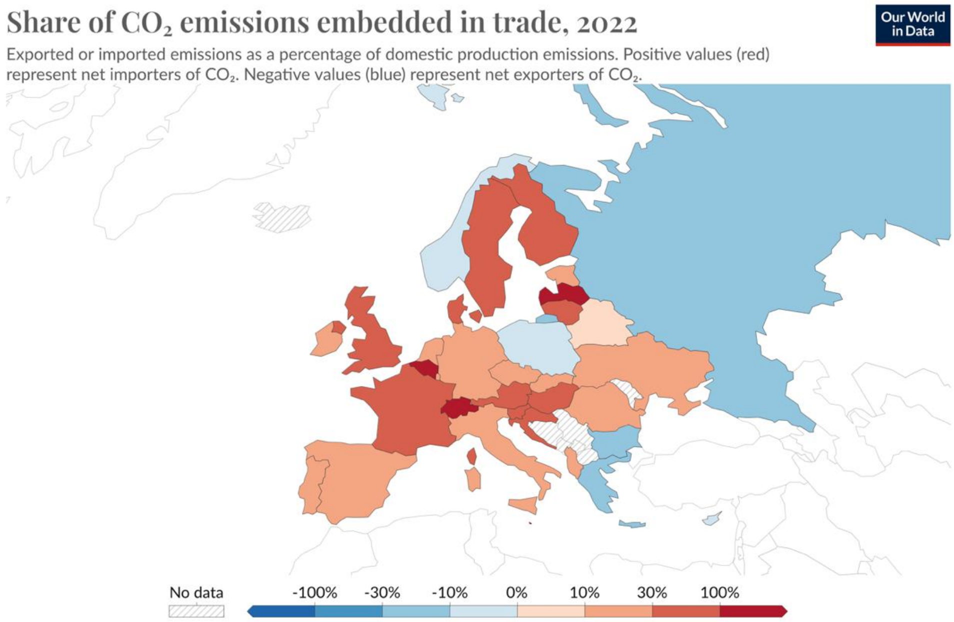


**Figure 4: Share of CO2 emissions embedded in trade in 2022 in Europe (Ritchie, 2024)**

In 2021, the average households' CBE footprint in the EU 27 was 8.0 tonnes $CO_2$ equivalent per person, excluding public consumption and investments (European Commission, 2023). Emissions ranged from 11.0 tonnes per person in Denmark and Luxembourg to 4.6 tonnes in Slovakia. To put this in perspective, we need to reduce global per capita carbon footprint to 2-3 tons CO2e by 2030 and to 0.5-1 CO2e by 2050 to stay within the 2-degree scenario (IPCC, 2022). Most developed countries exceed this target by a wide margin; for example, a round-trip flight from Frankfurt to New York City generates 2.2 tons of $CO_2$ per passenger, surpassing the target on its own.

From an environmental perspective the top 10% of global consumers have been responsible for 31–67% of Planetary Boundary (PB) breaches, far exceeding their equitable per capita limits across six key indicators (Tian et al., 2024). European cities hold significant potential to mitigate global environmental pressures. Scenarios where the top 20% of European consumers reduce their consumption to more sustainable levels could substantially reduce global environmental pressures (Tian et al., 2024).

Without systemic measures, increasing prosperity and population in the EU are likely to drive further increases in CBE (European Environment Agency, 2023)

## 2.2 A Systemic Approach Avoids Burden Shifting

A systemic approach to tracking both production- and consumption-based emissions is critical in helping cities to avoid burden shifting - a phenomenon where negative impacts are not resolved but *displaced*, either to outside of a major city or even another country.

To give an example, Mission Cities have identified retrofitting of existing buildings as a key action to take to meet their climate goals. To achieve this goal, decisions need to be made around sourcing of the material which will be used for the retrofit. If materials with high embedded carbon footprints are used, then the production of material resulting from this demand will still have significant emissions outside the city boundary.

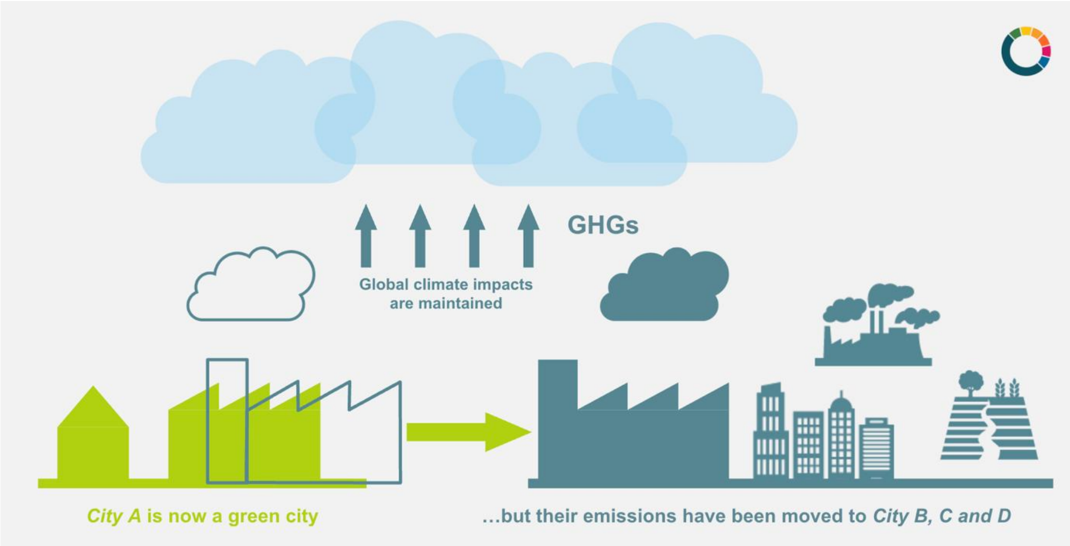


**Figure 5: An example of burden shifting where projected global climate impact is maintained despite reduction in territorial emissions in cities**

These types of systemic effects are crucial to understand and manage. Without a strategy that exerts efforts in the right places, we risk delaying progress towards achieving climate goals globally. While many Mission Cities aim for net-zero direct emissions, the exclusion of a complete overview of Scope 3 emissions within the Mission means that even if all cities achieve net-zero emissions within their borders, the impact on global climate goals may not reflect progress on the same scale.

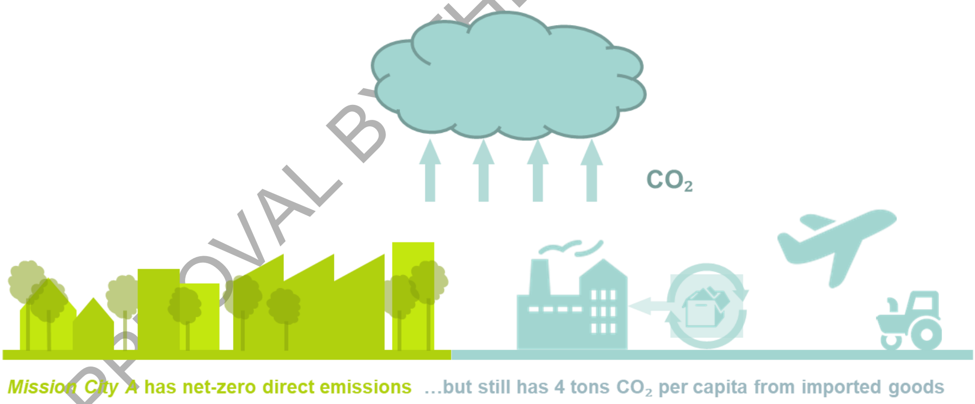


**Figure 6: An example of a city achieving "Carbon Neutrality" goals but with Scope 3 emissions still to be addressed.**

## 2.3 Acting on Embodied Emissions Provides Benefits for Cities

Using consumption-based accounts alongside existing city-wide inventories arguably encourages more holistic GHGs assessments, greater disclosure, and more meaningful benchmarking. It enables decision-makers to consider a wider range of opportunities to reduce global GHGs. It provides an additional perspective with which to engage cities' stakeholders in climate action. Another benefit of addressing Scope 3 emissions is the avoidance of burden shifting, by acknowledging the emissions created upstream and downstream of the city through consumption choices made by the municipality and citizens.

Alongside the multiple benefits of addressing Scope 3 emissions/CBE, there are many considerations to keep in mind:

- Scope 3/CBE inventories are **just an approach and a tool**. Extracting meaningful insights and action planning based on the inventories is still required after these inventories are generated
- Many cities need to follow **national guidelines** for inventory generation, which may lead to double accounting work for the cities
- Scope 3/CBEI should be presented as a useful **communication device** - as evidence to demand systemic change and for stakeholders across value chains to connect and work towards a common goal
- Communicating "citizen consumption" approaches can often be perceived as an act of **burden shifting** from the city authorities and industries.
- A drawback of CBE is that there is also no place for **negative emissions** in the accounting style, as consumption does not remove GHGs from the atmosphere the way that forests or CCS systems may.
- A common limitation of a CBE approach is the focus on household consumption, which can predominantly be addressed by adding two additional categories of (a) Consumption by public bodies and (b) Public and private investments.

# 3 Current State of Tracking Out-of-boundary emissions

## 3.1 Adoption According to the CDP-ICLEI Track Questionnaire

Efforts to address consumption-based emissions are gaining traction as cities increasingly recognise the importance of tracking indirect emissions. Platforms like the Carbon Disclosure Project (CDP) and the Global Covenant of Mayors for Climate & Energy (GCoM) demonstrate this growing trend, with more cities beginning to integrate Scope 3 and consumption-based assessments into their climate strategies. Despite progress, barriers such as data complexity and limited transparency in Scope 3 emissions remain significant challenges.

### Insights from the CDP-ICLEI Track Questionnaire

Since 2022, the CDP-ICLEI Track questionnaire has included a question assessing city-level efforts to develop CBEIs:

> "Does your jurisdiction have a consumption-based emissions inventory to measure emissions from consumption of goods and services?"

While these insights reflect the efforts of cities reporting to CDP-ICLEI, they exclude CBEIs developed at national levels and Mission Cities not reporting through this platform.

### Global Trends in CBEI Adoption

Among the 1,019 cities that responded to the 2023 questionnaire, 11% reported having a CBEI, 18% indicated plans to develop one within two years, and 71% had no plans to pursue a CBEI. This means that nearly 30% of responding cities are actively engaged in CBEI development, reflecting a growing interest in tackling consumption-related emissions compared to 2022 responses (REFERENCE).

However, within the group expressing interest in CBEI, the majority (64%) still do not have an inventory in place, suggesting a need for greater support to initiate development. European cities stood out, with 58% of those expressing interest already having a CBEI. This could point to better data availability or stronger political motivation to address consumption, which encourages cities to act.

For the 71% of cities not pursuing a CBEI, the common barriers that have been indicated in the questionnaire responses include financial constraints, insufficient technical expertise, data challenges, and competing priorities.

Regional differences are notable: Southeast Asia leads with 59% of reporting cities either having or planning to develop a CBEI. In Latin America, 34% of cities are on a similar path, both higher shares compared to Europe, where only 29% of cities are actively engaging with CBEI development.

#### Survey Responses in Mission Cities

Figure 7 illustrates the varying degrees of inclusion of Scope 3 emissions within the sectoral-based emissions reported in the Mission Cities' Climate City Contract (CCC) Action Plans. It is important to note that the self-reported Scope 3 figures may not perfectly align with the actual activities or inventories of a city, as the Mission guidance focuses on reporting Scope 3 emissions from the waste sector and not on reporting on Scope 3 beyond waste. Consequently, the data is categorised into three levels of reporting activity: “None,” where no Scope 3 emissions are included; “Waste,” where only Scope 3 emissions from the waste sector are reported; and “Waste+,” where Scope 3 calculations extend beyond the waste sector.

The figure highlights that among the 111 Mission Cities, a significant proportion do not report any Scope 3 emissions in their CCC’s, while others include only emissions from Scope 3 Waste, and a smaller fraction report on Scope 3 emissions beyond waste. While this data provides some insight into the varying levels of engagement with Scope 3 emissions, it is limited by the lack of a specific requirement to address Scope 3 comprehensively within the CCC Action Plans. In some cases, cities allude to their work on Scope 3 in their submissions, but this does not equate to a full Scope 3 inventory or systematic reporting. Furthermore, when comparing this reporting to data collected via the CDP-ICLEI Track, it becomes evident that the information is indicative rather than exhaustive. While over half of Mission Cities report to CDP-ICLEI Track regularly, their answers to the questionnaire, which explicitly queries comprehensive consumption-based emissions inventories (CBEIs), cannot be directly compared to the self-reported Scope 3 references in the CCCs. This distinction underscores the need for clearer guidance and more systematic data collection to assess the true extent of Mission Cities’ engagement with Scope 3 emissions.

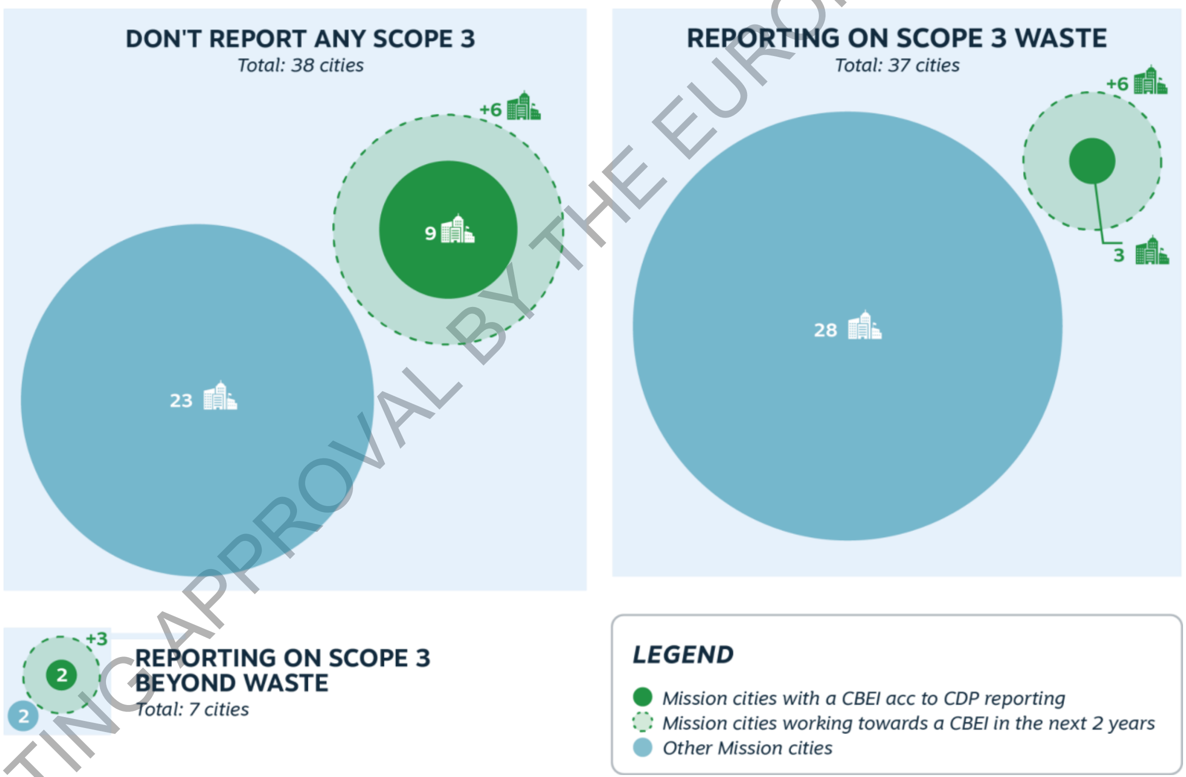


Figure 7: Overview of Scope 3 Emissions Reporting Across Mission Cities’ CCCs and their CBEI reporting on CDP-ICLEI Track platform

**CBE and Scope 3 in Mission Cities’ inventories**

For the Mission Cities which have a self-reported CBEIs or an extended Scope 3 inventory outside of the CDP-ICLEI Track, a comparison was performed to see the difference in scales of emissions addressed for the same year on a per-capita level. This overview does not allow for a true comparison between cities, as the inclusions of sectors, consumption categories, methodologies used, and terminologies used to explain the inventories are highly varied. What is consistent, irrespective of the difference in approaches, is the scale of difference between emissions in a standard inventory and a CBEI - which can range from being 2 to 13 times higher.

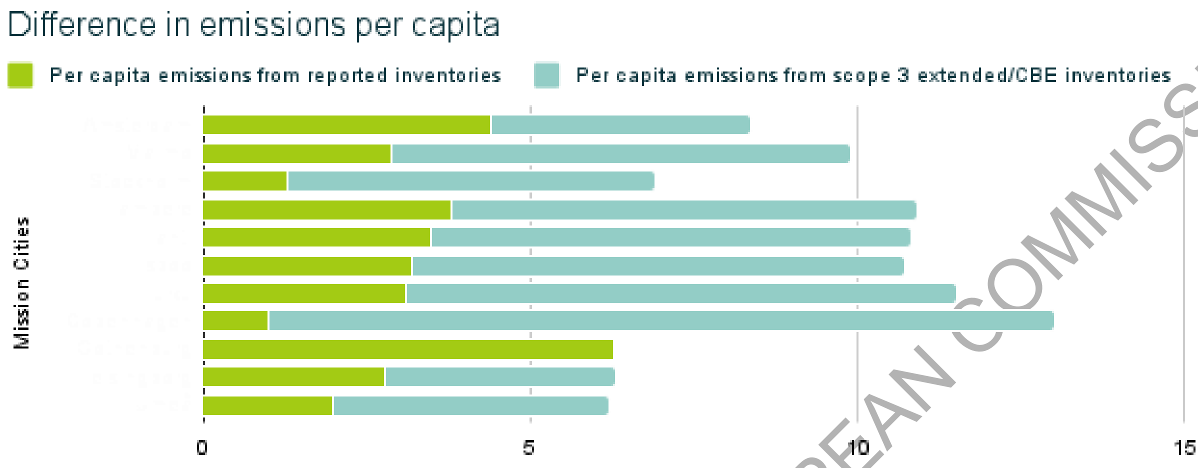


Figure 8: Overview of Scope 3 Emissions Reporting Across Mission Cities

## 3.2 Insights From Mission Cities

A non-systematic review had been conducted on groups of cities and countries involved in the development of consumption-based or Scope 3 emissions inventories, with a focus on Mission Cities that have submitted a Climate City Contract (CCC) Action Plan. The investigation began for each city with a review of their respective CCC Action Plans and was further extended by reviewing their municipal and national governmental websites, and other additional resources available online per city. As mission cities are not required to report on Scope 3 currently beyond waste, there might be other active initiatives at the city level not included in this analysis.

This sub-section will contain a list of insights gained from the reviewed cities concerning the information that was made available on the why's, what's, and how's of their Scope 3/CBE inventory building activities.

### 3.2.1 Drivers for Adoption

**Cities choose to work on CBE or Scope 3 emissions for several reasons that reflect their unique contexts, priorities, and constraints**

Many prioritise addressing high-emitting sectors as a practical entry point. For example, Sweden targets domestic transport, food waste, and energy use in buildings as key consumption areas to align with its net-zero goals. Although the country has not yet set a national CBE reduction target, this sectoral focus allows cities to address Scope 3 emissions without requiring comprehensive and costly CBE inventories. Similarly, Leuven's CCC includes Scope 3 interventions in the built environment sector, where it identifies up to 80% of material-related process emissions as avoidable through better material efficiency.

In some cases, cities address CBE because of the economic patterns that are most prominent. Typically, cities that are 'consumer economies' with high per capita carbon footprints, are more likely to adopt a CBE approach to climate-neutrality. Denmark, a "Consumer Country," recorded the second highest per capita CBE footprint amongst the EU countries in 2021 (European Commission, 2023). Its CBEI identified raw materials production and food waste as priority sectors for action, shaping both national and local CBE strategies. Additional to the national mandates, Copenhagen supplements the national CBEI efforts by additionally incorporating a sectoral approach in its emission reduction interventions to paint a more complementary and accurate picture of its emissions (Copenhagen AP, 2024; Axelsson et al., 2024)

Other cities focus on CBE as a response to data gaps and limitations in existing inventories. Finnish cities like Lahti and Espoo demonstrate this approach. While Lahti acknowledges the presence of Scope 3 data in its CBEI and GHG inventory, it is not yet disaggregated (Lahti AP, 2023). Espoo has expanded efforts to include Scope 3 emissions to help bring attention to the importance of citizen-driven consumption changes in bridging territorial and consumption-based approaches (Espoo AP, 2023).

**Clear language, monitoring and accounting methodologies strongly support the development of effective strategies**

In several CCCs, cities referenced circular economy strategies to address CBE, either explicitly linking them to indirect emissions or implicitly embedding them within broader climate-neutrality goals. However, very few cities provided detailed indicators to track the performance of their CE initiatives. This lack of specificity makes it challenging to assess the role of CE strategies in addressing Scope 3 emissions effectively. A key limitation lies in the scope of these indicators. While CE metrics often focus on waste reduction, recycling rates, or material efficiency, they do not always capture offsite emissions associated with material production and consumption, which are critical components of Scope 3 and CBE (Kopp et al., 2024).

### 3.2.2 Barriers to Adoption

**The challenges cities face in addressing Scope 3 or CB emissions, as identified in their CCCs cover analytical, implementation, and strategic areas.**

These challenges can be broadly grouped into three categories: data-related barriers (availability, granularity, and quality of data), methodological barriers (uncertainties in accounting approaches and comparability across cities), and jurisdictional barriers (limited authority over out-of-boundary emissions and perceptions of burden shifting).

*The lack of comprehensive, consistent, and high-quality data is a recurrent issue for several cities.*

This is present especially on emissions associated with materials use and is compounded by the fragmented nature of data across different systems and the varying availability of data depending on country or city (e.g., Sweden's CBEs face uncertainty due to assumptions about other countries' emissions). Diversity in methodologies and boundary conditions used further complicate data collection, aggregation and comparison. A few cities mention the high costs associated with setting up the required data collection and governance systems and investing in the technical acumen to overcome digitisation, legal and other data management issues. For instance, Tampere reports that the main challenge in gathering waste management emissions in Finland lies in the absence of reliable data. The national calculation methods use a top-down approach to calculate these waste related emissions, based mostly on landfills – the resulting recorded emissions are high, and the results vary greatly between the different Finnish regions, despite the top-down approach used. The combination of focusing on landfills and a top-down approach creates uncertainty in assessing whether the resulting emissions are truly of high magnitude, or that they are skewed due to unreliability in the data or the used model (Tampere AP, 2023).

For CBA, the most widely adopted approach utilises Input-Output (IO) data. Within this approach, besides data availability and quality, literature also describes data as vintage (on average used data being close to 10 years old), aggregation errors (merging multiple production sectors with varying emissions profiles into one IO sector), linearity (assuming a linear relation between emissions and prices), homogeneity (assuming equal emission factors for all products from each IO model sector) and domestic technology (not accounting for differences in technological efficiency between regions, but assuming equal technological availability) as the most commonly acknowledged weaknesses or uncertainty sources (Heinonen et al. 2020).

Expertise is also a challenge, as there are no common practices in conducting CBEI. New methodologies are emerging such as CBEI Guidebook (USDN, 2024) or CoolClimate Network (CoolClimate Network, n.d.), but the lack of skills at municipal staff can hinder the process (Moreno & López-Fernández, 2022).

**A lack of harmonised methodologies, accounting frameworks and terminologies harms collaboration and cooperation for assessment and monitoring.**

Cities also raised challenges related to the variety of methodologies employed to estimate Scope 3 or CB emissions. Lack of harmonised methodologies, accounting frameworks and even terminologies can make it challenging to compare emissions data or to create standardised interventions that can be applied across municipalities. A challenge mentioned in the French context, but which applies to all European countries, is the lack of (and need for) international collaboration and cooperation in the standardisation and monitoring of CBEI (Axelsson et al., 2024).For countries such as Denmark that have already established a nation-wide implementation of a CBEI, the main challenges lie in the methodological complexities of monitoring and establishing their legally binding national CBE target (Axelsson et al., 2024). The directive to collect municipal CBEI was set by the Danish government, and although a national emission calculator was provided, the exact methods and data sources to gather emissions data varied between cities. The preference in choosing to proceed in an imperfect manner means that the government will now focus on consolidating the CBEI methodology process but may also concurrently direct its focus on higher impact actions (Axelsson et al., 2024). These challenges are also visible in the scientific community. Studies often use the same terms to indicate different issues and methodologies are often not referenced clearly, through a variety of names, or mixed up with other methodologies (Heinonen et al., 2020, section 4.1).

**The nature of addressing emissions outside a city's jurisdiction brings particular challenges around spheres of influence and perceived burden shifting.**

Scope 3 emissions often fall outside a city's direct jurisdiction, particularly emissions from products consumed within city boundaries. This creates challenges in assigning responsibility and ensuring enforcement. Legal mandates, such as requiring businesses to sort waste, or citizens to separate food waste, are difficult to implement without strong local governance and ownership and coordinated public-private partnerships. Resistance from citizens can arise when governments are perceived to be shifting the burden of emission reductions onto citizens rather than businesses, particularly for emissions tied to global supply chains. This is also politically sensitive as the notion of infringing on the local industries or the citizens‘ private spheres isn't favourable (Axelsson et al., 2024). In Swedish cities, for instance, political sensitivities, communicating barriers among stakeholders, and the challenge of defining ‘sustainable consumption’ emerged as key obstacles to implementing CBEI at the national level. Solutions should involve designing policies that indirectly guide the consumer behaviour change by affecting the value-chains and system surrounding the consumption patterns rather than explicitly placing the responsibility on consumers (Axelsson et al., 2024).

**Scope 3 emissions reductions cannot occur in isolation and demand cohesive action involving multiple actors with aligned interests and shared power to influence changes in policy, citizen behaviour and other domains.**

Many cities are investing significant time and effort in collaboration to tackle Scope 3 and CBE, which largely fall outside their sphere of control and lie within their sphere of influence. Cities collaborate internally with national platforms, businesses, and citizens, and externally with other municipalities, national platforms, and cities in other countries. Actors who have broader authority or influence, such as national governments that set policies, businesses that manage supply chains, and citizens whose choices drive demand, can together help shape systems and decisions they cannot control alone. For cities there are high dependencies on stakeholders' inventories to correctly estimate the emissions from imports of goods and services, as well as citizen patterns on buying products. A collaborative approach allows cities to navigate these complexities more effectively and steer responsible consumption behaviours, thereby enabling more impactful and scalable solutions. Across the CCCs, we found several examples such collaborations and the involvement of different stakeholders.

### 3.2.3 Approaches and Scope Adopted by Cities

**Cities use a wide variety of language to frame their approach on addressing Scope 3 and CBE, often using terms interchangeably and drawing from the chosen accounting approach.**

Though clear language and accounting methodologies support the development of effective strategies, cities can begin tackling out-of-boundary emissions without it, as many already address them implicitly through for instance circular economy interventions.

Across the reviewed CCCs significant variation was observed in the terminologies cities used to frame interventions and strategies for addressing Scope 3 emissions. Commonly encountered terms included "Scope 3 emissions," "out-of-boundary emissions," and "consumption-based emissions". From scientific literature, “trans-boundary”, “supply chain emissions” and “indirect” emissions add to that list [Wiedmann et al. 2016]. However, even in cases where these terms were not explicitly mentioned, many cities were actively working to reduce Scope 3 emissions, often through policy or project interventions that mirrored those of cities using more formal terminology. For example, Paris has chosen to incorporate both the Scope 3 and CBE concepts in its AP and has combined the two concepts through the delineation of direct versus indirect emissions (Paris AP, 2024). They differentiate between the terms “local emissions” which are the same as territorial emissions (i.e. direct emissions within the Parisian city boundaries), and its “carbon footprint”, which relates more so to CBE, as it combines the direct local emissions and the indirect out of boundary emissions linked to the consumption habits of citizens outside of the city's boundaries. They do mention that they have been reporting the GHG emissions in a sectoral format for two decades, and in doing so, they disregard the Scope 2 emissions category altogether and divvy the emissions into either the direct ‘local’ Scope 1, or the indirect Scope 3.


**Figure 9: Diversity of approaches and terminologies currently used for emission inventories by cities**

Finnish cities such as Lahti and Espoo also tend to use terms related to both CBE, territorial emissions, and the sectoral approach interchangeably in their AP's (Espoo AP, 2023; Lahti AP, 2023). Both sets of terms are used in the description of Lahti's mission reduction goals, which leaves space for uncertainty in understanding whether both concepts remain relevant in their emission reduction, or whether the varying approaches are used synonymously. Despite the lack of clarity in framing of the methodology, these cities may still act as good examples for others which have begun implementing related climate actions and wish to communicate the beginning of alignment with an analogous methodology.

The distinction between Scope 3 and CBE becomes clearer when methodologies are explicitly mentioned. Scope 3 aligns with sector-based approaches, while CBE focuses on consumption categories such as food, goods, and services (Heinonen et al., 2020, 2022; Kuivalainen, 2020). We found that cities' choice of terminology often flows directly from the methodology they use to measure and account for emissions, rather than the language driving methodological choices.

**Starting to take meaningful action doesn't necessarily require comprehensive inventories.**

On the one hand, it is important to transparently communicate about accounting methodologies as differing approaches can significantly affect outcomes and the interpretation of emissions data. On the other hand, our review of the CCCs suggests that cities do not need comprehensive Scope 3 or CBE inventories or knowledge of complex accounting methodologies to start taking meaningful action. Instead, cities can lower the bar for entry by adopting interventions that address these emissions indirectly. For instance, cities often implement similar actions - such as circular economy policies - regardless of whether they explicitly use Scope 3 or CBE terminology. The city of Leuven has implemented pilot projects aimed at acquiring and reallocating building materials from old and torn down buildings. While originally placed under the 'CE activities' umbrella, these initiatives indirectly affect Scope 3 emissions in reducing the need for raw materials in future projects, which works towards reducing out-of-boundary emissions associated with the extraction of virgin materials (Leuven AP, 2023). While generally aware of its Scope 3 emissions, Amsterdam currently does not have a public and extensive out-of-boundary emission inventory but has progressed its endeavour of reducing its out of boundary emissions around the consumption of products and materials through its extensive CE strategy (Gemeente Amsterdam, 2020). With comprehensive emissions inventories,

**The language municipalities use to address emissions can significantly shape their strategies and stakeholder engagement.**

Scope 3 focuses on a city's influence over its value chain, such as procurement or supplier engagement, while CBE approaches it through a shared responsibility lens examining the entirety of a city's consumption choices across consumers, businesses, and governments (Metabolic, 2024). Precise terminology can help align actions with the appropriate sphere of influence that a city has – Scope 3 framing often drives internal or supply-chain-focused interventions, whereas CBE framing steers efforts toward behavioural change and cross-sector collaboration.

**Cities collaborate with a range of stakeholders on either data-related aspects or on undertaking joint actions**

Agreements around who collects which data and from where helps address challenges around data that were frequently cited by several cities in their CCCs. The structure and approach to collaboration on data for addressing Scope 3 emissions are not one-size-fits-all but instead depend on the specific goals, available resources, and governance contexts of the cities involved. For example, cities can follow a top-down collaboration model on data or a bottom-up one. Some Nordic countries such as Denmark and Finland have taken a top-down approach in establishing a national effort in the building of Scope 3 and/or CBE inventories through the use of national mandates, and by providing calculation methodologies. In contrast, Swedish cities have taken a bottom-up approach at individually establishing independent CBEI, with the possibility of aggregating the efforts from a wide local to a national one.

**Multi-city collaborative projects provide opportunities to test solutions to what are often cross-boundary issues**

Cross-boundary projects can help test technical solutions such as sustainable supply chain practices, resource sharing and waste management programs. It can also be a useful setup for testing behavioural change initiatives amongst diverse groups. As part of the NZC Pilot City Programme, we found examples of multi-city initiatives targeting Scope 3 emissions. Such is seen in the example of the German Pilot City Programme CoLAB, a project formed by the cities Aachen, Mannheim, and Muenster, who aim to target their city-borne CBE behaviours through novel 'non-technical' pathways, and the creation of a "House of Change" (NetZeroCities, n.d.). The "House of Change" will be city supported but citizen owned and run and will act as the central powerhouse between the different levels of stakeholders, and houses projects which evaluate and overcome turning points in behavioural change paradigms., transforming lone local efforts into consolidated execution of actions (NetZeroCities, n.d.). In doing so, the CoLAB project makes use of both inter- and intra-city collaboration to share knowledge and resources in tackling Scope 3 and CBE.

***Internal coordination between city departments and across cities through national platforms is a common mode of collaboration***

Sharing data and establishing governance mechanisms allows cities to ensure alignment in policies, actions, and accountability. This is seen amongst the Danish cities, who are almost all part of the DK2020 project, which utilises the network to align their climate action plans in accordance with the Paris agreement objectives (Axelsson et al., 2024). Partnering with national-level initiatives or national platforms provides cities with access to broader resources, policy alignment, and technical expertise. National platforms can facilitate shared learning and provide standardised methodologies around data collection and analyses. Sweden has two such example of multi-city and -regional networks, named Klimatkommunerna and Ekokommunerna, which each band the parts of Sweden together to enable knowledge transfer and align resources and efforts towards expediting the "sustainable consumption agenda" (Axelsson et al., 2024).

## 3.2.4 How Cities See the Pathway Forward

**Businesses are key stakeholders in shifting consumption patterns**

Businesses control supply chains, product offerings, and customer engagement. Collaborating with them allows cities to influence practices and create incentives for sustainable supply and demand of goods and services. For example, Valencia has become the first destination globally to verify the carbon footprint of its tourism sector, explicitly including Scope 3 emissions through a data-driven public-private partnership between Visit Valencia (a foundation backed by City Council) and the Global Omnium group. As a city government, Valencia lacks direct control over the wide-ranging and fragmented components of the tourism value chain, such as accommodation providers, event organisers, and transportation networks, which contribute significantly to Scope 3 emissions. To calculate these emissions, the partnership used advanced big data tools, segmenting Scope 3 emissions into ten categories, including transport, food services, and public services. The detailed breakdown provides insights into the most carbon-intensive activities, enabling targeted interventions. Building on these findings, the partnership is implementing a blockchain-based digital management system that tracks emissions in real time and helps organisations reduce their carbon footprints (UN Tourism, 2021).

**Citizens can help reduce Scope 3 emissions through their consumption choices**

Cities can drive change by investing in public awareness campaigns, participatory planning, and behavioural incentives. In 2020, Mannheim recorded Scope 3 emissions from the food and nutrition sector for the first time and aims to tackle part of these emissions through interventions on behavioural change and influencing consumption patterns through initiatives like the Plastic Strategy and Zero Waste Strategy. A key component of their strategy includes promoting regional and organic products, raising awareness about the emissions linked to various diets, and encouraging more sustainable consumption. These efforts are specifically aimed at reducing the environmental impact of imported goods, especially in food production and transportation.

**Cities can play broader and more dynamic roles in reducing Scope 3/CBE beyond policymaking**

Drawing on the CCC Action Plans, it was found that cities act as innovation hubs and facilitators of collaboration, in addition to their regulatory responsibilities, to drive change. Cities can serve as innovation hubs for circular economy initiatives by creating programmes and services that support startups and entrepreneurs. In creating spaces for collaboration between academia, industry, and civil society, cities play the role of conveners and incubators. For example, Espoo is transforming its Kera district into an international circular economy hub through projects like Smart and Clean Kera, which repurposes industrial spaces into sustainable residential and commercial buildings, supported by a physical and digital platform for innovation and collaboration (Kyrki, 2024).

Cities can also influence Scope 3 emissions by directing financial resources to support sustainability initiatives. Municipal grants and loans can target carbon-intensive sectors, catalysing change where it is needed most. The Hague, for example, uses a 'serial financing' approach to support circular initiatives, starting with pilot projects and scaling them with appropriate funding at each phase. Through a dedicated "Grant Expertise Point," the city helps match projects with local, national, and European funding opportunities, reducing the administrative burden and ensuring financial support throughout the project life cycle (Post, 2024).

Cities are well-positioned to act as connectors, facilitating collaboration and dialogue among stakeholders. This can involve expanding technical expertise (as mentioned by Benediktsson (2024)), linking stakeholders to funding opportunities (as done by the city of The Hague), or through joint problem-solving. For instance, the city of Espoo learnt that securing financing for circular projects can be challenging, particularly due to state aid regulations. In such cases, cities can help by convening businesses to align initiatives with long-term strategies, enabling companies with shared goals to collaborate or invest in circular projects and districts that promote industrial symbiosis (Kyrki, 2024).

# 4 Recommendations: What can Cities do to Understand, Measure and Act on Embodied Emissions?

Cities often start their climate journey with a focus on local emission production sources to reduce emissions because these impacts are the most straightforward to measure and present more immediate opportunities to act upon. Cities can clearly influence activities within their borders, such as transportation system planning, emissions standards for vehicles, and energy performance benchmarks. But while a transition to renewable energy, complemented by energy efficiency, is crucial, research by the Ellen Macarthur Foundation and Material Economics (2019), concludes that these measures can only address up to 55% of emissions: “the remaining 45% comes from producing the cars, buildings, clothes, food and other products we use every day” (Ellen MacArthur Foundation, 2019). A recent study comparing production-based emissions accounting and consumption-based emissions accounting of 10 European cities showed that scenarios for 2050 showed significant decreases for production-based emissions, falling up to 68%. However, consumption-based emissions increased for eight cities, rising up to 35%. This increase overrides the local and global energy efficiency improvements (Harris et al, 2020).

So, what can cities do? In the same way that they can guide local emissions by setting energy performance standards on buildings, there are many opportunities to establish the same kinds of standards for sustainable material consumption. In Amsterdam, for example, land is tendered out to developers based on circular economy criteria (Roemers & Faes, 2017). Beyond their legislative power, cities can influence local self-sufficiency, circularity, and the behaviour of citizens and companies. They can do this by developing a clear vision, facilitating bottom-up action, and aligning incentive frameworks with clear goals around consumption. Cities like Copenhagen, London and Paris are taking the lead on developing comprehensive strategies to reduce the environmental impacts of consumption.

Having explored the growing trend of cities addressing their out-of-boundary emissions, it is clear that the field also requires further maturing. This guide provides insight on two main pathways cities can take:

1) Assessing their emissions by developing more comprehensive inventories

2) Taking action to reduce these emissions, even without an inventory

This chapter covers the options cities can utilise to assess out-of-boundary emissions, while the next chapter covers ways to take action.

## 5.1 Building an Inventory

While building an inventory is not a mandatory starting point for cities to begin addressing out-of-bound emissions, it can serve as an important element towards understanding such emissions and for identifying the key hotspots where actions can be taken. This section gives a brief overview of common inventory styles used for understanding out-of-bound emissions, but a more detailed section on **how to build an inventory** along with relevant resources can be found under the "further exploration" chapter of this report.

The two common inventory styles that can be used to account for indirect emissions, **consumption-based and sector-based**, vary from one another in methodology, what is included, and how emissions are grouped for analysis.

The sector-based style groups emissions by sectors. The sectors can vary depending on the specific methodology but within the Mission, they are grouped into Buildings (or Stationary Energy), Transport, Waste, AFOLU, IPPU. This is in line with the Global Protocol for Community-Scale GHG Emission Inventories (GPC) and thus highly standardised. The GPC has existing guidelines on Scope 3 emissions which cities can refer to while looking into a sector based approach.

There is no equivalent level of standardised approach for consumption-based inventories, however there is guidance available from the SEI (Broekhoff et al., 2019). They suggest the following categories for a CBEI, with the caveat that the priority should be to have a grouping that is useful for developing policy based on the results of the inventory:

- Travel or transportation
- Housing or home
- Goods
- Services
- Food and beverages

Figure 10 below visualises the relationship between the two approaches.

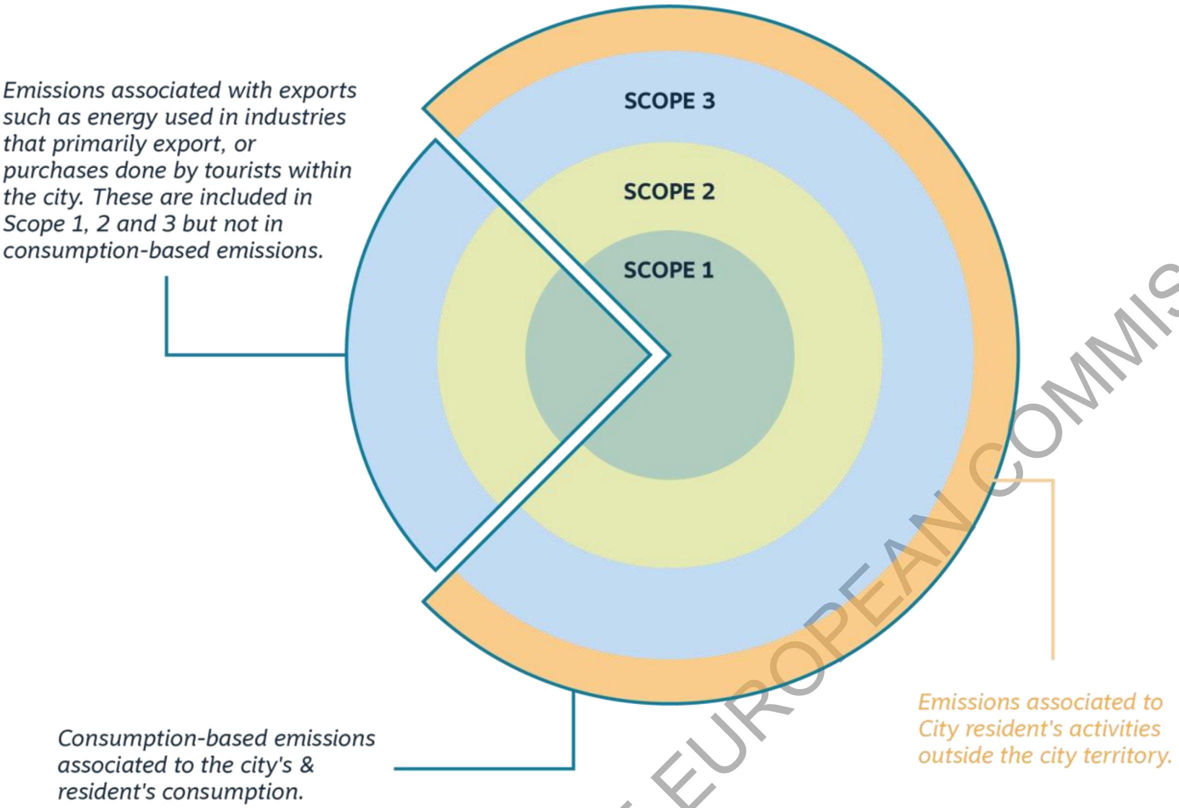


**Figure 10: Visualising the relationship between the Sectoral-based and Consumption-based emissions accounting styles. Adapted from source: City of Copenhagen Climate Unit.**



## 4.2 Take Action, Even Without an Inventory

If cities know where to act, they can have a direct impact on out-of-boundary emissions even when the sources fall outside their scope of influence. There are many existing mechanisms and levers which cities can identify and in turn utilise towards the reduction of Scope 3 emissions and CBE.

### 4.2.1 Map existing actions and policies

Cities can assess their current portfolio of actions to identify actions which potentially impact emissions outside the city boundary. These can include, but are not limited to, actions which promote Circular Economy (CE), resource efficiency, reduction of embedded emissions in the built environment, sustainable material use, green procurement, interventions in the food supply chain, plastic and packaging use, waste prevention and management etc. Such actions most often have an impact on Scope 3 and consumption-based emissions which might not be properly captured due to the lack of specific indicators aimed at measuring emission reductions outside the system boundary. A mapping of policies and regulations being enacted in the city can also highlight the state of the ecosystem in supporting such activities. For example, a building renovation action focused on reducing the embedded emissions of materials through reuse will still need to comply with regulations around energy standards and insulation values - which may or may not support the reuse of existing materials depending on the local context.

### 4.2.2 Define extended impact indicators

Cities can add indicators on measuring the change in upstream and downstream emissions for current and future actions. To properly assess the role played by existing actions on Scope 3 emissions, such as Circular Economy actions, it is important to track the impacts resulting from the actions. For example, while CE metrics often focus on waste reduction, recycling rates, or material efficiency, they might not always capture offsite emissions associated with material production and consumption, which are critical components of Scope 3 and CBE. Additionally, while measuring changes at the action level, the city may not need to create a baseline - the resulting changes can be tracked as part of a transition from BAU.

### 4.2.3 Focus on procurement

Public procurement is one of the most impactful mechanisms for cities to address indirect emissions. Governmental bodies can leverage their purchasing power to prioritize the procurement of sustainable materials and practices which have a positive impact both within the city and address indirect emissions which may be placed outside the city boundary. 39 Mission Cities are implementing one or more types of green procurement as part of their climate strategy, under categories of circular construction, energy procurement, renewable energy companies and certifications. The assessment of the procurement practices of the municipality can extend towards measuring environmental impacts with possibilities of locating the impacts geographically.

### 4.2.4 Assess the municipality as a company

When a city does not have the capacity or data infrastructure to develop a city scale inventory, a Scope 3 emissions assessment of a municipality can be undertaken following the Corporate Value Chain (Scope 3) Standard by the GPC. This will give insights on actionable hotspots within the immediate scope of influence for the municipality and its assets, which can then also inform the procurement practices for municipal assets.

### 4.2.5 Conduct a city-scale urban Material Flow Analysis (MFA)

A city-level Material Flow Analysis (MFA) looks at material inputs (like water, energy, construction materials, food) and material outputs (like emissions, solid waste, wastewater). This analysis can help to identify areas where a city can be more sustainable and efficient in resource use as well as support in identifying key intervention areas. As the MFA can be sector focused, it can also give insights on which material categories have the highest potential impact or require the most attention. Resource efficiency insights can include things like construction waste to improve local recycling, plastic waste to measure consumption by sector and increase circularity, or organic waste to identify political interventions that can enable a shift towards closing organic waste cycles.

A MFA visualisation, which is usually in the form of a Sankey diagram, is also useful as a communication tool for encouraging stakeholder collaboration and raising public awareness. A good example of a MFA used to identify insights for which material flows to address for consumption-based emissions can be seen in the study conducted by ReLondon on London's food footprint (ReLondon & Circle Economy, 2021).

### 4.2.6 Identifying Levers for Change

Addressing behavioural change mechanisms in response to high CBE is a commonly seen practice. However, the connection between the two is often assumed to lie solely at the point of what the citizens of a city buy. Since household expenditure is used as a data point for creating consumption-based emission inventories, it often becomes the sole focus of change initiatives.

From a municipality's perspective, the scope for driving behavioural change extends far beyond individual consumption. Cities can broaden their impact by engaging across the entire value chain of a given consumption category. For example, consider the value chain of food consumed within a city (see Figure 11 below). By mapping out the life cycle and identifying stakeholders involved in each stage, it is possible to identify critical decision-making points and develop more comprehensive change strategies.

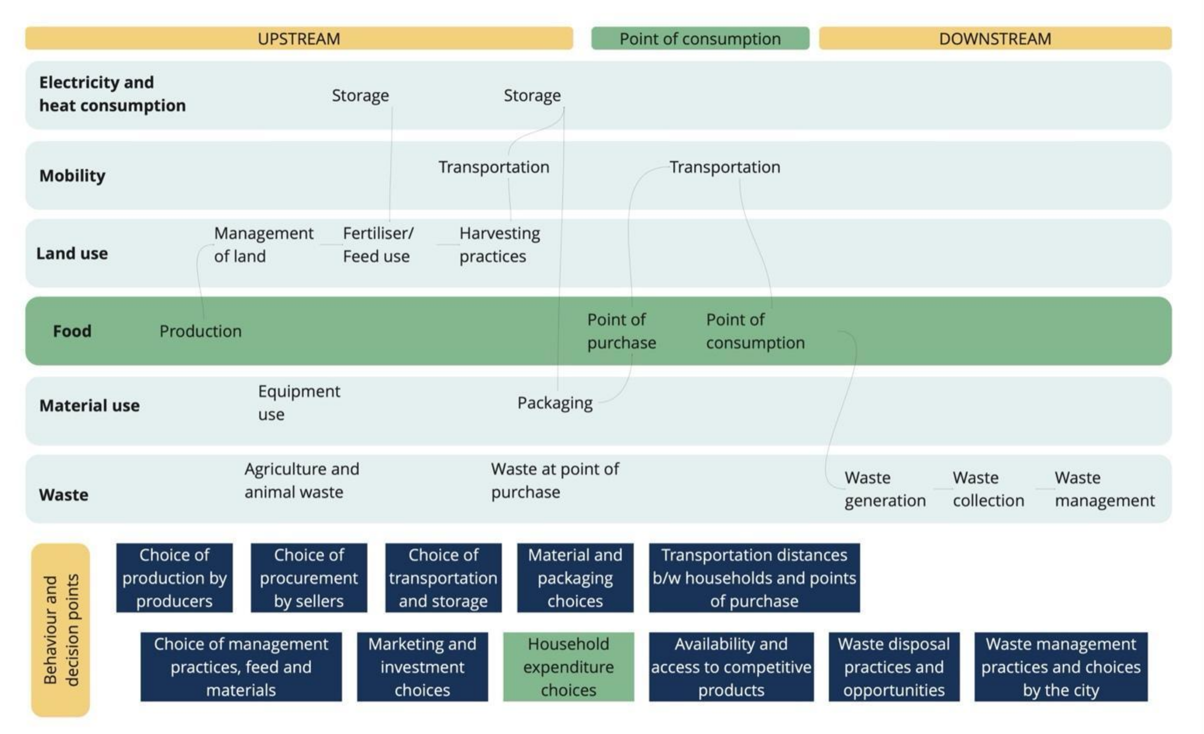


**Figure 11: Visualisation of the intersection between the value chain for food in a city and key decision making points**

(Visualisation of the value chain of Food products, including the various sectors, stages, stakeholders, decision points involved in the life cycle. This simplified image depicts the complexity of the system, while simultaneously allowing for the delineation of the different areas which may be targeted for decision-making focal points in the consideration of forming strategies.)

Mission Cities' current climate action portfolios have been noted to frequently address multiple levers for different action types. Through an assessment of the CCCs, it was noted however that most of the actions only address one to three levers:



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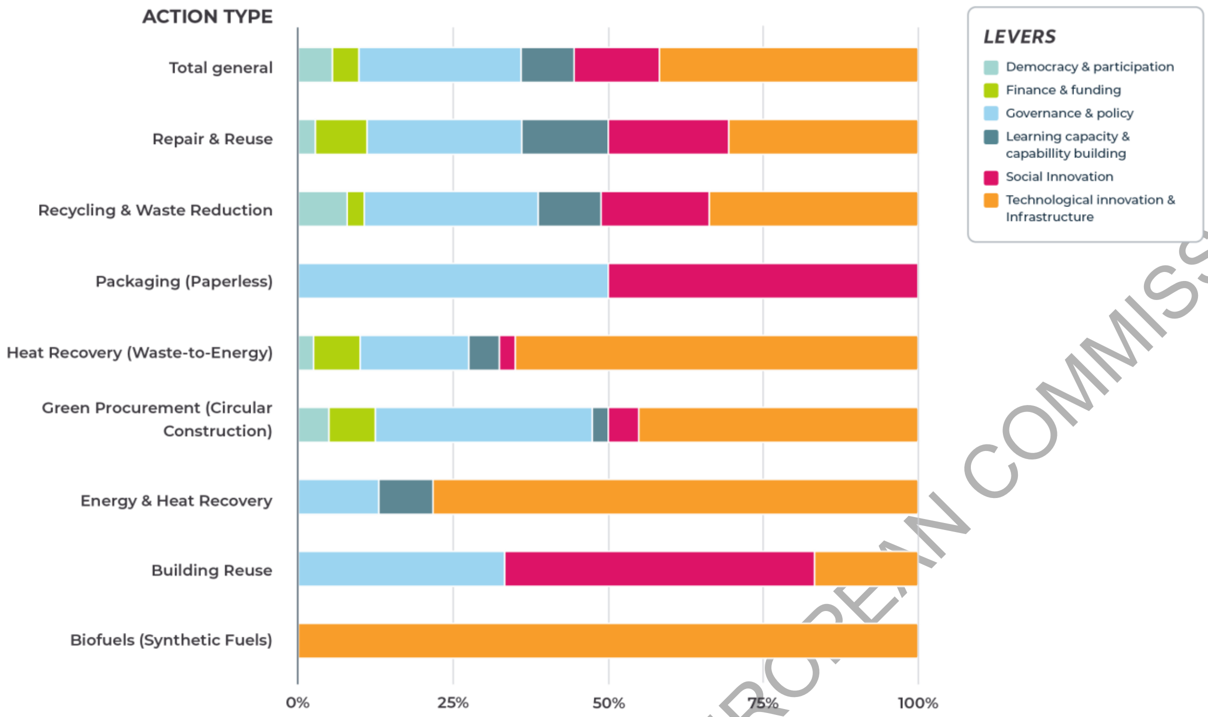


**Figure 12: Overview of the distribution of types of levers necessary to achieve the different actions**

Furthermore, due to the requirements of the Mission, not all the actions that possibly could be performed to address indirect emissions are being considered in the assessment. From the above list, most cities are focusing on recycling and waste reduction, anaerobic digestion or better ways of managing waste rather than focusing on the sourcing of raw materials or green procurements - so far only 15 cities out of the 57 CCC Actions plans reviewed have included green procurements.

## 4.2.7 Start with a Sectoral Focus

Some of the main sectors that a city or region has an influence on include buildings/built environment, transport/mobility, waste, industrial processes and product use (IPPU), and agrifood and land use (AFOLU). The types of levers that a city can use differ by sector, as indicated in Figure 13. This section delves into some of the details of these sectors and actions that can be taken to reduce Scope 3 or consumption-based emissions.

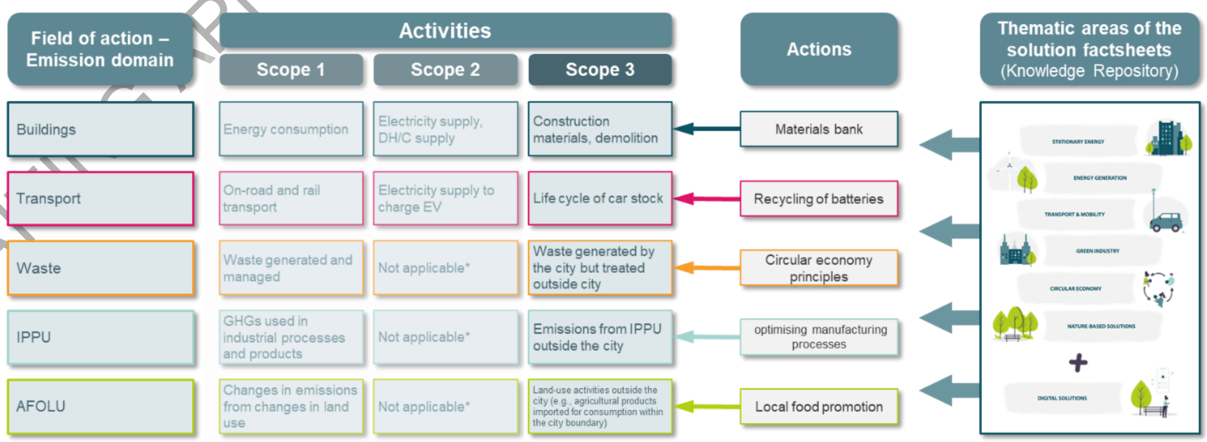


**Figure 13: Overview of the actions and thematic areas linked to the Scope 3 emission activities**

**Buildings and the Built Environment**

There are multiple existing mechanisms in the built environment that can support a direct approach towards the reduction of scope 3 emissions – such as introducing LCA in public procurements, reducing embodied carbon in construction materials, or incentivising sustainable building practices (such as material banks) (López-Fernández et al., 2023). Urban mining model (Charoniti & Gómez, 2023) to assess circular construction opportunities and optimize resource use and exchange and Circular Life Cycle Cost for deep renovation (López-Fernández, 2023) can be two solutions to promote material efficiency. Digital product passports and LCA tools are already being promoted in Energy Performance building directive and construction products regulations in the EU, which will need to be transposed by the different member states and applied at regional/city level.

There are a number of Mission Cities with promising projects in Circular Economy, with a focus on circular construction:

- Lahti's Circular Economy roadmap
- Leuven's Material Bank & Urban Resource Centre
- Malmo's open database for materials
- Mannheim's Second Life & Second Use - Circular markets, Network "Resource efficiency & Circular Economy", Zero Waste strategy, and circular economy procurement
- Marseille's circular construction platforms
- Milan's HCC EU CINCO and urban metabolism
- Pecs's online marketplace for secondary materials, construction waste hub deployment, and testing sites
- The Hague's Circular construction
- Leuven's Material Bank
- Espoo's Pilot Project

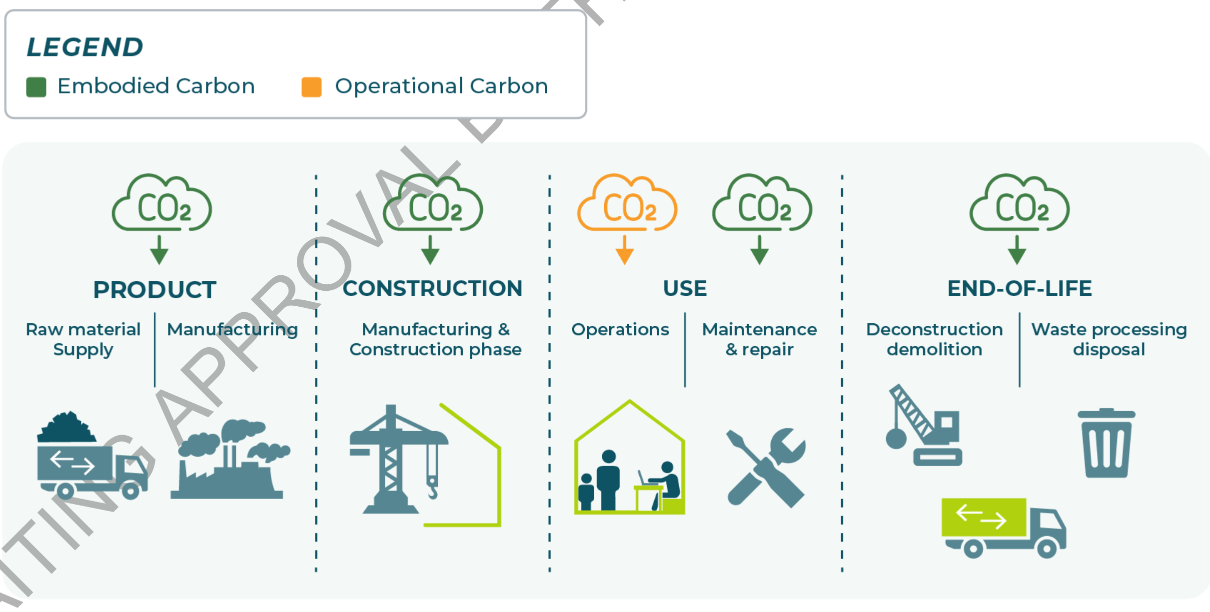


**Figure 14: Visualised overview of the Operational and Embodied carbon sources in buildings (Adapted from source: Toth et al., 2024)**

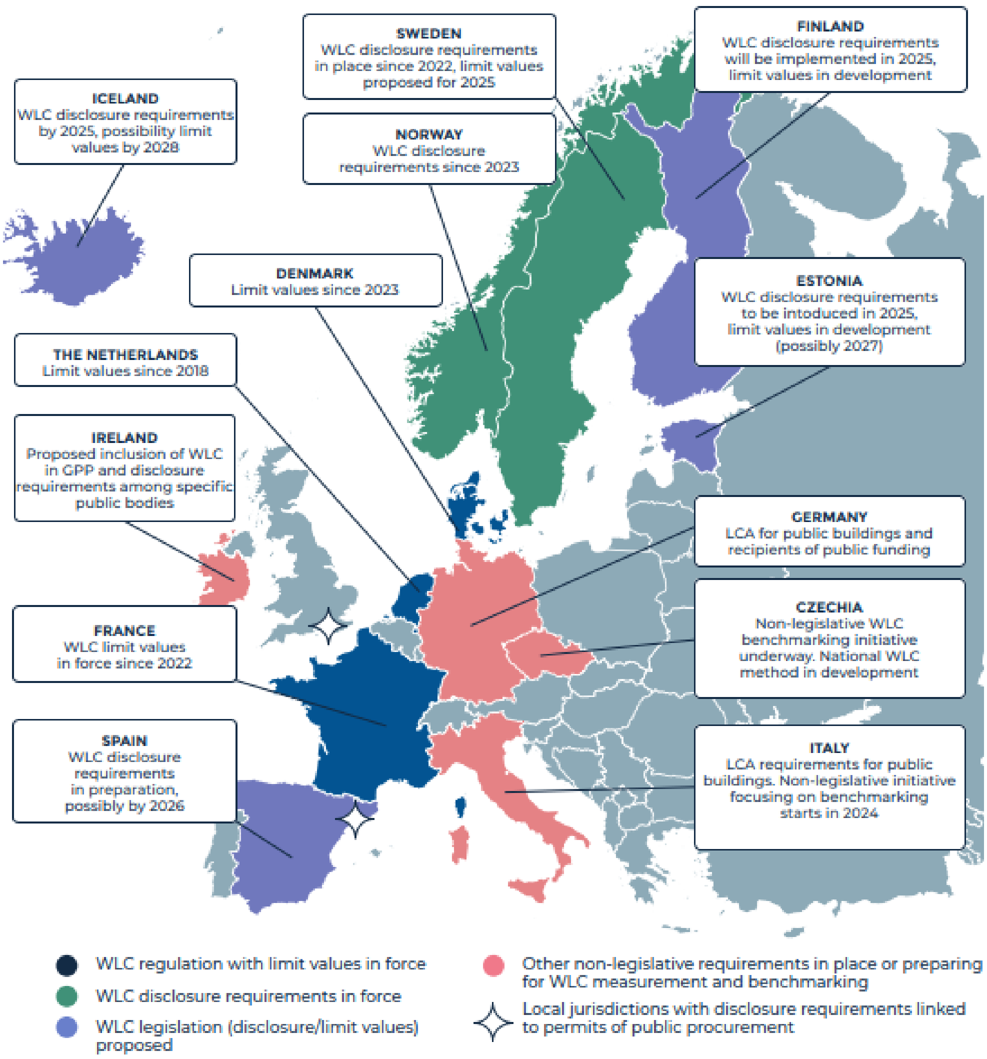


**Figure 15: Overview of regulations and initiatives across Europe regarding Whole Life Cycle emissions (Toth et al., 2024).**

**Transportation and Mobility (including aviation)**

Cities are beginning to evaluate transport data available through Google EIE to assess transport emissions using data from inbound and outbound trips. Valencia aims to reduce emissions in their transport sector by developing the technology surrounding the “green hydrogen infrastructure for transport and logistics”, in order to increase the usage of public transports (Valencia AP, 2024).

**Waste**

Promoting waste reduction, recycling and circular economy strategies have been noted to be a part of many Climate Action Plans. Actions which target reducing both the end-of-life and product/construction related emissions often have impacts which lie outside the city boundaries. E.g. Pay as you throw systems from Prato (Benigni & Mehmeti, 2024), anaerobic digestion of organic fractions (López-Fernández & Gómez, 2023).

This report won’t expand on the cities' actions focusing on Recycling and Waste Reduction as it has already been covered by a significant portion of the Mission Cities.

**Industrial Processes and Product Use (IPPU)**

Both Malmo and Amsterdam show proactive actions towards improving the treatment of textiles within the system, through the implementation of Circular Economy plans and principles. Falling under different initiatives, Malmo with the EU level "Circular Economy Action Plan", and Amsterdam with the "Green Deal Circular Textiles", both aim to target multiple parts of the value chain by supporting circular innovations and entrepreneurs in the field, educating and mobilizing consumers on sustainable practices, and increasing the collection and reuse of used clothing (Amsterdam AP, 2024; Malmö AP, 2023)

Amsterdam will follow a similar trajectory in the handling of electronic and consumer goods as it does with its textile industry, as both categories of goods fall under its initiative to counter the effects of its high material consumption. Details on the actions surrounding the collection and recycling of e-waste may be found in the Amsterdam CCC Action Plan (Amsterdam AP, 2024).

**Agrifood and Land Use (AFOLU)**

Six cities were noted through their actions catalogue in their CCC's as clearly stating actions and intentions towards improving and developing their food and agricultural systems in the endeavor to either directly or indirectly affect their Scope 3 emissions. These cities - comprising Lisbon, Lyon, Marseille, Munster, Valencia, and Vitoria-Gasteiz - unanimously expressed interest in achieving higher levels of "local self-sufficiency", often through the creation and/or fortification of local and regional supply chains. Efforts made to transfer the dependency of food demand and chains to local sources would potentially curtail the emissions and costs associated with supply from abroad. The French cities Lyon and Marseille presented a focus on the affordability of healthy and organic foods, especially for those disproportionally affected by inflation and rising prices. Lisbon has approached the issue with policies directly supporting "urban and per-urban agriculture", and Munster has focused on improving the standards and quality of the municipalities' catering services towards the community, schools, and city administrators. (Lisbon AP, 2023; Lyon AP, 2023; Marseille AP, 2023; Münster AP, 2024; Valencia AP, 2024; Vitoria Gasteiz AP, 2023)

### 4.2.8 Foster partnership

Cities can act as the facilitators and hosts for conversations between private stakeholders and industry players who hold key supply chain infrastructure or are a source of employment to a large proportion of their citizens. Cities can also influence Scope 3 emissions by directing financial resources to support sustainability initiatives.

# 5 Further exploration: building an inventory

## 5.1 Existing Frameworks, Guidance and Tools

Although the field of study is rapidly evolving, there are already many useful frameworks and resources available for cities to utilise.

**Guidelines**

- PAS 2070: (The British Standards Institution, 2014a)
- CBEI guidelines from the Stockholm Environment Institute
- CBEI Guidebook by USDN
- *GPC 2.0 guidelines (upcoming)*

For initial guidance on concepts, data collection, calculation, comparing production to CBE and data quality assurance, we would like to refer to The Future of Urban Consumption in a 1.5°C World (C40 Cities, Arup, & University of Leeds, 2019).

There are also possible interactions with the GPC guidelines for businesses to calculate Scope 3 emissions (WRI & WBCSD, 2013). The future research question is how company-level reporting interacts with reporting on the city level. Does the mandate for corporate reporting on Scope 3 emissions lead to double counting for the city, especially on employee commute? And what would be the future outlook on the requirements laid out for corporate reporting in the EU?

**Existing studies**

- Consumption-based GHG emissions of C40 Cities
- Application of PAS 2070: London Case Study; London CBE Borough report
- Three-scope carbon emission inventories of global cities
- Monthly direct and indirect greenhouse gases emissions from household consumption in the major Japanese cities

**Tools and datasets**

- CarbonMonitor: contains data on Scope 1,2,3 emissions for over 1500 cities worldwide.
- Environmental Footprint estimates of household carbon footprints for 27 EU countries
- European Multi-regional Input-Output data for 2008-2018
- Kulma Project by Sitowise: used by Finnish Cities

### 5.1.1 Case Examples

Below you can find summaries of 3 existing studies which provide tangible examples of the differences in purpose, approach, scope and utilized data and methodologies.

**Consumption-based GHG emissions of C40 Cities (C40 Cities, Arup, University of Leeds, & University of New South Wales, 2018)**

In a partnership effort, C40 Cities investigated the consumption-based GHG emissions from 79 global cities. Their report describes the applied methodology and breaks down the results in a comparative way. They have utilized the GTAP9 GMRIO in line with the PAS2070 consumption-based guidelines in a top-down approach with a PCF allocation, allocating for the emissions from residents, excluding visitor activities.

The purpose of this study is one of comparison. It illustrates how consumption-based GHG emissions compare to sector-based GHG inventories, highlighting the split between producer and consumer cities. It gives insight on the variation of per-capita CBE between world regions, how those are divided over consumption categories, and to which sectors they are attributable to.

Some of their main outcomes are that two-thirds of consumption-based GHG emissions originate from out-of-boundary sources and that most of those are coming from utilities and housing, capital, transportation, food supply and government services.

The study is limited to insights on this comparative level, providing an indicative approximation as data is not provided at a city-level.

Further methodological details can be found in Wiedmann et al. (2021).

**The carbon footprints of consumption of goods and services in Sweden at municipal and postcode level and policy interventions (Dawkins et al., 2024)**

Likely the most recent and detailed study on carbon footprints with local granularity is performed for all Swedish municipalities. Their approach has been to downscale the Swedish national carbon footprint data to the level of postcodes using local data on expenditure, GHG emissions and other data such as energy use available at the smallest geographical scale. The national level data is based on a top-down approach using the EXIOBASE GMRIO. Household consumption aligns with the COICOP classification. The results of this study use the PCF allocation principle, focusing on residents. Most of the used data sources for downscaling cover 2019.

The purpose of this study is to assess the suitability of this downscaling approach for local policy making, identify hotspot categories and variation across municipalities, and draw policy implications and recommendations from the results.

Some of their overarching outcomes are:

- Postcode level CF variations are significant, ranging approximately from 3.7 to 17.8 tCO2eq/capita, differing greatly from the 6.3 tCO2eq/capita national average and most particularly coming from activities such as flights and personal vehicle use.
- There is a strong correlation between income and CF. Population density doesn't significantly impact total CF, but per consumption category there are strong positive and negative correlations.
- Carbon footprint analyses should be coordinated between municipalities and supported at the national level to enable consistent comparisons, and monitoring over time that in turn inform policy and environmental strategies.
- Given the current size of carbon footprints in Sweden, urgent and substantial reductions are necessary to meet climate goals. The considerable variation in carbon footprints emphasizes the need for well targeted and ambitious policy measures across municipalities and for different consumption categories.

**PAS2070 DPSC & CB – London case example** (The British Standards Institution, 2014b)

The PAS2070 guidelines for emission inventories are extensively applied to London in this case example. It includes full details of implementing the Direct Plus Supply Chain (DPSC) and Consumption-Based (CB) methodologies and an outcome comparison to the London Energy and GHG Inventory (LEGGI) methodology. It is the first extensive implementation of these guidelines on a city level and acts as a guide for cities on how to apply the methodologies in detail.

The study was finished in 2014, and the time period of assessment is defined as 2010. Hence, this study is indicative for the comparison of these methodologies and for London was useful for the development of their policies.

**LEGGI** covers Scope 1 and Scope 2 carbon dioxide (CO2) emissions only from the combustion of energy used within the city boundary: (a) for transport; and (b) to power and heat homes/workplaces.

**DPSC** covers direct GHG emissions from activities within the city boundary and indirect emissions from the consumption of grid-supplied energy, transboundary travel and supply chains of key goods and services such as water supply, food and building materials. That said, it is a sector-based methodology that includes Scope 1, Scope 2 and a selection of Scope 3 emissions. It builds on the GPC to include a wider range of indirect emissions and is consistent with the emission sources covered by the GPC.

**CB** captures direct and life cycle GHG emissions for all goods and services consumed by residents of a city. It does not assess the impacts of the production of goods and services within a city that are exported for consumption outside the city boundary, visitor activities, or services provided to visitors.
The applied approach is top-down using an EE-MRIO with regional household expenditure data and national capital and government expenditure data.

*As a result, the total GHG emissions calculated using the CB methodology (114.10mtCO2e) are 40% higher than those calculated using the DPSC methodology (81.06 mtCO2e) and 157% higher than those calculated using the LEGGI method (44.44mtCO2e).*



## 5.2 Inventory Methodologies and Approaches

Out-of-boundary emissions are important to assess and Scope 3 and CBE are the two main inventory styles to do so. But how does such an inventory come to be? By reviewing scientific papers, reports from governmental bodies and other relevant organisations we have reviewed the current landscape of methodologies development, predominantly around CBEI. This review of methodologies is not exhaustive but is able to provide a soft landing and sound foundational basis for cities seeking the mainstream literature surrounding inventory building methodologies.

The main messages laid out in further detail in this chapter are:

1. The field of study has gone through rapid development in recent years, branching out in a variety of directions. Despite the developments, it is still immature in providing unified and clear guidance.
2. For a city, there are now a wide variety of methodological approaches and options to choose from for the assessment of their out of boundary emissions. Each comes with their own limitations.
3. For CBEI's, the main methodological differences arise around working through a top-down, bottom-up or hybrid approach, using either a Single-Region IO (SRIO) or Multi-Region IO (MRIO), and utilizing either a residential or territorial allocation principle. (Other differences arise around the amount and type of consumption categories and gases that are included in IOTs, and the type of consumer demand that is used)
4. The methodological choice a city makes should be guided by the availability of data, but even more so by the purpose of the assessment. For example, purposes could be - to educate residents or decision makers, roughly prioritise climate activities, compare amongst cities, or to develop and evaluate detailed policies.

5. The climate-neutrality transition is not just about addressing GHG emissions. The scientific field provides insights into dynamics at play and how to take steps towards more systems-level assessments that include environmental and social impacts, for governments to learn from.

**A maturing field of study**

Available review papers on the topic demonstrate that the lack of unity in methodologies is due to large varieties in the different building-blocks that make up an emission inventory. This list includes but is not restricted to the variety of different terms used to describe concepts, the different available models and methodologies, the different sorts of datasets used, the scopes and scales (varying from municipal, to local, national, regional, and international), and the different purposes for which to build an inventory (Heinonen et al., 2020; Kuivalainen, 2020; Wiedmann et al., 2016).

The advantage of this variety in the methodology building blocks is that it gives cities a large range of options to choose from so that they may build an inventory aligning to their needs and abilities. Despite the potential to find a suitable methodology, there are significant bottlenecks encountered by cities amongst which are the lack of data and/or expertise in the field. Each city will face their own limitations in building an inventory according to the national/surrounding landscape and will find that every decision taken in building a methodology comes with its own pros and cons. Three key choices in methodology building blocks were ascertained as priorities for cities beginning the inventory methodology building process: the types of models used, the type of data used, and the type of emissions allocation used.

**Type of approach used**

Mainly, CBE can be assessed through a top-down, bottom-up or hybrid approach.

Through a *top-down approach*, an Input-Output Table (IOT) is utilized to estimate CBE based on spending or consumer demand data. The IOTs describe trade flows from goods and services across sectors and regions. The output of these assessments is in emissions per monetary value distributed over categories such as commodities, type of consumer, life-cycle phase and location of emission. These estimates are often based on national-level data and come with a range of uncertainties to consider such as the age of used data, policy or technological developments and distinguishing between different origins of a commodity (Kuivalainen, 2020). An important variation to mention here is the type of consumer demand that is being used – either the final demand, as monetary value of consumer purchases or the gross demand as the sum of final demand and all the indirect or intermediate purchases which the final demand requires.

**Table 1: Input-Output Tables**

| **Input-Output Tables** |
|---|
| An IOT describes the flow of goods and services across sectors, and countries. By connecting that with emission intensities (EEIO), the impacts of production and consumption can be traced. An IOT typically consists of:<br><br>1. Rows (Outputs):<br>    a. Representing the distribution of a sector's output across other sectors, final consumption (households, government), capital formation, and exports.<br>2. Columns (Inputs):<br>    a. Showing the inputs used by a sector, including raw materials, intermediate goods, labour, and energy.<br>3. Final Demand:<br>    a. Reflecting the end-use of goods and services, including household consumption, government spending, investment, and exports.<br>4. Value Added: |

a. Including wages, profits, and taxes minus subsidies, representing the contribution of each sector to the overall economy.

Through a *bottom-up approach*, emissions are estimated based on physical units of consumption. Here, local data on consumption of goods and services can be combined with Life-Cycle Assessment (LCA) to estimate CBE per consumption of physical units. This approach is most often not reasonable to conduct on a city scale due to the lack of available data on level of consumption and corresponding emissions intensities. When it is available though, it can provide highly accurate results (Kuivalainen, 2020).

Finding a compromise results in employing a *hybrid-approach*. Starting from an overarching view from IOT, some categories can be detailed further through LCA this way. A common challenge here lies in the harmonization of different data sources which often have varied foundations such as the year of origin or the territory, population group or classification that is used (Kuivalainen, 2020).

For more information about these approaches and their pros and cons we would refer to Kuivalainen (2020) which references Balouktsi (2020), Broekhoff et al. (2019) and Heinonen et al. (2020).

These approaches distinguish themselves by the type of data they utilize. Often many sources of data are required for the development of these IOTs, LCAs and the monetary or physical units of consumption. It stands out that the underpinnings in terms of scope, scale and quality of these datasets are equally essential as the methodologies and models in defining what the assessment describes. As an example case, Girod and de Haan (2010) assessed the implications on GHG emissions data between allocating from monetary versus physical units.

**Type of models used**

Currently CBEI's most often rely on a top-down approach that utilizes IOT data, to translate consumer demand data into CBE, although hybrid approaches are winning ground. The two main types of models are Single-Region Input-Output (SRIO) and Multi-Region Input-Output (MRIO) models. In short, MRIOs explicitly account for different regions for economic activities such as imports and exports, while an SRIO focuses on a single geographic region or economy. For example, in an SRIO imports from multiple regions are treated as one assuming domestic GHG emission factors.

Disaggregating between regions, an MRIO is more complex to develop, but allows for higher accuracy results, for instance to track emissions across international supply chains. The increased complexity is accompanied by novel uncertainties which carefully need to be considered.

The increased availability of MRIO's has made them preferential over utilizing SRIO's. However, one should still consider using a detailed SRIO depending on the purpose of study and the data quality that can be reached.

On top of this it is important to mention that there is a wide variety between MRIO models, for instance around the scale and classifications they use internally. In their recent literature review, Heinonen et al. (2020) mention that "*... only a minor share of the most recent studies applies models reaching even 40 sectors, which Su et al. (2010) suggested as a minimum acceptable sector resolution.*" and that "*Following the development towards sub-national scale studies, particularly city-scale, sub-national level models have appeared, though still the majority of sub-national scale studies are performed using national-scale models*".

An overview of widely applied MRIO models is provided in Table 02.

**Table 2: Overview of the currently adopted MRIO models and supporting resources. Table adapted and extended from (Broekhoff et al., 2019; Kuivalainen, 2020).**

| Model name | Description | Scale / Region | Benefits & Limitations |
|---|---|---|---|
| GTAP GMRIO (Center for Global Trade Analysis, 2023) | An Environmentally Extended Global MRIO (EE-GMRIO) database and a tool to analyse global trade relations, including information on emissions. The most recent GTAP 11 has data for 141 countries and 65 sectors, covering the years 2004, 2007, 2011, 2014 and 2017. Good international comparability. | Global coverage with 141 countries | Territorial principle. License fee for non-academic sectors |
| EXIOBASE (EXIOBASE Consortium, 2015) | A global, detailed Multi-Regional Environmentally Extended Supply-Use Table and IOT (EE-MRIO). It distinguishes 200 products and 163 industries. The latest version covers data for 1995-2011. Frequently utilised in academic research. | A global coverage over<br>28 EU members, 16 major economies, 5 Rest of World regions | Residence principle. Free for use |
| FIGARO (Eurostat, 2024a) | FIGARO compiles EU inter country supply, use, and IOT and provides a unique tool for analysing the socioeconomic and environmental impacts of globalization. It builds on data from national accounts, business, trade, and jobs. Includes 64 products and production activities and 5 final demand categories. FIGARO aspires to be the EU's reference tool for policymakers and has produced annual data since 2021. It is currently able to provide time series data from 2010 to 2022. Economic activities classification NACE, which includes 64 industrial categories. | All EU member states, the UK, the US, and 17 other main EU trading partners. | Currently it only includes CO2 and no other types of GHG emissions (CO2e). Which is mentioned to change soon.<br><br>Free of charge |
| WIOD (University of Groningen, 2016) | WIOD is an MRIO database covering 43 countries, and data for 56 sectors. It covers the time period from 2000 to 2014. | Covers 28 EU countries and 15 other major countries in the world | Residence principle |
| EORA (KGM & Associates, 2024) | An EE-GMRIO that includes over 15,900 products with data for time series from 1990 to 2015. Widely used by academia, international organisations and global companies. | Global coverage with 190 countries | Territorial principle. License required |

| | | | |
|---|---|---|---|
| ENVIMAT | An EE-MRIO table for Finland. It includes 148 sectors and 229 products. It has recently been updated to cover consumption intensities for the year 2015. | Finland only | This is a SRIO. |
| IMPLAN (IMPLAN, n.d.) | Economic modelling tool. Includes IOTs for over 550 sectors, divided by intra-state, inter-state and international trade. It is possible to add environmental data, including various GHGs. Updated continuously. Regularly utilised for CBEI. | Designed for the US, but basic model structure can be adapted and applied to other countries when data is available. | Flexibility in incorporating user-supplied data at all stages of model building.<br><br>Commercial tool requiring license fees. |
| EIO – LCA (Greenhouse Gas Protocol, 2011) | Economic IO LCA tool.<br><br>Typical LCA's use mass as input unit, this uses dollars and outputs emissions per dollar to link monetary values to environmental IOs.<br><br>The information dates to 2002. It has been regularly used for academic studies in the past.<br><br>This is a semi-SRIO. | Includes data for the US and a few other countries, e.g. Germany and Peru. | Only covers upstream impacts, uses sector averages and product aggregation, and unrealistic linearity between dollar and emissions.<br><br>Outdated (2002) |
| USEEIO (Ingwersen et al., 2022) | Environmental-economic model that can be used for LCA, foot printing, national prioritization, and related applications., of US goods and services.<br><br>V2.0 (2022) covers 411 commodity categories,<br><br>Single-Region model with 50 US states modelled as one region.<br><br>The economic database year is 2012. | US goods and services | Environmental impacts, resource use and waste generation.<br><br>Uses final demand.<br><br>Rest of World uses domestic technology assumption |
| IELab (IELab, 2024) | At heart an e-research project, it provides a platform for environmental footprint and life cycle sustainability assessments based on MRIO modelling. It also includes satellite extensions (e.g. environmental or social data). | | |
| EcoInvent (ecoinvent, 2024) | An international LCA database that can be utilised as a supporting resource to estimate life-cycle emissions of over 10,000 products. The database is one of the main sources for estimations of | n.b. | License fee |

| | | | |
|---|---|---|---|
| | carbon intensity of imports in the ENVIMAT model. | | |

Arto et al. (2014), provide a comparison between WIOD and GTAP MRIO's which sheds light on the differences in their approaches and the resulting outcomes. Note that GTAP 8 was used and the WIOD version with data from 1995–2007.

**Table 3: Uncertainties in Input-Output Tables**

| **IOT uncertainties** |
|---|
| IOTs, and with them SRIOs and MRIOs have common uncertainties that are well elaborated on in scientific literature. The list of these uncertainties is lengthy, and we'll provide a non-exhaustive list of common ones here. The main message is one of being aware of uncertainties in the process of defining your inventory approach, performing the assessment and interpreting results. The impact on the results from these uncertainties logically varies in type and size, depending on the used model and data. For more information, one can start with looking at Heinonen et al. (2020), and Wiedmann (2009) which provide some overview and reference detailed studies.<br><br>Domestic technology: Inherently present in SRIO models this uncertainty originates from the assumption of the production technology of imported goods and services to be identical to the economy under investigation and with that the emission factors. The relaxation of this assumption and the reduction of the associated uncertainty is the very reason for the desire to create MRIO models, although it can still be present there. MRIO's can still introduce uncertainty by applying this assumption to a world region.<br><br>Data recency and frequency: Collecting data and performing analyses can take years. Also, crucial datasets such as consumer expenditure data are often repeated only after several years. This makes that on average, analyses thus far remain close to 10 years old and due to that don't incorporate time-sensitive changes such as the implications of policies and advances in technology.<br><br>Aggregation errors: Aggregation describes the merging of multiple production sectors with varying emissions profiles into one IO sector. For example, meat and vegetables are known to have drastically different environmental impacts but can be clustered in an aggregated food sector.<br><br>Homogeneity: Looking beyond the sector aggregation to the products within a sector, homogeneity describes the assumption of equal emission factors for all products within a sector. For example, the variety of products in a vegetable produce sector such as avocados and tomatoes have different emission factors.<br><br>Linearity: For IOTs the linearity error describes the assumption of a linear relation between emissions and prices. For example, a car that is twice as expensive doesn't necessarily have twice as high production emissions. |

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|---|
| Monetary exchange rates: Converting currencies in an MRIO either by utilizing a market exchange rate or purchasing power parity can significantly impact the number of emissions for models using an emissions per monetary value spent process.<br><br>Data uncertainties: On the side of input data, also a variety of uncertainties are to be considered. For example, around trade statistics there are uncertainties from 1) time lags between shipping of export and receipt of import, 2) differences in commodity classifications, 3) reporting errors, 4) losses from transit accidents and 5) discrepancies of origin and destination due to re-export. |

**Types of emission allocation used**

The types of emissions allocation used refers to which sources of emissions/consumption you include or exclude in your inventory. The 2 approaches involved here include Personal Carbon Footprint (PCF) and Aerial Carbon Footprint (ACF). The allocation principles of PCF comprise the residents of a specific jurisdiction, and accounts for the emissions of all those residents, including their consumption outside the territorial boundaries. You track everything that the residents consume, regardless of where they consume the products and services. This typically excludes capital investments and demand by governments. ACF uses a territorial allocation principle which accounts for the emissions caused by the consumption of every person inside a certain territory. Accordingly, mobile individuals such as tourists or people that commute into the specified territory are also included in the ACF, but not in the PCF. This typically also includes capital formation and other final demand categories. Again, a hybrid approach can also be utilized. The distinction between ACF and PCF is a good example of a case in which one isn't preferential over the other, but where the practitioner should consciously decide based on the purpose of their study and the capabilities at hand Heinonen et al. (2020, 2022).

A review of 111 studies by Heinonen et al. (2022) highlights besides ACF and PCF differences between studies as including or excluding governmental consumption and capital formation, differences in included fossil and non-fossil CO2 and other GHGs, in- or excluding impacts from land use, land use change and forestry (LULUCF), how the utilization of housing energy and spending on durable goods are incorporated, emission intensities of imports, the unit of analysis and the defined geographic scope. The review finds that these differences can lead to 80% of the emissions addressed by one to be excluded from the other and that describing these differences in allocation and scope is an uncommon practice thus far.

**The purpose of an assessment**

For cities beginning their trajectory in choosing a methodology, the combination of decisions should be made according to the purpose of building an inventory, and so it is key to clearly define the intended perspective which one aims to take to properly determine which building blocks suit them best.

A review of literature determined four main purposes in building an out-of-boundary emissions inventory (Broekhoff et al., 2019; Kuivalainen, 2020).

1. Educate residents about their emissions footprint
2. Develop a rough basis to prioritize impact categories to address and actions to start doing so
3. Compare cities to their peers
4. Continuous development and evaluations of detailed policies

For the first two purposes, a city would only require a breakdown of major consumption categories. These can likely be obtained from pre-existing analyses from literature or national or regional CBEI. When focusing on residents for instance, the impacts from government spending and capital investments might also be of lesser concern and thus be excluded. An example here is a report commissioned by the Umeå Municipality which includes recommendations on specific hotspot areas for emissions reductions suitable for citizens (Kuivalainen, 2020).

Whenever the purpose is to compare cities amongst each other (for a collaborative approach, scientific inquiry, or other reason), the focus should lie on an approach that is standardized and utilizes data that is as comparable as can be. This would require for instance to select a MRIO that is built from representative data and includes a categorization of consumption that is suitable to the local contexts. A great example here is the study that developed CBEI for 79 C40 cities. An important outcome here was the identification of the split between Scopes 1, 2, 3 and CBE emissions for each of these cities (Wiedmann, 2009).

If the purpose is to inform the design and evaluation of local policies, or to develop detailed action programmes to reduce carbon emissions in a city across the board, the requirements intensify around data quality and methodological tailoring. Assessments need to be accurate, comparable, comprehensive and complete. Evaluating changes in citizens' consumption behaviour requires local, detailed and recent consumer expenditure data. The use of downscaled national data won't reflect these changes, nor would outdated IOTs. Many MRIO's are unfortunately only updated every 4-5 years, if ever and often the data utilized for them dates back up to 10 years prior. Alternatively, a city can employ a hybrid approach in this case, starting with a IOT based study to obtain a comprehensive baseline of the consumption categories such as commodities, actors, and life-cycle phases after which small-scale high-quality studies can be performed and a select set of indicators can be designed to enable detailed development and evaluation of policies. These studies and indicators don't necessarily have to be spend-based, but could include activity, mass or other units. As long as they are accurate in reflecting the truth, comparable amongst backwards and forwards in time, comprehensive in their details and complete in painting a systemic picture (Axelsson et al., 2024; Balouktsi, 2020; Wiedmann, 2009).

To conclude, the main take-away for beginning cities in the building of an emissions inventory methodology remains a classic, 'quality rather than quantity'. It is important for municipalities to focus

on collecting robust and relevant data that aligns with the purpose of their study. An exhaustive full picture is not necessary to begin transforming knowledge to actions in reducing out of boundary GHG emissions. Municipalities may streamline a dynamic approach, either by focusing solely on the known specific data which will be used to make an evaluation, or by producing an approximate computation, and then returning to spot-check key areas using express indicators.

**Beyond GHG emissions**

The models and methodologies that are discussed here aren't exhaustive in showcasing the options cities have for understanding and addressing the societal dynamics at play and the resulting out-of-boundary impacts.

The scientific community has already and continues to study many dynamics that are at play in the topic to learn from and use for the monitoring, evaluation and learning cycles when taking action. Examples are on correlations between household carbon footprints and income, (Ottelin et al., 2018a) studies on consumer groups (Ala-Mantila et al., 2013, Ottelin et al. 2020), urban zones, (Ottelin et al., 2018b), rebound effects around ownership (Junnila et al. 2018, Linnanen et al., 2020), and policy implications (Balouktsi, 2020; Ottelin et al., 2019)

Lastly, the climate-neutrality transition is not just about addressing GHG emissions. The scientific field is already taking steps beyond that, towards more systems-level assessments that include a wider range of environmental and social impacts. Examples are:

- Environmentally extended IOTs (EE-MRIOs), in which environmental impacts are included outside GHG emissions alone.

- Environmental impact assessments, for instance using the LCA-based consumption footprint indicator from the Joint Research Centre (JRC) on a city-level. This assesses the impacts of five areas of consumption (food, mobility, housing, household goods, appliances), for 150 representative products, with the 16 impact categories of the Environmental Footprint method and assesses it against the Planetary Boundaries (PBs) framework (Genta et al., 2022).
- A study on comprehensive PB footprints to measure environmental impact on a global level. Utilizing the Global Resource Input Output Assessment MRIO tables to map 15 footprint indicators across 51 sectors and seven global regions, identifying key sectors driving PB impacts and suggesting targeted interventions for sustainability (Goodwin et al., 2024).
- A global-level study on how PB transgressions are distributed across different expenditure (income) groups and assessing the environmental mitigation effects of plausible consumption-reduction and efficiency-improvement options that target high-end consumers (Tian et al., 2024).

The benefit about these developments is that with any approach it is possible to add environmental impacts. If the inventory has a consumption category and amount, the study can be extended with environmental impacts.

## Glossary of Terms

| Term | Definition |
|---|---|
| **1.5- or 2-Degree Scenarios** | The 1.5°C scenario refers to pathways aiming to limit global warming to 1.5 degrees Celsius above pre-industrial levels. Achieving this requires rapid and far-reaching transitions in energy, land, urban, and industrial systems, with global net human-caused $CO_2$ emissions needing to decline by about 45% from 2010 levels by 2030, reaching net zero around 2050. (IPCC, 2022)<br><br>The 2°C scenario involves pathways that limit global warming to 2 degrees Celsius above pre-industrial levels. This scenario requires global $CO_2$ emissions to decline by about 25% from 2010 levels by 2030 and reach net zero around 2070. |
| **Carbon Footprint** | The carbon footprint quantifies GHG emissions associated with a defined system, which can include countries, cities, or products. For countries or cities, it encompasses emissions directly resulting from the activities of households and governments, as well as emissions indirectly arising from final demand and equity investments within the geographic area. These emissions account for the production, distribution, use, and disposal of purchased goods and services, including those linked to trade.<br><br>For products, the carbon footprint captures GHG emissions directly and indirectly associated with the entire life cycle of the product, including emissions from imported parts and products (ISO14067:2018). This life cycle encompasses production, distribution, use, and disposal, and the measurement is typically conducted using life cycle assessment (LCA) methods along the entire product chain. |
| **Consumption-based emissions (CBE)** | All GHG emissions associated with producing, transporting, using, and disposing of products and services consumed by a particular community or entity. These are also understood as territorial emissions adjusted for trade – with the addition of emissions embedded in imports and removal of emissions of exports. |
| **Direct Emissions** | Direct GHG emissions are emissions from sources that occur in the geographic boundary of the reporting entity (country/city/region etc.). (Greenhouse Gas Protocol, 2010) |
| **Embodied Emissions** | Embodied emissions, also known as embedded emissions, refer to the GHG emissions generated during the life cycle of a product or process, until the final delivery to the consumer. Within this report, embodied emissions have been used as an umbrella term to cover all indirect emissions associated with a city. |
| **Footprint** | An LCA-based metric that describes the potential negative environmental impacts of a product, process or organisation. It can be limited to a specific environmental theme or impact category, for example, carbon footprint (ISO, 14067:2018) or water footprint (ISO, 14046:2014). |
| **Indirect Emissions** | GHG emissions that are a consequence of the activity of the reporting entity (country/city/organisation etc.) but occur at sources outside the jurisdiction of the reporting entity. (Greenhouse Gas Protocol, 2010) |
| **Input-Output (IO) Analysis** | A quantitative economic research technique which aims to map the direct and indirect consequences of an initial input into an economic system across all economic sectors. The analysis specifies the required quantities of each input needed to produce each output, with each output potentially an input to another process. |

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|---|---|
| **Life Cycle Assessment (LCA)** | A methodology to quantify and assess the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle (ISO 14040, ISO 14044) |
| **Material Flow Analysis (MFA)** | An analytical method to quantify flows and stocks of materials within a defined temporal and spatial system. |
| **Out-of-boundary emissions** | Out-of-boundary emissions refer to all emissions that happen outside the geographic boundary of the reporting city, which can include both Scope 2 and Scope 3 emissions. This term is however often used synonymously to Scope 3 emissions (Zhang et.al, 2024). |
| **Personal Carbon Footprints (PCF)** | This metric accounts for the consumption activities of residents, regardless of where the consumption occurs. It includes all goods and services consumed by individuals residing in a specific area, irrespective of the geographic location of the consumption. Notably, PCF typically excludes governmental consumption and investments. (Heinonen et al., 2022).<br>Note: The acronym of PCF is commonly applied to Product Carbon Footprint, but in this report all occurrences of PCF refer to Personal Carbon Footprint. |
| **Planetary Boundaries** | 'The Planetary Boundaries are interrelated processes within the complex biophysical Earth system which mark the safe limits for human pressure on the nine critical processes which together maintain a stable and resilient Earth. (Stockholm, Resilience Centre, 2024) |
| **Production-based emissions** | Direct GHG emissions within the geographic boundaries of a region, excluding the indirect emissions from the consumption of products and services. |
| **Scope 1 emissions** | All GHG emissions that occur as a result from activities that directly emit GHG within the city boundary. |
| **Scope 2 emissions** | All GHG emissions from the consumption of grid-supplied electricity, heating and/or cooling. |
| **Scope 3 emissions** | All GHG emissions that occur outside the city boundary as a result of activities taking places within the city boundary. These exclude any emissions that are covered in Scope 1 and 2 categories.<br><br>These are also often referred to as trans-boundary emissions (Chavez & Ramaswami, 2011) and out-of-boundary emissions (Zhang et al., 2024) |
| **Supply chain** | A supply chain is the network of people, organisations, activities, information, and resources involved in creating and delivering a product or service, from the sourcing of raw materials to the final delivery to the customer. |
| **Territorial emissions** | GHG emissions that take place within a country or city's territorial boundaries and include exports but omit imports. The term 'territorial emissions' is often used synonymously to Scope 1 and (some) Scope 2 emissions (Zhang et al., 2024). |
| **Trans-boundary emissions** | Trans-boundary emissions are emissions which cross geographic boundaries, but may be synonymously used for Scope 3 emissions (Chavez & Ramaswami, 2011). |
| **Urban consumption** | Urban consumption emissions are the direct and indirect greenhouse gas emissions associated with all the material and energy demands of residents, tourists, commuters, businesses and government end-consumers in a city. (C40, 2019) |

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|---|---|
| **Areal Carbon Footprint (ACF)** | Areal Carbon Footprints – One of two distinct methodological approaches for a consumption-based emissions assessment. This method uses the territory allocation principle, including all the consumption activities that occur within the studied territory by locals and visitors but excluding the consumption of residents outside the territory (Heinonen et al., 2022). |
| **Carbon leakage** | Relocation of emissions from one area to another, for instance via relocation of industrial production, that leads to a decrease in emissions in one area while increasing them in another. This term is also used to refer to burden shifting in the context of GHG emissions. |
| **Rebound effect** | Phenomena whereby the reduction in energy consumption or emissions (relative to a baseline) associated with the implementation of mitigation measures in a jurisdiction is offset to some degree through induced changes in consumption, production, and prices within the same jurisdiction |

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## 2030 Climate Neutrality Action Plans of the Mission Cities mentioned in the report

The set of documents referenced in this section below refers to the publicly available 'Action Plans' of the various Mission Cities, which contain the details pertaining to each cities' approach towards achieving climate neutrality by 2030. Information was lifted from each of these documents to exemplify the variety in strategies currently utilised by the Mission Cities. Each of the documents may be accessed through the Knowledge Repository function of the NetZeroCities Portal.

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