Climate impact indicators

Deliverable D2.5

Version N°2

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Abbreviations and acronyms

Acronym	Description
CBA	Consumption-based accounting
CRF	Common Reporting Framework
EC	European Commission
EEA	European Environment Agency
EoI	Expression of Interest
ETS	Emission Trading System
EU	European Union
GHG	Greenhouse Gas
GMRIO	Global multi-regional input-output
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Center
MEL	Monitoring, Evaluation and Learning
NZC	Net Zero Cities
PBA	Production based accounting
TE	Territorial Emission
WP	Work Package

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Summary

This deliverable D2.5 presents a concise view of what cities require for reporting GHG emissions towards their climate neutrality goals within NetZeroCities. The report outlines the definition of climate neutrality under the mission, what information falls under each category and how cities can move towards a comprehensive GHG inventory accounting for their scope 1, 2, and 3 emissions. Along with D2.6, D2.7 and D2.8, D2.5 presents a set of indicators that the cities can use within the Monitoring, Evaluation and Learning (MEL) framework developed in D2.4.1 and D2.4.2.

Keywords

Climate Neutrality, GHG emissions, City indicators, GHG inventories, MEL, Scope 3

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1 Introduction

NetZeroCities (NZC) is a four-year project designed to support cities to overcome their current structural, institutional and cultural challenges to achieve climate neutrality by 2030. This NZC deliverable aims to give an overview of all the relevant frameworks that measure greenhouse gas emissions for cities and analyse them with regards to both their usability for the NZC MEL framework and for improvement in data availability, methodologies used, processing and display of data for reporting and communication. D2.5 is grounded in and built on the previous deliverables D2.1, D2.2, D2.3, and D2.4.1 as part of the NetZeroCities WP2, dedicated to the **"Impact Metrics & Monitoring, Evaluation and Learning (MEL) activities**". These deliverables have, amongst other things, outlined the overarching MEL framework that will be adopted by NZC as well as the requirements for the online platform. Central to these deliverables were the needs of the 112 selected cities, such as the need for capacity and the consolidation of data, which were all considered during the development of this deliverable.

Metabolic is the responsible partner for the preparation of this deliverable, with valuable inputs from ICLEI, CARTIF, AIT and Rupprecht.

1.1 Scope and main actions

Task 2.2.2, as outlined in the detailed work plan, focuses on the development of indicators to monitor direct and indirect greenhouse gas emissions from Scope 1, 2 and 3. Climate impact indicators are developed and applied within the overarching NZC framework (as described in deliverable D2.4) for e.g., grid supplied energy (Scope 2) and for out-of-boundary emissions related to waste and waste-water, transportation, and transmission distributions (Scope 3).

The four main actions are:

1. Analyse existing reporting frameworks and their impact indicators to explore scope 1, 2 & 3 indicators for evaluation and monitoring.
2. Explore additional innovative data sources and associated impact indicators (e.g., remote sensing, bottom-up data) to complement existing frameworks. The findings are shared with WP3 (Design & Operation of One-stop-shop Platform) for the development of the dashboard.
3. Explore and build alliances with third parties to source potential innovative data sources for impact assessment and reporting.
4. Develop an impact indicator set (included in this deliverable).

This deliverable feeds into the work of WP3 to develop a dashboard on the NZC one-stop-shop portal which allows cities to monitor their progress. Additionally, as part of action 1 an analysis was conducted to understand the current state of scope 3 and consumption-based inventories across cities. This included a literature review and one-on-one interviews with a few Mission Cities. More can be read in section 5.2.

1.2 How to read this deliverable

The deliverable is divided into five sections:

The **first section** explains the concept of climate neutrality as defined under the mission for climate neutral cities. This acts as a summarisation of **what emission sources cities need to take into account** while reporting towards their overall GHG emissions.

The **second section** gives an overview of the methodology and process undertaken by the authors to develop the GHG reporting and inventory outline for cities within the NZC project. This builds on existing reporting mechanisms and practices currently employed by the mission cities for building a full inventory of GHG emissions. This section also outlines a short comparative overview of existing reporting platforms which the cities can employ to supplement their NZC reporting.

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The **third section** provides insight into the existing frameworks that the Mission Cities already use to build their GHG inventory. Moreover, it shows in what way the current GHG reporting platforms and methodologies are interconnected.

The **fourth section** explores **what needs to be measured** under each emission source outlined in the first section by diving into exact data points. These data points become the indicators which can be used in isolation as well as a combined for building a comprehensive GHG inventory for a city. Each emission source is expanded to show the different data sources, methodologies and approaches (bottom-up/top-down) that can be used to calculate emissions for the associated scope (1, 2 or 3). This section is supplemented by upcoming and innovative data sources which the cities can use as an easy entry point towards assessing their GHG emissions or to supplement any bottom-up data collection for existing inventories.

The **fifth** and final section presents recommendations for cities moving towards a comprehensive GHG inventory focused on the inclusion of scope 3 out-of-boundary emissions. This section provides insight into the current challenges that cities face when they are inclined to report on scope 3 emissions. Moreover, it expands on the current state of scope 3 reporting of cities based on interviews and a literature review.

It is important to note that the attached **annexes** are integral to the report and must be read alongside the relevant sections. The annexes include (a) relevant sections and selected questions for city-level reporting platforms, specifically CDP-ICLEI Track (Annex A) and MyCovenant (Annex B); and (b) long list of GHG emission source activities per sector and different methods of accounting (Annex C & D)

1.3 Background on scope 1, 2 & 3 emissions

The EU's Mission defines the net-zero target as the abolition of greenhouse gas emissions as a result of human activities, which can be converted or absorbed through (natural) storage. The 'net' in net zero is very central to this, as cities need to achieve a balance between emitting GHG gases by scaling up removal technologies and carbon sinks. As outlined in the JRC Info Kit for Cities (EC, 2021) the GHG gases that should be covered by the NZC framework are the following: Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O), F-gases (Hydrofluorocarbons and Perfluorocarbons), Sulphur Hexafluoride (SF6), and Nitrogen Trifluoride (NF3). Since all Scope 1 (direct) emissions are mandatory to report on, it is most important to understand which indirect Scope 2 and Scope 3 emissions are required to report on in order to be mission aligned.

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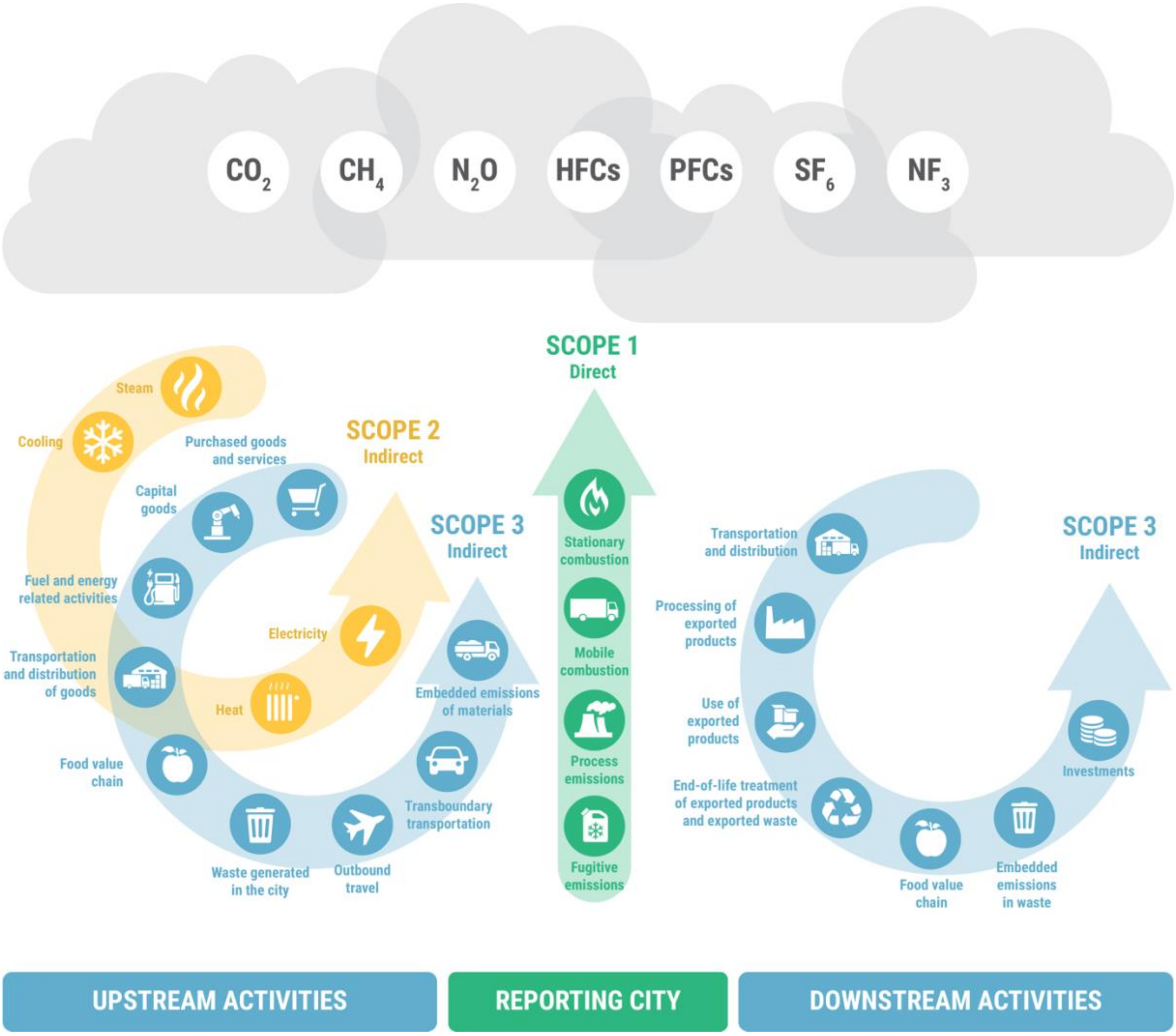

Figure 1: Overview of GHG emissions by scope

Inclusion of all the above-mentioned gases is key to creating a complete emission profile of climate impacts. For example, if only fossil CO2 emissions are seen in inventories between 2019 and 2020, globally emissions declined by 5.6% (UNEP, 2022) due to COVID. But with a full review of gasses, it has been noted that COVID-19 responses mainly impacted CO_2 emissions from fossil fuels and industry, while methane and nitrous oxide remained steady, and F-gases continued to surge (UNEP, 2022).

A 2019 study done by C40 cities, ARUP and University of Leeds (C40, 2019), it was found that cities are likely to under-report their annual GHG emissions by up to 60% if they only account for territorial emissions. In such situations, the GHG emissions that occur outside of the city boundaries as a result of activities that happen within the city (scope 3) are still largely left out of the equation. According to Weidmann et al. (2020), these unaccounted emissions may stem from crucial resources generated outside of the city such as food, water, goods, energy and transport (73%) and from service-related sectors (27%). In contrast, 41% of the total emissions were noted to have been generated by producing goods and services for the consumption outside of the city. In other words, using consumption-based accounts alongside existing city-wide inventories is vital for a realistic depiction of the city's impacts. It arguably encourages more holistic GHG assessments, greater disclosure, and more meaningful benchmarking. Such inventories can enable decision makers in identifying levers of change which may lead to greater GHG emissions reductions than current standard practices.

The study (Weidmann et al, 2020) suggests that cities should complement their GHG inventories, adding full Scope 3 to Scopes 1 and 2, and developing low-carbon consumption strategies in addition to current

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infrastructure-focused action on climate change. This deliverable supports this conclusion and provides the cities with stepping- tones for moving towards developing a scope 3 inventory depending on their starting point. Different inventory allocation methods have been explored in section 5.1 of this report as part of recommendations for cities to build robust inventories.

Currently the climate-neutral cities mission defines a specific coverage of sectors and scope. See Table 1 below to get an overview of which emissions sources and sectors should be included in the city inventory and reporting:

Table 1: Summary of sources and sectors of GHG emissions that should be included in a city's GHG inventory for the purposes of the mission (JRC Info kit for cities, 2021)

Table 1: Emission sources and sectors that should be covered			
	Direct Emissions (Scope 1)	**Indirect Emissions (Scope 2)**	**Out of boundary emissions (Scope 3)**
Buildings	x	x	-
Transport	x	x	Recommended by 2030
Waste	x	-	x
IPPU	x	-	-
AFOLU	x	-	-

Previous deliverables D2.2 (Inventory of existing MEL methodologies), D2.3 (Identified city needs for MEL, metrics, indicators), and D2.4.1 (Comprehensive indicator framework) provide more extensive information on the emission types, the importance of including Scope 3 emissions in city reporting, carbon offsetting, and what principles are further outlined in the JRC Info kit that is central to NetZeroCities.

1.4 Implications of the EU Mission on developing climate indicators

The JRC info kit for cities (EC, 2021) outlines reporting requirements for the cities proposed under the EU climate neutral cities mission.

- All direct **Scope 1** emissions are required to be reported, divided by the following sectors: Buildings, Transport, Waste, Industrial Production and Product Use (IPPU), and Agriculture, Forestry and Other Land Use (AFOLU).
- **Scope 2** emissions of buildings - which include emissions from outside the city boundary due to the use of grid-supplied energy (electricity or district heating/cooling) within the city boundary - and transport emissions from outside the city boundary due to the use of grid-supplied electricity used to charge electric vehicles, should be reported on.
- Under the current framework of the mission, only **Scope 3** emissions associated with disposal and management of waste will be included under the definition of climate neutrality. To be more precise, these are Scope 3 emissions from waste generated within the city boundary but managed/sent to landfill or treatment outside of the city boundary. Other emissions that fall under Scope 3 such as transport occurring outside the city do not have to be included in a city’s GHG inventory for the purposes of the Mission for now.

An overview of the Mission alignment is in Table 2.

Table 2: The sources and sectors of GHG emissions which should be included in a city's GHG inventory for the purposes of the mission (JRC Info kit for cities, 2021)

	Direct emissions (Scope 1)	**Indirect emissions (Scope 2)**	**Out-of-boundary missions (Scope 3)**
Buildings	Emissions from all buildings, facilities and permanent infrastructure / equipment	Emissions from outside the city boundary due to the use of grid-supplied energy	*Not applicable (Includes any residual emission sources in buildings and embodied*

	(collectively referred to as 'stationary energy' and including public, private, residential and industrial sectors) within the city boundary (excluding EU ETS registered facilities).	(electricity or district heating/cooling) within the city boundary	*emissions associated with the construction, materials, etc.)*
Transport	Emissions from on-road and rail (as a minimum) transport within the city boundary, disaggregated by municipal fleet, public transport, private and commercial transport.	Emissions from outside the city boundary due to the use of grid-supplied electricity used to charge electric vehicles	Recommended by 2030 *(Includes emissions associated with vehicles manufacturing happening outside the city)*
Waste	Emissions from waste generated and managed/ sent to landfill within the city boundary.	Not applicable	Emissions from waste generated within the city boundary but managed/ sent to landfill outside the city boundary.
IPPU	Emissions from GHGs used in, or as a by-product of industrial processes and products (if present / significant)	Not applicable	Not applicable
AFOLU	Changes in GHG emissions from any changes in land use giving rise to (sources) or sequestering (sinks) emissions (if significant)	Not applicable	Not applicable

2. Methodology

Developing an overview of GHG reporting for cities was developed through the process visualised below. Three key inputs were considered: the Expression of Interest (EoI) filled by mission cities, a review of state-of-the-art GHG frameworks including EU-level indicators, and a literature review of academic research for GHG accounting, with a special focus on scope 3 accounting for cities. A step-by-step description of the research process is described below:

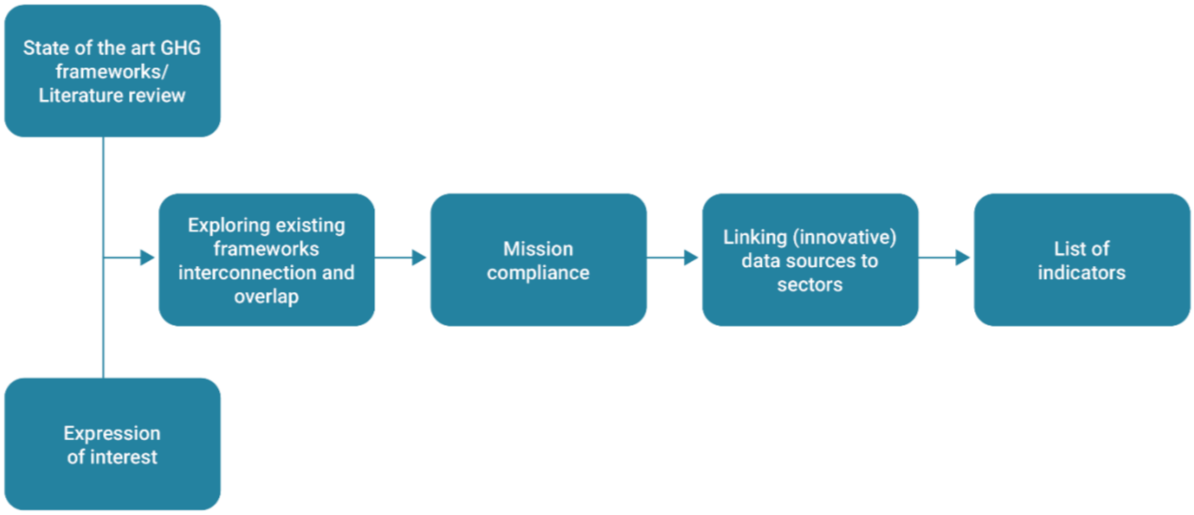

Figure 2: Research process steps to arrive at list of indicators

Preliminary research

Expression of Interest and *State of the art GHG frameworks*

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The climate impact indicator research was launched by analysing the existing greenhouse gas frameworks that are most frequently used by cities - with a specific focus on European cities. Even though a number of cities were found to use their own methodologies and set of indicators, there are a few common frameworks that are used by a significant number of cities:

- The Greenhouse Gas Protocol (GPC)
- C40 Consumption-based Approach
- PAS 20:70 Specification for the assessment of greenhouse gas emissions of a city
- 2006 IPCC guidelines for national greenhouse gas inventories
- Global Covenant of Mayors (GCoM) Common Reporting Framework
- Covenant of Mayors - MyCovenant
- CDP/ICLEI track

To understand the mission cities' familiarity with the above frameworks, responses from the EoI were reviewed. The Expression of Interest (EoI) is an extensive questionnaire that all participating cities have completed as an entry point in NetZeroCities. Amongst other questions, the EoI includes questions on which frameworks the cities already have in use to record their GHG emissions. The answers to this questionnaire have been central in the decision-making process on what frameworks will be used by NZC and developing a set of climate impact indicators. A key objective of NZC is to not reinvent the wheel but to build on existing practices, support cohesion across relevant initiatives and prevent the need for double reporting for cities.

a) *Literature review*

In addition to exploring the state-of-the-art GHG frameworks, a literature review has been conducted to include academic analyses of the measurement of scope 1, 2, and 3 emissions of cities. The inclusion of scope 3 indicators into existing frameworks has been a more recent development and is often not mandatory and/or cohesive. In order to fill this gap in the current indicator inventories of existing frameworks, a literature review on scope 3 indicators and their data points has been done. To evaluate the novel GHG indicators in literature, we also did a review of indicator datasets separate from the EU directives and national goals of the member states. These publications were identified in ScienceDirect and Google Scholar using keywords such as 'city level carbon emission inventory', 'GHG allocation', 'consumption-based inventories' and more.

In addition to academic literature, city-level indicator sets which have been developed under EU-funded projects were also reviewed. These include but are not limited to projects such as the CITYkeys project city indicator framework, Smart Cities Marketplace, MakingCity, REFLOW, REPLICATE project city level monitoring, CIVIS, Eurbanlab, Carbocount-CITY, and the ICOS Cities project.

For the GHG inventories, all indicators have been considered equally important; no statistical or empirical evidence was used to develop a hierarchical weightage at this stage. The equal weighting strategy as mentioned above is the most commonly used method of indicator weighting worldwide (Gan, 2017).

b) *Existing EU level indicators*

In addition to city-level indicators developed across different projects, connection to existing EU level indicators were also reviewed. This allowed us to take into account what cities might already be reporting on, for example EU-level indicator frameworks including the Waste directive, Circular Economy Action Plan, SUMI transportation indicators, etc.

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3. Deep dive analysis

3.1. Exploring interconnections in existing frameworks

An analysis of responses from the Expression of Interest (EoI) from the mission cities indicated that a considerable share of existing city GHG inventories had been built using the following known frameworks: 2006 IPCC, Covenant of Mayors methodology, the Global CoM Common Reporting Framework (GCoM CRF) and the GPC.

Table 3: Overview of standard/methodology applied for compiling GHG inventories by the 112 NetZeroCities and their frequency of reporting derived from the Expression of Interest.

COUNT of cities	**The standard/methodology applied for compiling the GHG inventory**								
Is your city regularly compiling GHG emissions inventories for its territory?	**None**	**2006 IPCC**	**City specific method**	**Covenant of Mayors Europe (CoM)**	**GCoM Common Reporting Framework (CRF)**	**GPC**	**Other**	**Regional or country specific method**	**Total**
No		1		6	1		1		**9**
No existing inventory	4								**4**
Yes, at least annually		11	8	12	2	12	8	6	**59**
Yes, at least every 2 years		5		10		1	1	7	**24**
Yes, at least every 4 years		1	2	5	1	2	2		**13**
Yes, less frequently than every 4 years			2	1					**3**
Grand Total	**4**	**18**	**12**	**34**	**4**	**15**	**12**	**13**	**112**

From the list of GHG frameworks that was composed in the first step of the research through expert insights and recommendations (Deliverable 2.2), and the frameworks used most often by the Mission cities (Table 03), 6 were further explored. 2006 IPCC, GPC and CoM methodologies were selected for review due to being the 3 most common methodologies applied by mission cities. PAS 20:70 was included to understand the possible future inclusion of scope 3 and CBE methodologies in city inventories. Out of the 6 frameworks reviewed, 4 are methodologies (GPC, 2006 IPCC, GCoM and PAS 20:70) and two most widely used reporting platforms (CDP-ICLEI Track and MyCovenant). Within this process, the indicators identified by the respective frameworks were listed and compared for overlaps in relation to the sectors defined by the Info kit for cities. This analysis was extended to understand and map the interdependencies between the different frameworks, since all 6 were found to be connected, cross-referencing and/or drafted based on already existing frameworks. An overview of the interconnectedness of these frameworks is shown in the following visual (Figure 4):

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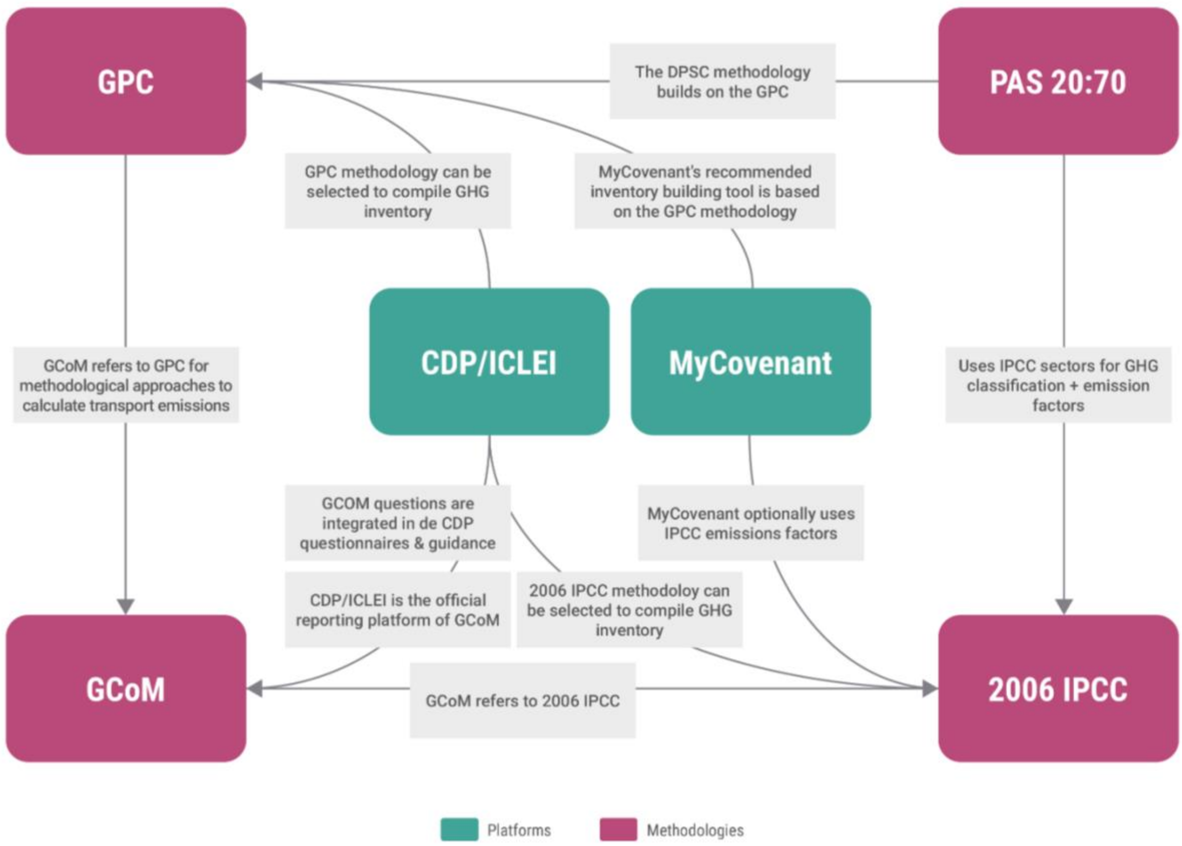

Figure 3: Interconnections of GHG reporting platforms and methodologies.

This analysis indicated the foundational use of inventory and reporting indicators outlined by the **Greenhouse Gas Protocol for Cities (GPC)** (WRI et al., 2014) as a common methodological thread for the most common reporting platforms (MyCovenant and CDP-ICLEI Track) and inventory-building tools such as C40's City Inventory Reporting and Information System (CIRIS), which is a recommended inventory building tool for both platforms.

This insight also feeds into the development of the city dashboard on the NZC one-stop-shop portal. To reduce complexity and prevent interoperability issues, GHG data already reported on the two reporting platforms will be importable to the portal. For cities currently not using either of the reporting platforms, it is recommended to carefully review the characteristics of each reporting mechanism and associated indicators to assess which platform meets the city's needs most closely. To support this exercise, a brief comparative overview can be seen below in Table 4 or a detailed comparative analysis can be reviewed in the Deliverable 2.10 (Requirements for data & visual data interface systems).

3.2. Selected reporting frameworks

Grounded in the aforementioned analysis, it has been decided to include MyCovenant and CDP/ICLEI Track as the two platforms that the cities can employ to report their GHG emissions to NetZeroCities. These frameworks are not only the mostly used ones by the Mission Cities, but also have cohesive indicator lists and data resources already available.

As of Jan 2023, out of the 112 Mission cities, the coverage of the two platforms is as follows:

- Cities as members of at least one platform: 107
- Cities as members of both platforms: 50
- Cities not a part of either platform: 6

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It should be noted however that membership is not an indication of annual data reporting on either platform. An estimate of frequency of inventories by cities can be seen above in Table 3. The figures above also account for 113 cities, with Eindhoven and Helmond counted separately.

MyCovenant and CDP/ICLEI Track are both the officially recognized platforms of the Global Covenant of Mayors. Both reporting systems are fully adapted for European signatory cities on their climate action commitments, and therefore are equally placed as acceptable reporting platforms. The following table shows a comparison between the two platforms with further information and links:

Table 4: Comparative overview of MyCovenant and CDP-ICLEI Track

	MyCovenant	**CDP-ICLEI Track**
Managing organisation(s)	European Commission (and the European Regional Covenant secretariat funded by the EC)	CDP & ICLEI – Local Governments for Sustainability
Users	10,300+ cities worldwide	More than 10,000 companies, investors, cities, states and regions worldwide
Links with other initiatives	UNFCCC's Race to Zero and Race to Resilience Campaign(s)	
	Several EU, national and regional initiatives (more information on the www.eumayors.eu website)	• Several ICLEI initiatives - see https://carbonn.org/initiatives for more information. • WWF's biennial One Planet City Challenge
Reporting format	Online template available in all EU languages, accessible at any time	Annually updated online reporting questionnaire
Guidance	• Guidebook 'How to develop a Sustainable Energy and Climate Action Plan' (Part 1) • Reporting Guidelines – also available in other EU languages here • Various workshops & webinars	• Annually updated reporting guidance (EN, ES, FR, PT) • Topic specific guidance is provided by each relevant question, including links to tools such as the CIRIS GHG Inventory tool and the City Climate Hazard Taxonomy. • Annually updated reporting tutorial webinars in English, Portuguese and Spanish • Various workshops & webinars
Offline version	Working version in Excel, available in all EU languages and Russian (versions downloadable from here)	An excel version of the questionnaire, with versions in all languages noted above, is available for cities to work offline. Reference versions are also available in Word and in PDF (see here)
Data feed-in tools	• Calculation tool: calculating GHG emissions based on the activity data and emission factors provided by city users • Data verification tool: verifying, through automatic checks, the overall completion, but also coherence of the data inserted by city users • Automatic pre-filling: new templates are pre-filled with information reported in previous versions. • Links with several other national and regional tools offering export features in MyCovenant format.	• Data copy-forward function: New questionnaire is pre-filled with information reported in the previous reporting cycle. • GCoM validation tool: It supports automatic validation of city reports against GCoM CRF. Based on evaluation of cities' report, this tool gives recommendations to cities regarding improvements needed to achieve GCoM badges. • GHG inventory tools such as CIRIS: It helps city compile GHG inventory and directly insert the inventory to questionnaire
Expert review	The Joint Research Centre (JRC) of the European Commission performs an evaluation of the action plans reported through either platform within six months of submission.	
	Cities signatory to the Covenant of Mayors - Europe are eligible for peer learning and review programmes to support in	• Cities reporting before the annual scoring deadline receive a unique CDP score and snapshot report.

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	development and implementation of action plans.	• Cities participating in ICLEI initiatives may receive additional feedback in relation to these initiatives.
Data publication	• Global Covenant of Mayors website (regularly updated GCoM signatory profiles) • Global Covenant Impact Report (Published every year) • UNFCCC's Non-State Actor Zone for Climate Action (NAZCA) platform	
	• EU Open Data Portal • European Commission's JRC Data Catalogue	• GCoM Data portal for cities • CDP's Open Data Portal • ICLEI's carbonn Climate Registry

For an in-depth comparative analysis of data coverage from both platforms, please refer to the Deliverable 2.10 (Requirements for a data & visual data interface systems incl. proceedings of workshops), which showcases the detailed comparison of reporting guidelines and inventories from a sample of 6 cities reporting to both platforms.

4. GHG indicators

The central product of this deliverable has been the development of a list of indicators for the Mission Cities. The list is divided into the sectors outlined by the JRC Info Kit for Cities. Under the NZC MEL framework, the top-level GHG indicators are marked as "Required indicators for direct emissions reporting". The Required indicators within the direct emissions are the same as the information requested from cities in the CCC Action Plan, therefore do not impose additional burden on the cities for reporting. While Deliverable D2.4.1 and D2.4.2 give an overview of the MEL framework and full list of indicators, D2.5 provides cities with the full detail of GHG emission sources and activities which can form the base of their inventory or act as optional indicators for a more in-depth analysis.

Annex C of this deliverable provides a comprehensive list of GHG indicators for each sector, the structure of which is explained further below. Annexes A and B include an overview of the GHG reporting parameters of CDP-ICLEI Track and MyCovenant respectively, which have been actively mapped by the NZC consortium to be aligned with the reporting requirements for mission cities. Annex D lastly outlines sectoral emission sources by greenhouse gas emissions.

In the figure below you can see the relevant indicator levels and associated annexes.

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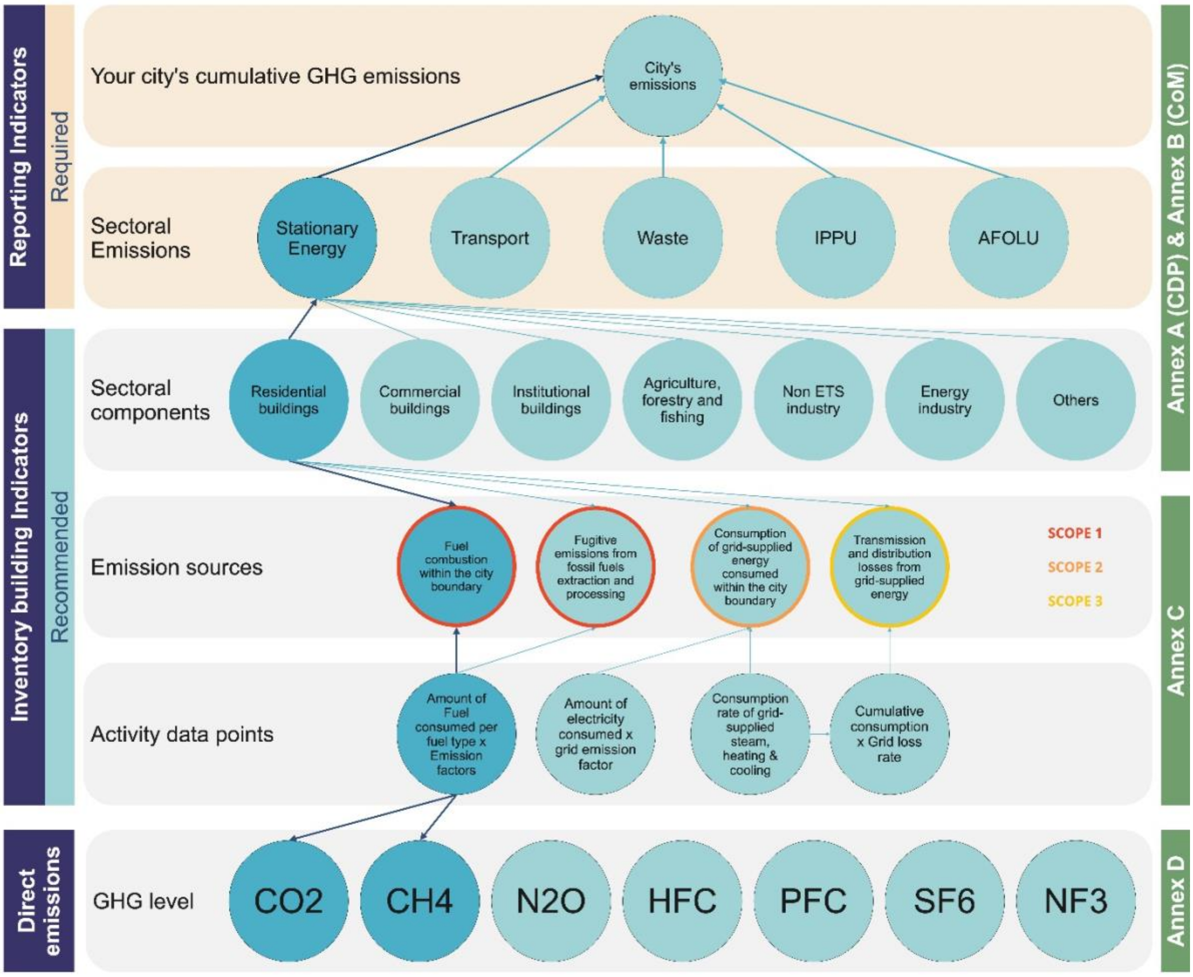

Figure 4: Overview for GHG indicators system and relationships

The list is divided amongst two levels: **Reporting-level indicators** and **Inventory-building indicators**:

The reporting-level indicators are cumulative emissions across sectors and scopes similar to reporting completed under CDP-ICLEI Track and MyCovenant reporting frameworks for cities. These also form the "required" GHG indicators for direct emission reporting under the NZC MEL framework.

The inventory-building indicators are a more granular approach of which information goes into the cumulative reporting under each sector. The "recommended" GHG indicators within the NZC MEL framework have been derived from this list using the highest level of activity data possible under each sector. Inventory indicators in isolation may also be suitable for pilot projects when relevant, where data collection will be done bottom-up to reflect impacts of granular actions, while reporting-level indicators are more useful for the monitoring of climate neutrality action plans for cities in long term assessments.

However, it is important to note that to reflect the 'real' climate impact in a local context (so called "sense-making") for both the reporting level indicators as well as the inventory building indicators, it is advised to additionally select and review the associated co-benefits. These are described in more detail in D2.4.2 and will support building comprehensive impact pathways for cities.

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4.1. Reporting Indicators

Reporting indicators for direct emissions have been shown in detail in Deliverable D2.4.2 with units of measurement, definition, source, calculation formula, relevant emission scopes as well as use case examples of how a city may be able to use or calculate each indicator. As shown in Figure 6, for **all sectors** mentioned in Table 02, the cities should report on cumulative emission in metric tonnes of CO_2 equivalent for the recommended scopes:

- Direct emissions (Scope 1) in Metric tonne CO_2 equivalent
- Indirect emissions from the use of grid-supplied electricity, heat, steam and/or cooling (Scope 2)
- Emissions occurring outside the jurisdiction boundary as a result of in-jurisdiction activities (Scope 3)

In the subsections below, we aim to show the separate sectors with their required direct emission indicator, an overview of what is included in that sector and what is the range of starting points of the mission cities in emissions per capita. In the interest of not repeating the full tables of indicators included in D2.4.2, we request the reader to refer to section 4 of D2.4.2 for basic calculation formulas and use cases for each indicator. D2.4.2 also contains links to the original source documentation of IPCC, GPC, GCoM CRF and the JRC Info kit for cities that further elaborates on the underlying methodologies of each indicator.

4.1.1 Stationary Energy

Table 5: Stationary energy indicators

Required or Recommended	Indicator title	Scope	Calculation and use case no. in D2.4.2
Required	**GHG emission from stationary energy (tCO2eq)**	1,2	4.1.1
Recommended	Energy use by fuel/energy type within city boundary (MWh/year)	1,2	4.1.1
Required	**GHG emission from grid supplied energy (tCO2eq)**	2	4.1.7
Recommended	Grid specific emission factor (tCO2eq/MWh)	2	4.1.7
Recommended	Transmission and distribution loss factor for grid supplied energy (%)	3	4.1.7
Recommended	Energy (in)dependence (%)	2	4.1.6
Recommended	Local renewable energy production (%)	1	4.1.6

What is included in the sector: The 'stationary energy sector' includes all emissions from permanent and temporary structures, facilities or equipment and public lighting within the city's boundary. This will include the residential, commercial, industrial and municipal/public buildings and facilities.

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Table 6: Sectoral components of stationary energy indicators

Sectoral components	Inclusions
Residential buildings	All emissions from energy use in households.
Commercial and Institutional buildings and facilities	All emissions from energy use in commercial buildings and facilities. Emissions from Institutional buildings include all emissions from energy use in public buildings such as schools, hospitals, government offices, highway street lighting, and other public facilities.
Manufacturing industries and construction	All emissions from energy use in industrial facilities and construction activities, except those included in energy industries sub-sector. This also includes combustion for the generation of electricity and heat for own use in these industries.
Energy industries	All emissions from energy production and energy use in energy industries.
Non-ETS Industries	Emissions that are not covered by the European Union Emission Trading Scheme (EU ETS). Non-ETS emissions include the following sectors: transport, agriculture, waste, industrial emissions outside the EU ETS and the municipal and housing sector with buildings, small sources, households, services, etc.
Agriculture, forestry and fishing activities	All emissions from energy use in agriculture, forestry, and fishing activities.
Non-specified sources	All remaining emissions from facilities producing or consuming energy not specified elsewhere.
Fugitive emissions from coal	Includes all fugitive emissions from mining, processing, storage and transportation of coal.
Fugitive emissions from oil and natural gas systems	Includes all intentional and unintentional emissions from the extraction, processing, storage and transport of fuel to the point of final use Note: Some product uses may also give rise to emissions termed as "fugitive," such as the release of refrigerants and fire suppressants. These shall be reported in IPPU.

What is the current baseline range of the mission cities: Based on the Expression of Interest, mission cities' emissions from stationary energy range from 0.04 tCO2e per capita to 22.17 tCO2e per capita. It is however important to note that not all mission cities reported values separately for stationary energy, which may lead to an incorrect representation for the ranges mentioned above. A better understanding of baselines will become available after the first submissions of baseline inventories by all mission cities.

What are the 2030 benchmark ranges defined for Europe: The Climate Action Tracker has defined Paris Agreement-compatible benchmarks for the power generation industry and the buildings sector separately. In the 2020 report (CAT, 2020), the following benchmarks for 2030 have been proposed:

Energy/Power generation

- Electricity emissions intensity: 75-80g CO2/kWh; The EEA and JRC have also proposed reaching below 100g CO2/kWh in 2030 (JRC Info Kit for Cities).
- Share of Renewable Energy (including biomass): 70-90% of total generation

Buildings Sector (as % reductions from 2015 levels)

- Emissions intensity (kgCO2/m2): 60% reduction for residential buildings; 75% reduction for commercial buildings
- Energy intensity (kWh/m2): 30% reduction for residential buildings; 20-25% reduction for commercial buildings
- Renovation rates (% stock renovated/year): 3.5% of buildings renovated per year

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4.1.2 Transport and Mobility

Table 7: Transport and mobility indicators

Required or Recommended	Indicator title	Scope	Calculation and use case no. in D2.4.2
Required	**GHG emission from transport (tCO_2eq)**	1, 2. Scope 3 can be calculated but is not mandatory.	4.1.2
Recommended	Fuel consumption for in-boundary transportation per fuel type (MJ/kg/kWh)	1	4.1.2

What is included in the sector: The transport sector includes all mobility-related activity within the city. This includes emissions stemming from on-road transport, waterborne navigation, rail, air transport and off-road transport.

Table 8: Sectoral components of transport and mobility indicators

Sectoral components	Inclusions
On-road transportation	Emissions from transport that happens on official roads including electric and fuel powered cars, taxis, buses, etc.
Railways	Railway, including trams, urban railway subway systems, regional (inter-city) commuter rail transport, national rail system, and international rail systems, etc.
Waterborne navigation	Water-borne transportation, including sightseeing ferries, domestic inter-city vehicles, or international water–borne vehicles.
Aviation	Aviation, including helicopters, domestic inter-city flights, and international flights, etc.
Off-road transportation	Off-road transportation, including airport ground support equipment, agricultural tractors, chain saws, forklifts, snowmobiles, etc.
Transport not allocated	Emissions from any transport that does not fall under the previously mentioned emission sources.

What is the current baseline range of the mission cities: Based on the Expression of Interest, mission cities' emissions from the transport sector range from 0.3 to 14.8 tCO_2e per capita, with most cities who reported emissions under the transport sector falling on an average of 1.4 tCO_2e per capita. Due to the high amounts of variation between transport emission allocation models between cities, it is difficult to compare cumulative emission values to provide a baseline, therefore it is recommended to use fuel consumption and emissions per kilometer as better suited values for comparison between baseline values and targets for cities.

What are the 2030 benchmark ranges defined for Europe: The Climate Action Tracker has defined Paris Agreement-compatible benchmarks for the transport sector. In the 2020 report (CAT, 2020), the following benchmarks for 2030 have been proposed:

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- Land-based emissions per passenger kilometres (gCO2/pkm): 50gCO2/pkm
- Share of low-emissions fuels (biofuels, electricity and hydrogen) of the total (domestic) transport sector demand: 15-20% of final energy demand, including passenger and freight
- EV share in stock (%): 40-55% of overall Light Duty Vehicle (LDV) fleet
- Share of electric vehicle sales (%): 95-100% of overall LDV sales

4.1.3 Circular Economy and Waste

Table 9: Circular economy and waste indicators

Required or Recommended	Indicator title	Scope	Calculation and use case no. in D2.4.2
Required	**GHG emission from waste (tCO2eq)**	1	4.1.3
Recommended	Mass of waste processed per end-of-life treatment type within city boundary (tCO2eq)	1, 3	4.1.3
Recommended	Mass of waste processed per end-of-life treatment type outside city boundary (tCO2eq)	3	4.1.3

What is included in the sector: Solid waste and wastewater (together referred to collectively as "waste") that may be disposed of and/or treated at facilities inside the city boundary or transported to other cities for treatment. Waste disposal and treatment produces GHG emissions through aerobic or anaerobic decomposition, or incineration. Solid waste and wastewater may be generated and treated within the same city boundary, or in different cities. Scope 1: Emissions from waste treated inside the city. This includes all GHG emissions from treatment and disposal of waste within the city boundary regardless of whether the waste is generated within or outside the city boundary. Scope 3: Emissions from waste generated by the city but treated outside the city. This includes all GHG emissions from treatment of waste generated by the city but treated at a facility outside the city boundary.

Table 10: Sectoral components of circular economy and waste indicators

Sectoral components	Inclusions
Solid waste disposal	Solid waste generated in the city disposed in landfills or open dumps inside/ outside the city
Biological treatment of waste	Solid waste generated inside/ outside the city that is treated biologically
Incineration and open burning	Solid waste generated in / outside the city incinerated or burned in the open
Wastewater treatment and discharge	Wastewater generated in or outside the city

What is the current baseline range of the mission cities: Based on the Expression of Interest, only 54% of the mission cities responded with values for emissions from the waste sector. The cities that reported had a baseline emission range from 0.01 to 0.5 tCO2e per capita. These values should be revised when more data from the same year for all cities is available, with the consideration of which scopes have been covered within the inventories for the waste sector.

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What are the 2030 benchmark ranges defined for Europe: European-level policies addressing waste include the European Green Deal (EC, 2019), the 2020 circular economy action plan (EC, 2020) and the Waste Framework Directive (EU, 2018). Based on these policies, two targets have been set for municipal waste for 2030. Both targets below do not comment on the emissions resulting from waste management, but address the amounts of waste going towards different end-of-life management:

At least 60% of municipal waste generated should be prepared for reuse or recycled (Waste Framework Directive). This is a binding obligation that has to be met by each EU Member State individually.

Residual (non-recycled) municipal waste should be reduced by half (circular economy action plan and zero pollution action plan). This effectively means a maximum of 56.5 million tonnes of municipal waste by 2030 (EEA, 2022). This is a non-binding commitment that should be achieved at the EU level.

4.1.4 Industrial Processes and Product Use (IPPU)

Table 11: Industrial processes and product use indicators

Required or Recommended	Indicator title	Scope	Calculation and use case no. in D2.4.2
Required	**GHG emission from IPPU (tCO2eq)**	1, 3[2]	4.1.4
Recommended	Emission intensity: emission generation potential per unit of input/output for industrial processes within the city boundary (CO2eq/ kg of production)	1, 3[2]	4.1.4
Recommended	Emissions from non-energy product use (tCO2eq)	1, 3[2]	4.1.4

[2] *Calculations for scope 3 (not mandatory) can also be applied if a consumption-based approach is taken which may include all imported products and their full lifecycle impacts.*

What is included in the sector: Emissions resulting from non-energy related industrial activities and product uses. This includes all GHG emissions occurring from industrial processes, product use, and non-energy uses of fossil fuel.

Table 12: Sectoral components of industrial processes and product use indicators

Sectoral components	Inclusions
Industrial processes	Emissions from industrials processes. Examples of industrial processes; production and use of mineral products (cement, lime, glass), production and use of chemicals, Production of metals
Product use	Emissions from product uses includes those from lubricants and paraffin waxes used in non-energy products, FC gases used in electronics production, Fluorinated gases used as substitutes for Ozone depleting substances

What is the current baseline range of the mission cities: Based on the Expression of Interest, 44% of the mission cities reported values for the IPPU sector. The cities that reported had a baseline emission range from 0.001 to 83.3 tCO2e per capita, with most reporting cities falling at an average of 0.44 tCO2e per capita. The high values are reported by production-oriented cities, while the low values are reported by consumption-oriented cities, which makes any direct comparisons of baselines purposeless. Emissions per capita are also likely to be much higher for consumer cities compared to producer cities if a consumption-based approach is taken (Sudmant et al., 2018). Therefore, baseline values should be

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revised with consideration of which scopes have been covered within the inventories for the cities as well as understanding the different allocation methods used.

What are the 2030 benchmark ranges defined for Europe: The Climate Action Tracker has defined Paris Agreement-compatible benchmarks for the IPPU sector specific to the Cement and Iron & Steel industries. In the 2020 report (CAT, 2020), the following benchmarks for 2030 have been proposed:

- Cement emission intensity (kgCO2/tonne): 355-350 kgCO2/t; 35-40% reduction from 2015 levels
- Steel emission intensity (kgCO2/tonne): 680-700 kgCO2/t; 45% reduction from 2015 levels

4.1.5 Agriculture, Forestry, and Other Land Use (AFOLU)

Table 13: Agriculture, forestry and other land use indicators

Required or Recommended	Indicator title	Scope	Calculation and use case no. in D2.4.2
Required	**GHG emission from AFOLU (tCO2eq)**	1, 3[3]	4.1.5
Recommended	Net annual rate of change in carbon stocks per hectare of land (tCO2/ha)	1	4.1.5

[3] Scope 3 can be included in calculations if emissions from imported agricultural and animal products are included using a consumption-based approach.

What is included in the sector: Agriculture, Forestry and Other Land Use (AFOLU) sector produces GHG emissions and removals through a variety of pathways, including land-use changes that alter the composition of vegetation and soil, management of forests and other lands, methane produced in the digestive processes of livestock, and nutrient management for agricultural purposes.

Table 14: Sectoral components of agriculture, forestry and other land use indicators

Sectoral components	Inclusions
Livestock	Reporting on the methane produced in the digestive processes of livestock, manure management
Land	Land use, land use change, management of forests and agricultural land
Aggregate sources and non-CO2 emissions sources on land	Aggregate sources and non-CO2 emissions sources on land such as rice cultivation, fertilizer use, liming, and urea application.

What is the current baseline range of the mission cities: Based on the Expression of Interest, 38% mission cities reported on emissions from the AFOLU sector. The cities that reported had a baseline emission range from –0.5 to 0.48 tCO2e per capita. It is important to note here that not many cities include the AFOLU sector in their current inventories for various reasons such as limited agricultural and animal husbandry practices within the city territory, or negligible amounts of emissions compared to other key sectors.

What are the benchmark ranges defined for Europe: The AFOLU sector includes LULUCF and agriculture. In 2021, the European Parliament revised the LULUCF regulations (EU COM/2021/554), including the 2030 targets (Urrutia, C. et al., 2021). The proposal, as part of the Fit for 55 legislative package, is to increase the carbon removals to -310 million tonnes CO2 equivalent by 2030 and to achieve climate neutrality in the combined land use, forestry and agriculture sector by 2035 at EU level.

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- From 2021 to 2025 stays close to the current LULUCF Regulation, which had been set to generate no less than -225 Mt CO2 equivalent of net removals (so-called ‘no-debit’ commitment)
- From 2026 to 2030, the EU net removal target will increase to -310 Mt of CO2 equivalent. Each Member States will contribute towards the target which will be distributed among them based on the recent level of removals or emissions and the potential to further increase removals.

4.1.6 Carbon capture and residual emissions

Table 15: Carbon capture and residual emissions indicators

Required or Recommended	Indicator title	Scope	Calculation and use case no. in D2.4.2
Required	Residual emissions (%)	1 & 2; 3 optional	4.1.8
Recommended	Amount of permanent sequestration of GHG within city boundary (tCO2eq)	1	4.1.8
Recommended	Negative emissions through natural sinks (tCO2eq)	1	4.1.8

What is included: Carbon sinks, i.e., removals through natural and technological solutions, within the city boundary can be used to account for any residual GHG emissions. There are two potential options for carbon sinks:

Table 16: Components of carbon capture and residual emissions indicators

Components	Inclusions
Technological sinks	Carbon sequestration through “Technological sinks”, such as industrial CSS, Biomass for Energy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Dioxide Capture and Storage (DACCS) technologies as well as the use of bio-based materials. It may also include Carbon Capture Project (CCP) applications which result in permanent sequestration of the CO2 (i.e., injected into geological structures, or stored in bio-based construction materials used in buildings)
Natural sinks	Natural sinks refer to the planting of trees or other conversion of land use. Cities are allowed to account for negative emissions through the enlargement or enhancement of natural sinks within the territory to address residual emissions (accounting for all changes in the carbon stock). Carbon sinks should be accounted for as part of the ‘AFOLU’ sector of the GHG inventory and can be independently monitored as a progress indicator to show negative emissions.

What is the current baseline range of the mission cities: A better understanding of residual emissions and carbon capture baselines for mission cities will be possible after the submissions of the Climate City Contracts (CCCs).

What are the benchmark ranges defined for Europe: The Mission recommends as a guideline to aim for a level of ‘residual emissions’ within the city boundary in 2030 that does not exceed 20% of the baseline GHG inventory, with the possibility that the remainder could be accounted for using carbon sinks or credits. (EC, 2021)

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4.2. Inventory building indicators

The section below explains how to read the inventory indicators lists (Annex C) as a "cheat sheet" for identifying key emission activities needed for building a city's inventory. This may help cities to be able to report on the GHG emissions with a complete overview of all sectors involved in the mission requirement. These indicators build on the Greenhouse Gas Protocol for Cities (WRI, 2014) and the 2006 IPCC guidelines which form the basis of inventory development guidelines followed by multiple reporting platforms considered in the review above. After a review of data sources and subsequent collection of identified data points, cities can employ tools such as the CIRIS Tool to build their sectoral inventory.

The table below shows how the inventory building indicator list (Annex C) is structured.

Table 517: Structure of Annex C Inventory indicator list

Sectors	Emission sources	Scope	Calculation Approaches	Activity data	Emission factor unit	Data collection approach	Data points: Bottom up	Possible data sources	Notes
The sector under which this data point is relevant	*What source of emission needs to be considered*	*Scope 1, 2 or 3.*	*Which different approaches can be taken to calculate these emissions*	*Title of activity data associated to the emission*	*Unit*	*Indication whether the calculation approach is bottom-up, top-down, mixed or undefined. Bottom-up*	*Data required to fulfil the calculation for the selected approach*	*Based on the approaches selected for calculation and data collection, which possible data sources can be used*	*Any additional consideration or comments*
EXAMPLE: Stationary Energy	Fuel combustion within the city boundary	1	Fuel consumption approach	Amount of fuel consumption	Mass GHG emissions per unit of fuel	Bottom-up	Real consumption data for each fuel type disaggregated by sub-sector	Energy tariffs and billing; Direct data reporting from utility or fuel providers in the city.	Note on how to deal with incomplete datasets

4.3. Data collection

The accuracy and reliability of the indicators will highly depend on the available data sources and the collection process in each city for each source and sector. It is recommended to primarily use data that is collected via a bottom-up approach, as its granularity and accuracy will enable a detailed evaluation. However, in practice, this data may not always be available. Therefore, we recommend combining bottom-up data collection with top-down data to fill known gaps. This is to ensure the number of indicators that can be evaluated is optimized. This is particularly relevant for scope 3 emissions which most cities do not or only in a limited way report on. Many European cities are net consumers, but notable industrial cities may also be net producers and exporting consumer goods, which makes the weightage of territorial emissions (Scope 1 + 2) and consumption-based emissions (Scope 3) dependent on the typology of the city. Only when all emission sources are covered with either bottom-up and top-down data collection that a 'fair' picture of the city's emissions will emerge.

Another factor that impacts the reliability of the indicators, is how the system boundaries are selected and thus how the collected data is attributed. For example, are the emissions of the airport or landfill adjacent to the city included or excluded? Clear justification for such decisions is needed as the impact and overall picture that the indicators provide could be significantly impacted by such choices. Another factor to keep in mind for data consistency is that some cities might use older versions of the IPCC GHG conversion factors to be consistent with country level inventories.

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4.4. Innovative data sources

Innovative open data sources can be used to optimize or supplement traditional data collection processes in cities. Creutzig et al. (2019) suggests three routes to overcome urban data barriers towards climate solutions: mainstream data collection in cities around the world, exploit big data; and apply data science techniques to explore published information. This section will cover different recoverable data sources and existing data-building initiatives which could be connected by cities to their inventories. The purpose of this list is to aid cities in identifying easily available data as a starting point, improve quality of existing emission data and to supplement bottom-up data gaps with estimations from readily available observation sources.

A short list of examples is covered in Table 6 below, which acts as a growing list of reliable data sources. This list is expected to grow throughout the duration of the NZC project as a supporting resource for cities.

Table 618: Innovative Data Sources

Source name	Scope	What information does it provide?	How can a city use this?
Global Gridded Model of Carbon Footprints (GGMCF)	Scope 3	This model provides a globally consistent, spatially resolved (250m), estimate of carbon footprints (Scope 3) in per capita and absolute terms across 189 countries.	Cities may use the per capita carbon footprint to get a baseline estimate of city-level scope 3 emissions. This estimation may differ vastly from bottom-up data based on local consumption patterns.
OpenGHGMap .net	Scope 1	Municipality level atmospheric observation of GHG emissions allocated backwards to sectors with an underlying set of assumptions (Scope 1 Territorial emissions)	For cities with no base data, the GHG mapper can be a viable source for baseline GHG figures allocated across sectors. This data will require additional validation from the city.
WRI Dynamic World	Scope 1	Near realtime data on land use and green cover changes with 9 different land cover types.	Due to a 10m resolution, this GIS dataset can provide cities with a time series of granular urban greening data.
Google Environmental Insights Explorer	Scope 1, 2, 3	Google EIE uses bottom-up data and modelling to measure city-level emissions for buildings, transport, rooftop solar potential. For limited cities there is also data on air quality and tree canopy cover.	Cities which do not yet have comprehensive scope 1, 2 and 3 transport data can get a modelled baseline from GoogleEIE. The building emissions data is non-granular so is not recommended as a good source for a city's inventory, though may be used for baseline estimations.
Environmental Footprints Explorer	Scope 1, 2, 3	National level data segmented by sectors on environmental impact indicators for scope 3 emissions. Data is shown in impacts per million USD (using current market exchange rates)	Cities can use this dataset to get estimates on sectoral division of GHG emissions and other environmental impacts using parameters such as production, consumption and trade.
WorldMRIO: The Eora Global Supply Chain Database	Scope 3	A multi-region input-output table (MRIO) model that provides a time series of high-resolution IO tables with matching environmental and social satellite accounts for 190 countries. This dataset provides both Consumption-based accounting (CBA) and Production based accounting (PBA) at country level as carbon footprint per unit GDP.	Cities can use the footprint per unit GDP as an indicator of both production and consumption-based emissions to formulate a baseline for scope 3 emissions.
Carbon Monitor Cities	Scope 1	CMC is an online CO2 emissions dataset which provides near-real-time daily city-level CO2 emissions data for 1500 cities in 46 countries. This data is downscaled from Carbon Monitor, which is a real time national level CO2 monitor. Their methodology is peer reviewed and publicly accessible, but it	The data of 50 selected cities is available to download for free from the Carbon Monitor Cities website and the complete dataset of 1,500 cities can be downloaded for free from Figshare. The data output is an excel spreadsheet that contains daily emissions data for every city for every

		is not currently aligned with GPC or CRF.	sector. Cities however need to add the daily emissions data for each sector for their city to get annual total or sectoral emissions. (The above text has been extracted from the CDP website)
Electricity Maps	Scope 1, 2	Carbon intensity data for electricity on an hourly basis for countries divided by consumption and production. Carbon intensity of exported energy are also included.	Cities with no existing data for the emissions from the national energy grid production and consumption can use this data as a baseline
CarbonMapper	Scope 1	Sattelite based atmospheric emissions observation, with CO2 and methane emission data from point-sources	Once available for European cities, it can be a viable source for validating and allocating methane emissions for point sources in cities.

5. Recommendations

5.1. Proposed framework, indicators and & data collection practices

Based on the above assessment, the following recommendations have been made;

- **Use of the two reporting frameworks namely MyCovenant and CDP-ICLEI Track.** Both are fully adapted for European signatory cities on their climate action commitments. Moreover, both platforms are compatible with the base GPC methodology as well as a multitude of alternate platforms. Therefore, would be able to meet the needs of the majority of the 112 cities of which most (107) are already familiar with at least one of these two platforms.
- **Use of inventory building tools and innovative data sources.** Through an assessment of the current state of data and inventory of each city, it can be reviewed which data sources could fill existing gaps.
- **Use of bottom-data and top-down data collection.** It is recommended to adopt both approaches to data collection to provide the most comprehensive assessment of the greenhouse gases emitted by each city.
- **Align the list of indicators based on the questionnaires of the selected platforms.** To ensure that cities are not burdened with inconsistent or additional data reporting requests, it has been important to align the long list of selected indicators by NetZeroCities with the selected reporting frameworks i.e., MyCovenant and CDP/ICLEI.
- **Support cities to develop a scope 3 inventory**. While a standard on how to report on scope 3 does not yet exist, it is recommended for cities to continue developing frameworks of what is included and excluded in their inventories that support their decision-making and action planning.

5.2. Moving towards Scope 3

As mentioned, it is likely that current city inventories under-represent emission values (by up to 60%) if scope 3 is not taken into account. This section contains considerations and recommendations for supporting the understanding of scope 3 emissions for cities in the upcoming years.

For most cities, when identifying scope 3 emissions, two key questions need to be answered:

- How will the emissions be allocated?

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- What type of data will be collected?

Based on different allocation models, the total reported GHG values for cities are prone to result in different values. In an analysis based on Sugar, et al., (2012) for Shanghai's GHG inventory, 4 different frameworks were compared for the same inventory year. This comparison showed a range of per capita emissions between 10.7 tCO_2 in a scope 1+2 inventory (ECoM) to 12.8 tCO_2 in a Scope 1+2+3 inventory (UN/World Bank), showing almost a 20% difference (Arioli et al., 2020). This places importance on the selection and consistency in use of allocation methods and scoping of inventories by the city for the purpose of fair comparison and to understand developments over time.

Scope 3 can become the key factor challenging current urban planning and climate change adaptation. Shown through an analysis by Weidmann et al (2020), previous studies usually find an Environmental Kuznets Curve (EKC) behaviour for urban industrial and energy-related CO_2 emissions, that is, emissions first grow then decline with rising GDP per capita in an inverted U shape (Fujii, Iwata, Chapman, Kagawa, & Managi, 2018; Wang et al., 2019). However, none of this research has included Scope 3 emissions and the possibility of urban residents outsourcing environmental impacts to urban hinterlands or other production regions globally. Wiedmann et al find that when Scope 3 is considered, city emission profiles no longer follow an EKC. A known downside of CBCF (Consumption-based Carbon Footprint) is that many of these emissions occur outside the city or even country boundary, thus are deemed outside of the city's scope of influence. Thus, from a communication and action planning perspective, a CBA inventory of emissions may carry negative connotations of burden shifting from municipal action to consumer behaviour in citizens.

Although the current ambition of cities to include scope 3 in their GHG inventory may differ based on capacity, know-how and data availability, cities are encouraged to explore different inventory methods that can be employed. An underlying principle for this decision for cities must always be to not let data perfection be a limiting factor to progress.

5.2.1. Current state of Scope 3 reporting in cities

An analysis was conducted to understand which Mission cities have already developed interest or have progressed towards an inventory of scope 3 emissions. Through this review, the cities were listed into different groups with a distinction between:

- Cities that have advanced towards scope 3 or consumption-based emissions
- Cities that would like to include scope 3 or consumption-based emissions
- Cities that aren't actively developing scope 3 or consumption-based emissions

Moreover, C40 Cities has developed a C40 Climate Action Planning Resource Centre which has pushed forward similar efforts to develop indicators to measure scope 3 emissions for cities, which shows significance promise in the further development of the field in the coming years. As a large part of the European C40 Cities are also Mission Cities, knowledge sharing and developing a common understanding would be a key step in the right direction.

Based on the reviews, a couple of European cities were approached to understand their current state of scope 3/consumption-based emissions reporting. These cities had a publicly available calculation of scope 3 or CBE in their GHG inventories or had expressed interest in developing such inventories. There were 5 European cities (predominantly based in Northern Europe) that were reached out to, of which 3 - Aarhus, Copenhagen and Amsterdam - took part in a one-on-one interview and shared their insights on their city's scope 3 emissions.

Important to note, what was understood from the preliminary analysis is that no city has been able to complete a full-fledged inventory of their scope 3 emissions yet. Cities are facing multiple barriers in gathering a complete overview of what scope 3 emissions entail, this can mostly be attributed to limited data availability as well as the presence of multiple interpretations of scope 3 and CBE allocations. The

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following notes from the one-on-one interviews with the cities are therefore meant as an insight into some of the cities' own inventory developments and in what way the NetZeroCities consortium can learn from this.

Aarhus

The Municipality of Aarhus is keen to develop an inventory for consumption-based emissions. The city is aware that scope 3 is a large part of their emissions and that a trustworthy calculation of all 3 scopes is vital in identifying the most polluting sectors of the city. Aarhus' analysis is based on invoice data (around 650.000 invoices per year) which is compartmentalized and coupled to emissions factors by an AI driven Danish consultancy. This calculation put forward a couple of sectors that are the largest emitters such as transport, healthcare and food. As a response to the high emission outcomes of the latter sector, Aarhus has already imposed a climate tax on beef which caused their consumption to fall with over 30% (read article here in Danish). Furthermore, as the available data is still quite high level, the city is working on gathering more granular data in order to create a more accurate inventory. For instance, the invoices from the building sector are relatively crude and include few particularities on what has been purchased. In order to create a more holistic overview, the 1100 emission factors that are now in use are planned to be expanded - however for this, more (accurate) data is needed.

Amsterdam

The city of Amsterdam aims to reduce CO2-emissions by 60% in 2030 and 95% in 2050. As a good example, the municipal organisation wants to become a climate neutral organisation already by 2030. Therefore, the city has not only committed to becoming climate neutral, but also will make its business operations 100% circular. The city has also analysed that although direct emissions are steadily decreasing, the CO2 emissions due to the extraction, production and transportation of goods consumed in Amsterdam (scope 3 emissions) are four times higher than these direct emissions. To define a baseline, the city has analysed their material and immaterial expenditures in 2019 which indicated that over 60% of the city's total emissions were linked to purchase of materials such as concrete, metals and plastics. In particular, the purchase of building materials for public spaces has been identified as an area where significant improvements can be made. The original sustainability measures of Amsterdam were insufficiently targeting this area. To meet the desired reduction goals more ambitious and specific measures have since then been put in place. Measures in procurement are, for example, substituting primary building materials for secondary (the low-hanging fruit) and aiming for the lowest environmental costs of the materials. Additionally, for the materials already present in public space the policy is adopted that all should be reused unless technically impossible. In the mean-time Amsterdam is working with its suppliers to increase transparency regarding environmental performance, for better insight and steering information. Lastly, Amsterdam is working on broadening the CO2 focus to a broader perspective on environmental and social effects (e.g. by using the donut economy framework).

Copenhagen

The current climate plan for the city of Copenhagen will run out at the end of 2025, and the city administration is currently in the process of developing the next plan that will run to 2035. The scope of the next climate plan will be extended to include global emissions associated with consumption. To this end the city's Technical and Environmental Administration, which leads the development of the climate plan, has expanded its climate unit to include a team focusing exclusively on consumption-based emissions. One of the first tasks of the climate unit was to define boundaries for activities and associated emissions to be addressed by goals and initiatives in the coming climate plan. This was a complex process during which the climate unit studied what other forefront cities in the Nordics, Europe and North America are planning, and weighed up the advantages and disadvantages of different scoping boundaries and combinations of these. The final recommendation was for two scoping boundaries which will eventually be linked to goals and objectives. The recommended boundaries are territorial GHG

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emissions (GHGs emitted within the city borders) and local and global GHGs caused by Copenhageners consumption, government consumption and capital investments. Next steps are to develop historical trends of emissions within these boundaries, forecast future trends and develop emissions-reduction scenarios. The city administration foresees the adoption by the city council of overall climate goals during 2024.

The city's representatives underline the critical importance of using the correct terminology associated with scoping of emissions associated with a city. As can be seen in the visual below (Figure 5), consumption-based emissions and scope 1, 2 and 3 emissions under the GHG Protocol, only partially overlap with one another. For example, the GHG Protocol scopes include a whole wedge of emissions that are connected with export from the city for consumption by others. Tourism activity in the city should also be perceived as an export (to residents of other cities). Emissions associated with exports are not included in a consumption-based boundary but are included in scope-based reporting. On the other hand, consumption-based emissions for a city should include the city residents' consumption when they're on holiday elsewhere. These emissions are not included in scope-based reporting for a city. These significant differences are important to grasp and communicate; a lot of current literature and initiatives use the phrase consumption-based emissions interchangeably with scope 3.

This proves that it is currently crucial that a consistent terminology surrounding scope 3, consumption-based emissions, and all other greenhouse gas emissions is established that can be adopted by all cities and has homogenous methodologies throughout.

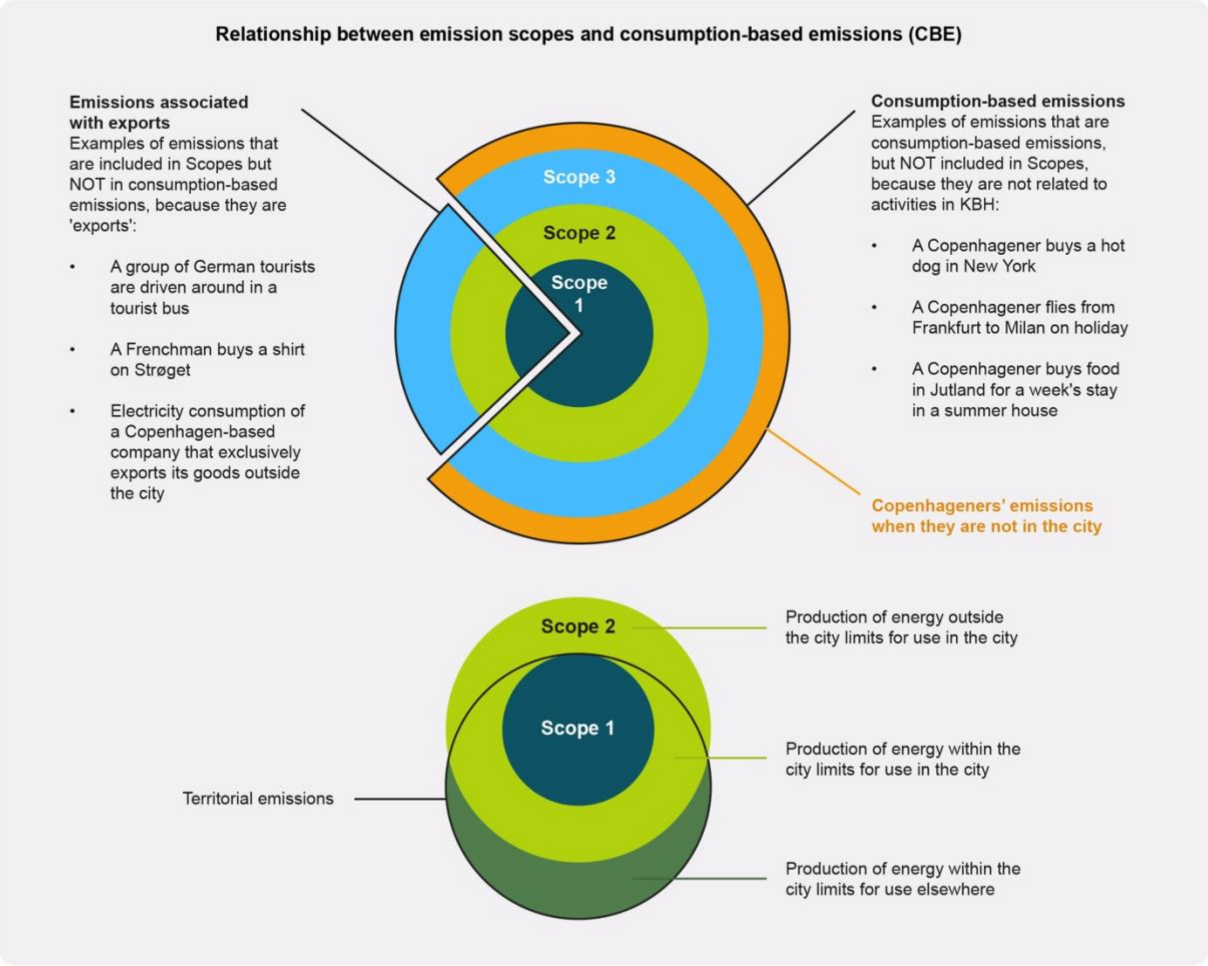

Figure 5: Relationship between emission scopes and the consumption-based emissions. (Source: City of Copenhagen Climate Unit, 2022).

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Figure 6: Different approaches used by cities to include out-of-boundary emissions.

Global state of city-level Scope 3 reporting

Globally, there are numerous initiatives which aim to include scope 3 in their city inventories. San Francisco for instance already released a [Consumption-Based Emissions Inventory]() in 2011 and Seattle included a preliminary calculation of consumption-based emissions in their [2018 Community Greenhouse Gas Emissions Inventory.]() In academic literature there are also repeated efforts to develop consumption-based emissions accounting for cities. For instance, Long et al. (2021) developed a method to construct an emission inventory of urban household emissions for 52 major cities in Japan which includes more than 500 emission categories. Their analysis holds that urban households are accountable for 70-80% of a country's emissions and therefore essential to include in a GHG inventory. Another example is Mi et al. (2016) who calculated consumption-based CO2 emissions for thirteen Chinese cities. They found that in megacities such as Shanghai and Beijing around 70% of consumption-based emissions are imported from other regions and that capital investments to CBE are driven by governmental policies, large scale economic growth and urbanization.

As a final remark, it is important to mention that it has been a conscious decision to not prescribe any additional indicators for scope 3/consumption-based emissions in this deliverable. Based on the high variety in approaches that appeared from the literature review and city interviews, it has become clear that in order to conclusively measure scope 3, first and foremost a European-level directive on the scoping boundaries would have to be defined. Ideally, this would include set terminology on what scope 3 and consumption-based emissions entail and relate to each other, as well as their geographical boundaries.

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Conclusion

Climate indicators allow cities to monitor and evaluate their progress towards their climate goals. This can, in turn, provide guidance on possible routes and impacts of interventions and can also act as a learning tool. Therefore, in this work, a detailed analysis of current greenhouse gas emission frameworks and indicators has been performed.

The platforms of MyCovenant and CDP/ICLEI are proposed to be used as foundation for NetZeroCities MEL activities. It includes all emissions sources and sectors as outlined in the JRC Info Kit for Cities and is used by many of the 112 cities already and is compatible with the approaches and platforms used by the other cities.

A list of climate impact indicators has been included in this deliverable which align with the NetZeroCities MEL framework and contribute to the full list of indicators defined in Deliverable 2.4.2. To prevent future underreporting of GHG emissions, the consortium supports the recommendation to add Scope 3 emission reporting to Scopes 1 and 2 over the course of the next few years. It is planned to provide the cities with stepping-stones for moving towards developing a scope 3 inventory depending on their starting point, to gain initial insights and to prepare them for future reporting. For cities that have not yet considered scope 3 emissions, it is recommended to start thinking on how to include this in their GHG inventory and assess which data sources are available.

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NetZeroCities Deliverable 2.1 Work Plan for MEL activities framework

NetZeroCities Deliverable 2.2 Inventory of existing MEL methodologies

NetZeroCities Deliverable 2.3 Identified city needs for MEL, metrics, indicators

NetZeroCities Deliverable 2.4.1 Comprehensive indicator framework

NetZeroCities Deliverable 2.4.2 Comprehensive indicator framework

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Annex A – CDP/ICLEI Track Questionnaire

2023 Q/Col No.	2023 Question	Net Zero Cities Initiative
0.1	Provide details of your jurisdiction in the table below	Yes (required)
0.3	Report how your jurisdiction assesses the wider environmental, social, and economic opportunities and benefits of climate action.	Yes (recommended)
0.4	Report on your engagement with other levels of government regarding your jurisdiction's climate action.	Yes (recommended)
0.5	Report your jurisdiction's most significant examples of collaboration with government, business, and/or civil society on climate-related issues.	Yes (recommended)
2.1	Does your jurisdiction have a community-wide emissions inventory to report?	Yes (required)
2.1a	Provide information on and an attachment (in spreadsheet format)/direct link to your main community-wide GHG emissions inventory.	Yes (required)
2.1b	Provide a breakdown of your community-wide emissions by scope. If the inventory has been developed using the Global Protocol for Community Greenhouse Gas Emissions Inventories (GPC) you will also be requested to provide a breakdown by sector.	Yes (required)
2.1c	Provide a breakdown of your community-wide emissions in the format of the Common Reporting Framework.	Yes (recommended)
2.1d	Provide a breakdown of your community-wide emissions by sector.	Yes (required)
2.2	Does your jurisdiction have a consumption-based emissions inventory to measure emissions from consumption of goods and services? The consumption-based approach captures direct and lifecycle GHG emissions of goods and services and allocates GHG emissions to the final consumers, rather than to the producers.	Yes (recommended)
2.3	Do you have an emissions inventory for your government operations to report?	Yes (recommended)
2.3a	Attach your government operations emissions inventory and report the following information regarding this inventory.	Yes (recommended)
2.3b	Report your government operations emissions in metric tonnes CO2e.	Yes (recommended)
3.1	Report the following information regarding your jurisdiction-wide energy consumption.	Yes (recommended)
3.1a	Report the total electricity consumption in MWh and the energy mix used for electricity consumption in your jurisdiction.	Yes (recommended)
3.1b	Report the total thermal (heating/cooling) energy consumption in MWh and the energy mix used for thermal (heating/cooling) source mix breakdown for energy consumption in your jurisdiction.	Yes (recommended)
3.1d	Report the total jurisdiction-wide annual electricity and heating and cooling consumption for each sector listed and for your government operations.	Yes (recommended)
3.1c	For each type of renewable energy within the jurisdiction boundary, report the installed capacity (MW) and annual generation (MWh).	Yes (recommended)
3.5	Report your jurisdiction's passenger and/or freight mode share data.	Yes (recommended)

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3.6	Report the total emissions, fleet size and number of vehicle types for the following modes of transport.	Yes (recommended)
3.7	Report the following waste-related data for your jurisdiction.	Yes (recommended)
3.8	Report on how climate change impacts health outcomes and health services in your jurisdiction.	Yes (recommended)
3.9	Report the following air pollution data for the jurisdiction.	Yes (recommended)
5.1	Does your jurisdiction have an active greenhouse gas emission reduction target(s) in place? If no active GHG emissions reduction target is in place, please indicate the primary reason why.	Yes (recommended)
5.1a	Provide details of your emissions reduction target(s).	Yes (recommended)
5.1b	Provide details on the current or planned use of carbon credits sold to or purchased from outside the jurisdiction or target boundary.	Yes (recommended)
6.1	Provide details of your jurisdiction's energy-related targets active in the reporting year. In addition, you can report other climate-related targets active in the reporting year.	Yes (recommended)
7.1	Does your jurisdiction have a climate action plan or strategy that addresses mitigation, adaptation (resilience) and/or energy?	Yes (required)
7.1a	Report details on the climate action plan or strategy that addresses mitigation, adaptation (resilience) and/or energy-related issues in your jurisdiction.	Yes (required)
7.2	Report details on the other climate-related plans, policies and/or strategies in your jurisdiction.	Yes (recommended)
7.3	Does your jurisdiction have a strategy for reducing emissions from consumption of the most relevant goods and services?	Yes (recommended)
7.4	Does your jurisdiction have a strategy or standard for reducing emissions from the jurisdiction's procurement and purchases of goods and services?	Yes (recommended)
7.5	Describe any planned climate-related projects within your jurisdiction for which you hope to attract financing.	Yes (recommended)
7.6	Report the factors that support climate-related investment and financial planning in your jurisdiction.	Yes (required)
8.1	Describe the outcomes of the most significant adaptation actions your jurisdiction is currently undertaking. Note that this can include those in the planning and/or implementation phase.	Yes (recommended)
9.1	Describe the outcomes of the most significant mitigation actions your jurisdiction is currently undertaking. Note that this can include those in the planning and/or implementation phases.	Yes (recommended)

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Annex B – MyCovenant GHG reporting parameters

MyCovenant		
Question	**Copy as many "emission inventory" tabs as necessary. Minimum 1 "baseline emission inventory" (BEI) at the 1st reporting stage; at least 1 "monitoring emission inventory" (MEI) every 4 years.**	
Reporting factor	Inventory year	
Reporting factor	Population	
Reporting factor	Emission factors	• IPCC (Intergovernmental Panel on Climate Change) • LCA (Life Cycle Assessment) • National/sub-national
Reporting factor	Emission reporting unit	• tonnes CO2 • tonnes CO2 equivalent
Reporting factor	Methodological note	
Question	**A. Final energy consumption**	
Sector	Buildings, equipment/facilities and industries	
Reporting factor	Municipal buildings, equipment/facilities	• Municipal buildings, equipment/facilities • Public lighting • Other
Reporting factor	Tertiary (non municipal) buildings, equipment/facilities	• Institutional buildings • Other
Reporting factor	Residential buildings	
Reporting factor	Industry	• Non-ETS • ETS (not recommended)
Reporting factor	Buildings, equipment/facilities and industries not allocated	
Sector	Transport	
Reporting factor	Municipal fleet	• Road • Other
Reporting factor	Public transport	• Road • Rail • Local and domestic waterways • Other
Reporting factor	Private and commercial transport	• Road • Rail • Local and domestic waterways

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		• Local aviation • Other
Reporting factor	Transport not allocated	
Sector	Other	
Reporting factor	Agriculture, Forestry, Fisheries	
Reporting factor	Other not allocated	
Question	**B. Energy supply**	
Sector	B1. Certified green electricity	
Reporting factor	Purchases Guarantees of Origins (within the municipality boundaries)	
Reporting factor	Sales Guarantees of Origins (within the municipality boundaries)	
Sector	B2. Local/distributed electricity production (Renewable energy only)	
Reporting factor	Wind	
Reporting factor	Hydroelectric	
Reporting factor	Photovoltaics	
Reporting factor	Geothermal	
Reporting factor	Other	
Sector	B3. Local/distributed electricity production	
Reporting factor	Combined Heat and Power	
Reporting factor	Other (ETS and large-scale plants > 20 MW not recommended)	
Sector	B4. Local heat/cold production	
Reporting factor	Combined Heat and Power	
Reporting factor	District heating (heat-only)	
Reporting factor	Other	
Question	**C. CO2 emissions**	
Sector	C1. Please insert the CO2 emission factors adopted [t/MWh]:	
Reporting factor	Electricity	
Reporting factor	Fossil fuels	
Reporting factor	Renewable energies	
Sector	C2. Please complete in case non-energy related sectors are included:	
Reporting factor	Waste management	• Solid waste disposal • Biological Treatment of Solid Waste • Incineration and Open Burning of Waste • Other
Reporting factor	Wastewater treatment and discharge	
Reporting factor	Other non-energy related such as fugitive emissions	

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Annex C – Emission sources and data points per sector

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ANNEX C: Emission sources and data points per sector

Identifier	Sectors	Emission sources	Scope	Approaches	Activity data	Emission factors/Unit	Data collection approach	Data points	Possible data sources	Note	Source
1,1	**Stationary Energy**	Fuel combustion within the city boundary	1	By fuel consumption	Amount of fuel consumption by fuel type	Mass GHG emissions per unit of fuel	Bottom-up	Real consumption data for each fuel type disagregateds by sub-sector	Energy tariffs and billing; Direct data reporting from utility or fuel providers in the city.	Where data are only available for a few of the total number of fuel suppliers, determine the population (or other indicators such as industrial output, floor space, etc.) served by real data to scale-up the partial data for total city-wide energy consumption.	GPC
		Fuel combustion within the city boundary	1	By fuel consumption	Amount of fuel consumption by fuel type	Mass GHG emissions per unit of fuel	Bottom-up	A representative sample set of real consumption data from surveys. While surveying for fuel consumption for each sub-sector, determine the built space (i.e., square meters of office space and otherbuilding characteristics) of the surveyed buildings for scaling factor.	A representative sample set of real consumption data from surveys	Where data are only available for one building type, determine a stationary combustion energy intensity figure by using built space of that building type, and use as a scaling factor with built space for the other building types.	GPC
		Fuel combustion within the city boundary	1	By fuel consumption	Amount of fuel consumption by fuel type	Mass GHG emissions per unit of fuel	Mixed	Modeled energy consumption data. Determine energy intensity, by building and/or facility type, expressed as energy used per square meter (e.g., GJ/m2/year) or per unit of output.	Modeled energy consumption data		GPC
		Fuel combustion within the city boundary	1	By fuel consumption	Amount of fuel consumption by fuel type	Mass GHG emissions per unit of fuel	Top-down	Regional or national fuel consumption data scaled down using population or other indicators.			GPC
1,2	**Stationary Energy**	Consumption of grid-supplied energy consumed within the city boundary	2	Location based grid-energy consumption	Grid-supplied electricity consumption	Mass GHG emissions per unit of grid-supplied energy (grid specific emission factor)	Bottom-up	Real consumption data from utility providers, disaggregated by building type or non-building facility for Stationary Energy	Energy tariffs and billing; Direct data reporting from utility or electricity providers in the city.	A location-based method is based on average energy generation emission factors for defined locations, including local, sub-national or national boundaries. It yields a grid average emission factor representing the energy produced in a region, and allocates that to energy consumers in that region.	GPC
		Consumption of grid-supplied energy consumed within the city boundary	2	Location based grid-energy consumption	Grid-supplied electricity consumption	Mass GHG emissions per unit of grid-supplied energy (grid specific emission factor)	Bottom-up	Representative sample sets of real consumption data from surveys scaled up for total city-wide fuel consumption and based on the total built space for each building type.			
		Consumption of grid-supplied energy consumed within the city boundary	2	Location based grid-energy consumption	Grid-supplied electricity consumption	Mass GHG emissions per unit of grid-supplied energy (grid specific emission factor)	Mixed	Modeled energy consumption data by building and/ or facility type, adjusted for inventory-year consumption data by weather.			
		Consumption of grid-supplied energy consumed within the city boundary	2	Location based grid-energy consumption	Grid-supplied electricity consumption	Mass GHG emissions per unit of grid-supplied energy (grid specific emission factor)	Top-down	Regional or national consumption data scaled down using population, adjusted for inventory-year consumption data by weather.		Cities should use regional or sub-national grid average emissions factors. If these are not available, national electricity production emission factors may be used.	
		Consumption of grid-supplied energy consumed within the city boundary	2	Market-based allocation of energy generation	Annual electricity use by the city disaggregated by sector based on user profiles	Mass GHG emissions per unit of grid-supplied energy (grid specific emission factor)	Top-down	Allocation of energy use by sectors through the use of user codes associated with end users.		Market-based allocation of energy generation helps identify and indicate the emissions from energy choices that businesses, institutions, or residential consumers have made,	GPC
		Consumption of grid-supplied energy consumed within the city boundary	2	Location based grid-energy consumption	Consumption of grid-supplied steam, heating and cooling	Mass GHG emissions per unit of grid-supplied energy (grid specific emission factor)	Bottom-up	Average emissions rate for the energy generation facilities supplying the district steam, heating and/or cooling systems	Average emission rates should be available through local energy utility or the district grid operator		
1,3	**Stationary Energy**	Transmission and distribution losses from grid-supplied energy	3	Loss rate based approach	Amount of energy transmitted and average Grid Loss Rate of the region	Mass GHG emissions per unit of grid-supplied energy	Bottom-up	Multiplying total consumption for each grid-supplied energy type (activity data for scope 2) by their corresponding loss factor yields the activity data for transmission and distribution (T&D) losses. This figure is then multiplied by the grid average emissions factors.	Grid Loss Factors are usually provided by local utility or government publications.		GPC
1,4	**Stationary Energy**	Fugitive emissions from fossil fuels extraction and	1	Direct Measurement	Direct measurement of GHG emissions	Direct measurement of GHG emissions					GPC
	Stationary Energy	Fugitive emissions from fossil fuels extraction and	1	Production-based estimation	Quantity of production in fuel extraction and processing	Mass GHG emissions per unit of fossil fuel production					GPC
2,1	**Transportation**	Fuel combustion for in-boundary transportation	1	ASIF model (Activity, Share, Intensity, Fuel)	Distance traveled or fuel consumed by type of vehicle using type of fuel	Mass GHG emissions per unit distance traveled by type of vehicle using type of fuel	Bottom-up	The ASIF framework uses data points: travel activity (VKT: Vehicle Kilometer Traveled); the mode share: portion of trips taken by different modes; energy intensity of each mode (Energy consumed per vehicle kilometer & vehicle types), and composition of local fuel stock (fuel types, carbon content of each fuel to total emissions).	The city's transportation model(s) developed by the transportation planners.	Cities should first consult any transport models developed by city transportation planners. In the absence of a transportation model, cities can use the fuel sales method.	ADB
	Transportation	Fuel combustion for in-boundary transportation	1	Fuel sales method	Total fuel sold within the city boundary as a proxy for transportation activity	Mass GHG emissions per unit of sold fuel	Top-down	Volume of fuel sold/purchased within the city boundary. Calculating fuel sales emissions requires multiplying activity data (quantity of fuel sold) by the GHG-content of the fuel by gas (CO_2, CH_4, N_2O).	The volume of fuel sold within the city boundary can be obtained from fuel dispensing facilities and/or distributors, or fuel sales tax receipts and city-wide fuel statistics.		GPC
	Transportation	Fuel combustion for in-boundary transportation	1	Induced activity method	in-boundary trips and 50% of transboundary trips that originate or terminate within the city boundary.	Mass GHG emissions per unit distance traveled by type of vehicle using type of fuel	Bottom-up	Vehicle kilometers traveled (VKT) figure for each identified vehicle class; Vehicle fuel intensity (or efficiency) and fuel emission factors.	Models or surveys to assess the number and length of all on-road trips occurring—both transboundary and in-boundary only.		GPC
	Transportation	Fuel combustion for in-boundary transportation	1	Geographic allocation method	all on-road travel occuring within the geographic boundary, regardless of start and end destinations	Mass GHG emissions per unit distance traveled by type of vehicle using type of fuel	Mixed		Typical geographic coverage for city border VKT surveys and some European travel demand models.	Some European traffic demand models quantify these emissions primarily for local air pollution estimates or traffic pricing, but GHG emissions can be quantified based on the ASIF model, limiting VKT to in-city travel.	GPC

	Transportation	Fuel combustion for in-boundary transportation	1	Resident activity	a measurement of the transport activities of city residents.	Mass GHG emissions per unit distance traveled by type of vehicle using type of fuel	Bottom-up	Requires information on resident VKT, from vehicle registration records and surveys on resident travels.	Typical geographic coverage for household surveys, vehicle registration data (city or regional), and vehicle inspections (e.g., sample odometer readings).	The limitation of this aproach to only resident activity overlooks the impact of non-city resident traffic by commuters, tourists, logistics providers, and other travelers	GPC
	Transportation	Fuel combustion for in-boundary transportation	1 and 3	Well-to-wheels	Well-to-wheels GHG emissions by all urban area passenger and freight transport modes	Mass GHG emissions per capita per year (tonnes CO2(eq.) /cap. Per year)	Mixed	Refer to: https://transport.ec.europa.eu/other-pages/transport-basic-page/greenhouse-gas-emissions-indicator_en			SUMI
2,2	**Transportation**	Consumption of grid-supplied energy for in-boundary transportation	2	Grid-energy consumption model	Amount of electricity consumed	Mass GHG emissions per unit of grid-supplied energy (grid specific emission factor)	Mixed	Emissions from any grid-supplied energy that powers electric vehicles (electric charging stations in the city boundary), rail based transport charged within the city boundary, Aircraft charging and/or is purchased and consumed by marine-vessels typically at docks, ports or harbors.	Grid supply energy utility providers; Port operators on water vessel consumption.	Grid-supplied electricity used to power rail-based transportation systems is accounted for at points of supply (where the electricity is being supplied to the railway system), regardless of trip origin or destination. Therefore, all electricity charged for railway vehicle travel within the city boundary shall be accounted for under scope 2 emissions.	GPC
2,3	**Transportation**	Emissions from transboundary transportation portions occuring outside the city	3	ASIF model (Activity, Share, Intensity, Fuel)	Distance traveled or fuel consumed by type of vehicle using type of fuel	Mass GHG per unit distance traveled or fuel consumed by type of vehicle using type of fuel	Mixed	VKT and types of fuels consumed in departing trips, Aviation: the quantity (volume or energy) of each type of fuel consumed by the aircraft associated with outgoing flights, and whether the trips are domestic or international. Rail: For inter-city, national or international railway travel, a city can allocate based on: Resident travel, where the number of city residents disembarking at each out-of-boundary stop (relative to the total riders on the out-of-boundary stops) can be used to scale down total emissions from the out-of-boundary stops. Freight quantity (weight or volume), where the freight quantity coming from the city (relative to the total freight on the out-of-boundary stops) can be used to scale down total emissions from out-of-boundary stops. Waterborne: Cities can estimate the proportion of passengers and cargo traveling from the city, using official records, manifests, or surveys to determine the apportionment to calculate VKT, or the distance travelled from the seaport within the city to the next destination; Fuel combustion, quantifying the combustion of fuel loaded at the stations within the city boundary.	Cities can determine this based on surveys.	The city may report just the emissions from departing flights that are attributable to the city by estimating the proportion of passengers traveling from the city to airports that serve the city, using carrier flight data or surveys to determine the allocation. Cities shall transparently document the methods used in the inventory reports. Landing-take off (LTO) emissions from international and regional flights should be accounted for as scope 3 emissions.	GPC
	Transportation	Emissions from transboundary transportation portions occuring outside the	3	ASIF model (Activity, Share, Intensity, Fuel)	Distance traveled or fuel consumed by type of vehicle using type of fuel	Mass GHG per unit distance traveled or fuel consumed by type of vehicle using type of fuel	Bottom-up	Survey based activity data and real fuel consumption amounts			
	Transportation	Emissions from transboundary transportation portions occuring outside the city	3	ASIF model (Activity, Share, Intensity, Fuel)	Distance traveled or fuel consumed by type of vehicle using type of fuel	Mass GHG per unit distance traveled or fuel consumed by type of vehicle using type of fuel	Top-down	Scale down regional transit system fuel consumption based on: • Population served by the region's model and the population of the city, to derive an in-boundary number. • Share of transit revenue service miles served by the region (utilize data on scheduled stops and length of the transport mode) and the number of miles that are within the city's geopolitical boundary. • Scale down national railway/waterborne/aviation fuel consumption based on city population or other indicators.			
2,4	**Transportation**	Transmission and distribution losses from grid-supplied energy	3	Loss rate based approach	Amount of energy transmitted and average loss rate of the grid	Mass GHG emissions per unit of grid-supplied energy	Undefined	All grid supply energy use in transportation x regional Grid Loss Rate			GPC
3,1	**Waste**	Solid waste disposal	1 and 3	First Order of Decay method (IPCC and GPC recommended)	Amount of waste received at landfill site and its composition for all historical years	Methane generation potential of the waste	Mixed	Mass of waste disposed and amount of degradable organic carbon (DOC) within the waste, which determines the methane generation potential		In the absence of local or country-specific data on waste generation and disposal, the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories provide national default values for waste generation rates based upon a tonnes/capita/year basis and default breakdowns of fraction of waste disposed in landfills (SWDS), incinerated, composted (biological treatment), and unspecified (landfill methodology applies here)	GPC
	Waste	Solid waste disposal	2 and 3	Methane Commitment method	Amount of waste disposed at landfill site in inventory year and its composition	Methane generation potential of the waste	Mixed	Mass of solid waste disposed by type (tonne)			GPC
3,2	**Waste**	Biological treatment of waste	1 and 3	Waste composition based approach	Mass of organic waste treated by treatment type	Mass GHG emission per unit of organic waste treated, by treatment type	Mixed	Mass of organic waste by treatement type (tonne)			GPC
3,3	**Waste**	Incineration and open burning	1 and 3	Waste composition based approach	Mass of waste incinerated and its fossil carbon fraction	Oxidation factor, by type of treatment	Bottom-up				GPC
3,4	**Waste**	Wastewater treatement and discharge	1 and 3	Organic content based approach	Organic content of wastewater per treatment type	Emission generation potential of such treatment type	Bottom-up				GPC
4,1	**IPPU**	Industrial processes occurring in the city boundary	1	Input or output based approach	Mass of material input or product output	Emission generation potential per unit of input/output	Top-down				GPC

	IPPU	Industrial processes occurring in the city boundary		Direct Measurement	Direct measurement of GHG emissions		Bottom-up				GPC
4,2	**IPPU**	Product use occurring within the city boundary	1	Input or output based approach	Mass of material input or product output	Emission generation potential per unit of input/output	Bottom-up	Refer to GPC, Chapter 9			GPC
	IPPU	Product use occurring within the city boundary		Direct Measurement	Direct measurement of GHG emissions		Bottom-up				GPC
	IPPU	Product use occurring within the city boundary		Scaling approach	National or regional level activity or emissions data	Emission factor or scaling factor	Top-down				GPC
5,1	**AFOLU**	Livestock emission sources	1	Livestock based approach: Enteric Fermentation	Number of animals by livestock category and manure management system	Emission factor per head and nitrogen excretion per manure management system	Mixed	The amount of CH4 emitted by enteric fermentation is driven primarily by the number of animals, type of digestive system, and type and amount of feed consumed. Methane emissions can be estimated by multiplying the number of livestock for each animal type by a pre-specified emission factor.	Activity data on livestock can be obtained from various sources, including government and agricultural industry. If such data are not available, estimates may be made based on survey and land-use data.	Livestock should be disaggregated by animal type, consistent with IPCC categorization: Cattle (dairy and other); Buffalo; Sheep; Goats; Camels; Horses; Mules and Asses; Deer; Alpacas; Swine; Poultry; and Other.	GPC
	AFOLU	Livestock emission sources	1	Livestock based approach: Manure management	Rate of waste production per animal	Rate of waste production per animal	Mixed	The main factors affecting CH4 emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. The former depends on the rate of waste production per animal and the number of animals, and the latter on how the manure is managed.	Manure management requires data on livestock by animal type and average annual temperature, in combination with relevant emission factors	Average annual temperature data can be obtained from international and national weather centers, as well as academic sources. Country-specific temperature-dependent emission factors should be used, where available; alternatively, default IPCC emission factors may be use	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use. Available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html
5,2	**AFOLU**	Land uses emission sources	1	Land area based approach	Surface area of different land use categories	Net annual rate of change in carbon stocks per hectare of land	Top-down	Surface area of land use (ha)			2019 Refinement to 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 Agriculture Forestry and Other Land Use, Section 2.2.1, eq 2.1. Available at: https://www.ipcc-
5,3	**AFOLU**	Aggregate sources and non-CO2 emission sources on land	1	See detailed approach in the Greenhouse Gap Protocol for cities			Undefined	Aggregate of GHG emissions from biomass burning, Liming, Urea application, Direct and indirect N2O from managed soils, indirect N2O from manure management, rice cultivation and harvested wood products.	See data sources defined by GPC, section 10.4		GPC

Annex D – Sectoral emission sources by GHGs

Key Sector Detailed Emission Sources by GHGs	
Transportation	
CO_2	Motor Gasoline
	Distillate Fuel
	Jet Fuel, Kerosene
	Natural Gas
	Residual Fuel
	Lubricants
	Aviation Gasoline
	LPG
	Light Rail Electricity Use - Other
	Jet Fuel, Naphtha
CH_4	Passenger & Light Vehicles
	Non-Road Vehicles & Equipment
	Heavy-Duty Vehicles
	Natural Gas Distribution (sector share)
N_2O	Passenger & Light Vehicles
	Non-Road Vehicles & Equipment
	Heavy-Duty Vehicles
HFC and PFC	Refrigerants
	Air Conditioners
	Fire Protection Use
SF_6	Electric Power Transmission and distribution
Stationary Energy	
CO_2	Residential Electricity Use
	Commercial Electricity Use
	Residential Natural Gas Combustion
	Commercial Natural Gas Combustion
	Commercial Petroleum Combustion
	Residential Petroleum Combustion
	Waste Incineration
	Residential Coal Combustion

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	Commercial Coal Combustion
CH4	Municipal Solid Waste Landfills
	Natural Gas Distribution (sector share)
	Municipal Wastewater
	Residential Combustion Byproducts
	Commercial Combustion Byproducts
	Waste Incineration
	Compost
N2O	Fertilization of Landscaped Areas
	Residential Combustion Byproducts
	Waste Incineration
	Compost
	Commercial Combustion Byproducts
	Municipal Wastewater
HFC, PFC	Refrigerants, Aerosols, Fire Protection Use
	Aerosols
	Fire Protection Use
IPPU	
CO2	Industrial Electricity Use
	Natural Gas Combustion
	Petroleum Combustion
	Cement Manufacture
	Coal Combustion
	Ammonia Production
	Urea Consumption
	Waste Incineration
	Iron & Steel Production
	Soda Ash Production & Consumption
	Limestone and Dolomite Use
	Lime Manufacture
	Pulp & Paper including wastewater
	Aluminum production
CH4	Natural Gas Distribution & Production
	Industrial Landfills
	Combustion Byproducts

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	Food Processing Wastewater
	Waste Incineration
N2O	Combustion Byproducts
	Waste Incineration
	Nitric Acid Production
	Adipic Acid production
HFC, PFC, NF3, SF6	Semiconductor Manufacturing
	Magnesium Production and Processing
	Refrigerants manufacture and use
	Aluminum Production
	Foams
	Solvents
	Aerosol Use
AFOLU	
CO2	Urea Fertilization
	Liming of Agricultural Soils
CH4	Enteric Fermentation
	Manure Management
	Agricultural Residue Burning
N2O	Agricultural Soil Management
	Manure Management
	Agricultural Residue Burning

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