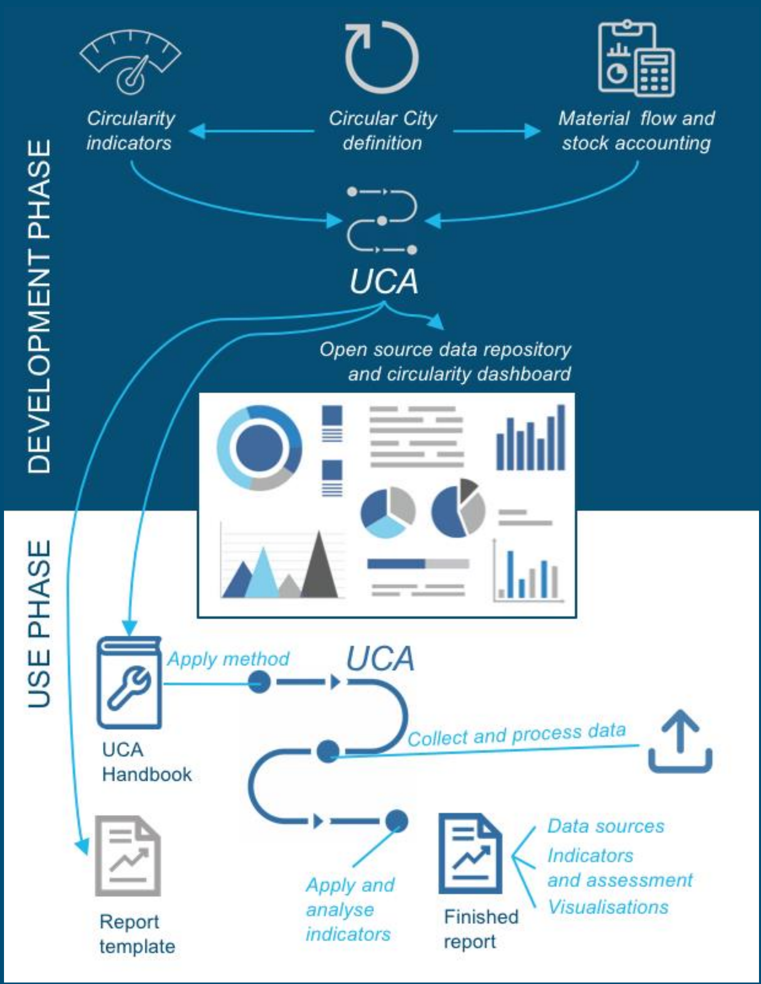
URBAN CIRCULARITY ASSESSMENT METHOD

Deliverable 4.4

Metabolism of Cities



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Abstract	The document presents the Urban Circularity Assessment (UCA) method. It is an urban material flow and stock accounting method paired with system-wide indicators to assess the material circularity of a city. The material flows are accounted economy-wide for two years, applying the Mayer et al. (2019) framework, which in itself builds on the EW-MFA method, including the wide material scope, while optimised for a circular economy assessment. The material stock accounting is limited to buildings of a municipality, with the material scope depending on data availability. Finally, the mass-based, "circularity" Indicators cover the entire system and enable the assessment of a city's circularity. The developed UCA method seeks to find a balance between scientific rigour and comprehensiveness on the one hand, and operability by urban policy makers and practitioners on the other.
Keywords	Urban circularity assessment; Material flow accounting; Building stock; Circularity indicators; Urban metabolism; Circular city;
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Executive Summary

The Urban Circularity Assessment (UCA) is an **urban, economy-wide material flow and stock accounting method, which paired with indicators, will enable the assessment of material circularity** of a municipality or city. Similarly to Economy-Wide Material Flow Analysis (EW-MFA), the method presented here is more than a compilation of data. When joined with indicators, it provides systemic and synthetic insights into cities' resource requirements and circularity. It aims to maximise circularity insights while reducing data needs and staying scientifically sound, easily transferable, and comparable to national and EU statistics.

The **aim of the UCA** is to monitor progress toward a Circular Economy (CE) from an economy-wide perspective at the city-level, rather than just at the level of individual products or sectors. Only at this scale can system-wide effects like displacement and rebound be captured, as well as the determination made whether absolute reductions in resource use and waste flows have been accomplished or are feasible (Mayer et al. 2019). This necessitates a comprehensive approach that takes into account biomass, metals, non-metallic minerals, and fossil energy carriers flows through extraction, imports/exports, processing, use and waste (including collection and treatment) phases. With this information, a consistent mass balance can be performed, in order to establish systematic monitoring of resource utilisation, waste, and recycling across the socio-economic system.

The UCA consists of three main parts: (1) (a) material flow and (b) stock accounting (MFSA), (2) indicators and (3) CE assessment.

These parts will be described in more detail in the following paragraphs, while the chapters go into depth on each of the main components.

(1a) Material Flow Accounting

Based on an evaluation of 29 urban material flow accounting methods as part of Deliverable 4.1 and building on the experience of the Sector-wide Circularity Assessment (SCA), it was decided to adopt and enhance Eurostat's Economy-Wide Material Flow Analysis, which is already utilised by European member states and the European Circular Economy monitoring framework. To contextualise this method and specifically the Mayer et al. (2019) framework at the urban level, some specific geographical and economic characteristics, i.e. accounting for imports and exports to a city, have to be adjusted to the method that was designed for the national level. As such, the method proposed here aims to shed light on what is typically a black box of traditional EW-MFA studies, by including flows of secondary materials to allow for monitoring socio-economic loop closing.

The material flow accounting component of the UCA makes use of the existing database structure and intends to monitor materials through time and space using Eurostat nomenclatures (on material flows, waste statistics, EW-MFA terminology) in order to assure consistency with national and European initiatives to quantify physical flows.

The system boundaries for the MFA are as follows:

- Spatial boundaries: those corresponding to the administrative boundaries of the municipality/city.
- Temporal boundaries: two reference years, thus allowing to analyse a “time series” and to observe trends.
- Material boundaries: The material scope encompasses Eurostat’s MF materials and waste materials, see Figure 5 (and Annex 1 and 2). On the most detailed level (4-digit), EW-MFA data is accessible for 45 material categories, which can be aggregated into 16 and eventually four major material groupings, namely biomass, metals, non-metallic minerals, and fossil energy carriers. The EW-MFA classification system is based on material characteristics and, in some circumstances, their intended usage. On the other hand, the information on municipal waste should be sorted and disaggregated according to its treatment (landfill, incineration, energy recovery, recycling and backfilling) and waste categories (chemical and medical wastes, recyclable wastes, equipment, biomass, mixed , mineral and metallic wastes). Water and energy are excluded.

Following data collection and processing, the structured data serves as input for Sankey diagrams, indicator calculations and eventually a data dashboard.

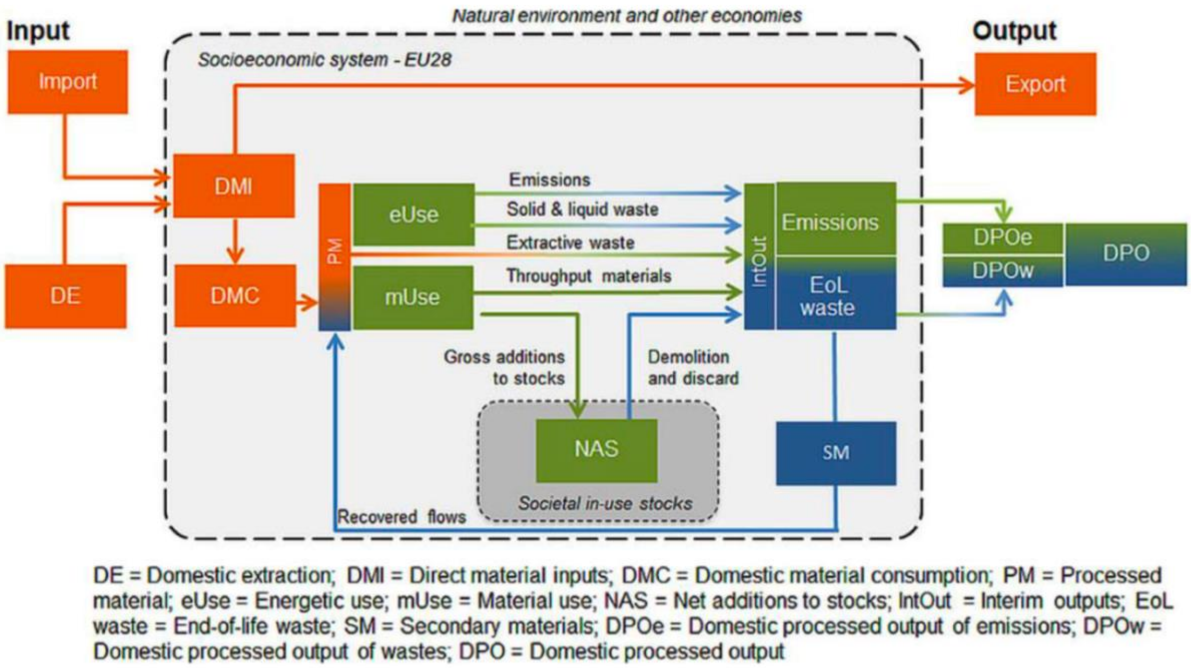

Figure 1 - Framework and throughput indicators for an economy-wide CE assessment (Mayer et al. 2019)

(1b) Material Stock Accounting

To complement the circularity insights from the Material Flow Accounting, a bottom-up Material Stock Accounting (MSA) part will be carried out for the UCA. In fact, MSA will enable to contextualise the accumulation of flows and the generation of CDW within cities (while exploring the potential of closing material loops through reusing, repurposing and recycling). The MSA will only focus on the building stock, as it represents the highest share of the total material stock and is, in most cases, the easiest to assess. The method employed (Stephan and Athanassiadis 2017) requires three main steps of obtaining (1) the location, land use and floor area of buildings, (2) building typologies and (3) building typologies' material composition (t/m^2).

The system boundaries for the MSA are as follows:

- Spatial boundaries: those corresponding to the administrative boundaries of the municipality/city.
- Temporal boundaries: one reference year.
- Material boundaries: The material scope encompasses the material that can be found by cities in their building typologies' material composition. The number of materials can be different from city to city depending on data availability.

By finding the location, land use and floor area of buildings, it is possible to develop building typologies for which their material composition needs to be determined. Once these three elements are gathered, it is possible to calculate the material stock for each building of a city and spatialise it through a choropleth map.

(2) Analysis of Flows and Stocks: Measuring Indicators

Using the collected and processed data from the MFSA, the flows and stocks are analysed in the form of indicators. In order to measure the state of urban circularity, an indicator framework composed of direct and indirect indicators has been designed. After a review of the existing literature on circularity indicators (Fischer-Kowalski and Hüttler 1998; Kennedy et al. 2014; Nigohosyan 2019; OECD 2020; Schandl et al. 2016; UNEP 2021) as well as the different applications of the MFA method at different scales (Haas et al. 2015; Jacobi et al. 2018; Maarten and Vercalsteren 2020; 2021; Mayer et al. 2019; Noll et al. 2022), a set of indicators is proposed that also includes two indicators (Barles 2009) that allow to make the necessary corrections to adapt the method to the city scale. Ten direct or scale indicators have been proposed that allow to dimension material flows, while another eight indirect circularity indicators exist to be able analyse ratios, productivity and intensity. Scale indicators can reveal not just the types and amounts of natural resources entering the economy, but also what happens to materials as they transit inside and outside the economy, and how this affects resource productivity meanwhile the circularity indicators allow analysing the degree of loop closing and its efficiency.

(3) Analysis of Indicators: Assessing Circularity

To determine the circularity of the material flows in the city, the indicators have to be assessed. The indicators, allow to reveal and analyse trends, as at least two time points in time will be evaluated. Moreover, they can be tied to EU or national objectives to benchmark the city's status quo. However, although the indicators have been adapted to the local scale, they should be complemented with information on the local situation. While data helps to size the problem, knowledge of local circumstances helps to enrich the analysis and the search for solutions.

To summarise, the UCA approach that captures the material movements and stocks connected with a city is vital, given the increasing relevance and urgency of cities and their global implications. The suggested approach is well-grounded in existing academic literature and primarily relies on the EW-MFA's data sources, indicators, and nomenclatures; nevertheless, it differs in order to be appropriate for urban scales and to reduce the effort for cities while remaining comprehensive. It is also aligned with current circular economy endeavours by cities and can help public administrators, waste companies, and practitioners understand and improve urban resource utilisation, reducing environmental degradation and identifying energy, material, and waste flows environmental impacts. Therefore, it is time for cities to begin to assess their urban circularity.

Contents

Acronyms and Abbreviations

BIM	Building Information Modelling
CDW	Construction and Demolition Waste
CE	Circular Economy
DE	Domestic Extraction
DMC	Domestic Material Consumption
DMCcorr	Domestic Material Consumption corrected
DMI	Direct Material Input
DPO	Domestic Processed Output
EoL	End-of-Life
eUse	Energetic Use
EW-MFA	Economy-Wide Material Flow Analysis
GDP	Gross Domestic Product
GIS	Geographic Information System
IECrp	Input Ecological Cycling Rate Potential
INCr	Input non-circularity rate
IntOut	Interim Outputs
ISCr	Input socioeconomic cycling rate
LEPO	Local and Exported Processed Output
MFA	Material Flow Analysis
MFSA	Material Flow and Stock Accounting
MI	Material Intensity
MoC	Metabolism of Cities
MP	Material Productivity
MSA	Material Stock Accounting
mUse	Material use
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne (Statistical Classification of Economic Activities in the European Community)
NAS	Net Addition to Stock
NUTS	Nomenclature of Territorial Units for Statistics
OECrp	Output Ecological Cycling Rate Potential
ONCr	Output Non-circularity Rate
OSCr	Output Socioeconomic Cycling Rate
OSM	Open Street Map
PM	Processed Material
PTB	Physical Trade Balance
SCA	Sector Circularity Assessment
SDG	Sustainable Development Goal
SFH	Single Family Home
SM	Secondary Material
UCA	Urban Circularity Assessment
UMAn	Urban Metabolism Analyst Model

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1. Introduction

CityLoops is an EU Horizon 2020 funded project that brings together seven ambitious European cities to demonstrate a series of innovative tools and urban planning approaches, aimed at closing the loops of urban material flows and increasing their regenerative capacity. This report is part of Work Package (WP) 4: Urban Circularity Assessment (UCA). This WP has two objectives:

- To develop and implement a sector-wide material flow and stock accounting method, designed to help optimise demonstration activities through a detailed analysis of material flows (exploring stakeholder involvement and valorisation pathways).
- To **develop and demonstrate a comprehensive city-wide circularity assessment procedure**, designed to **enable cities to monitor their progress towards circularity and effectively integrate circularity into planning and decision making**.

While the first objective was addressed through Deliverable 4.3 "Sector-Wide Circularity Assessment Method", this deliverable focuses on the second objective of WP4. It is a report for Task 4.4: Urban Circularity Assessment, with the key objective of presenting the Urban Circularity Assessment method that was developed.

The **aim of the task** at hand was to develop a method that accounts for urban material flows and stocks, which paired with indicators assesses the circularity of a city. In turn, the **aim of the UCA method**, which is meant for cities (of the CityLoops project) to apply on their own, is to gain a more systemic understanding and provide a comparable circularity baseline for their entire city, as well as to further develop circularity upscaling plans (in WP7).

Task 4.4 is not independent, as can be seen in Figure 2, depicting its relationships to the remaining tasks in WP4, showing how other tasks feed into or rely on the outputs of Task 4.4. Therefore, it can be easily understood how this report and UCA method development partly build on the three previous deliverables in WP4:

- *"Deliverable 4.1: Urban Material Flows and Stocks Accounting: A Review of Methods and Their Application"*: Deliverable 4.1 demonstrated the findings and insights from a literature review on the different urban material flow and stock accounting methods, and provided an overview of other projects that deal with such methods.
- *"Deliverable 4.2: Development of an Urban Material Flow and Stock Database Structure"*: Deliverable 4.2 documented the development of a database structure that caters to the data used and generated by the accounting methods.
- *"Deliverable 4.3: Sector-Wide Circularity Assessment Method"*: Deliverable 4.3 presented the SCA accounting method and indicators that assess the circularity of a (construction or biomass) sector.

Thus, these deliverables and the previous work and experience gained in the project were also the **starting points for the UCA method development**. It was originally planned that the specific sectors from the SCA could be added up or compiled with others to make up the entire city. However, it became evident that this is not possible due to the definition of the sectors and the understanding that materials cannot be subjected to a single sector only. To avoid double counting of materials, or a complex approach to circumvent that (which would require a considerable additional amount of work and data), the scaling up of sectors was dismissed and sectors do not play a role in the UCA. Instead, the city is seen as a whole system on its own.

Although the idea of adding up sectors was abandoned, the SCA's accounting method and the review of others in D4.1 was reverted back to and used as a basis for the UCA. The database structure also remains the same for the UCA.

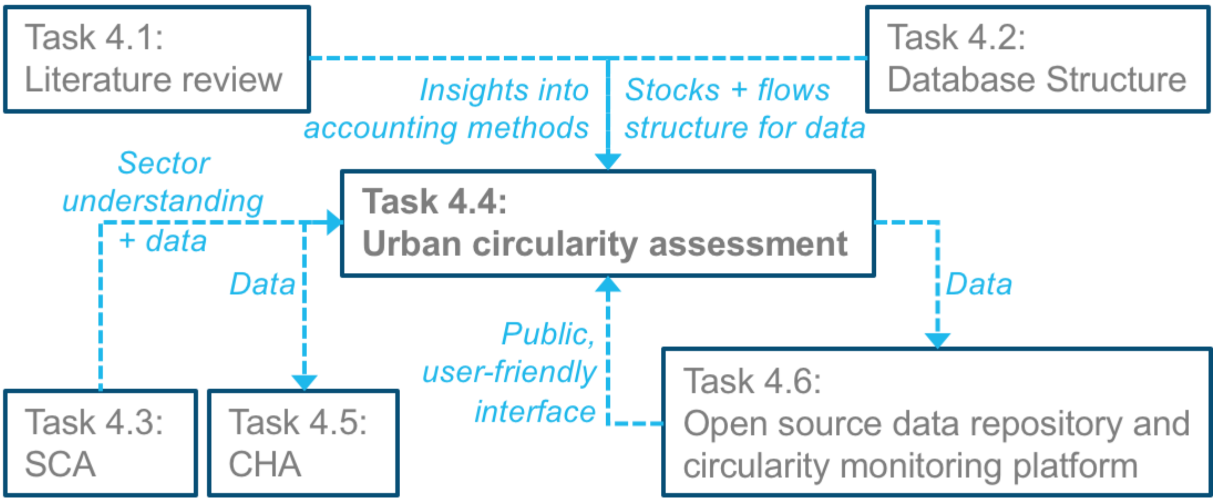

Figure 2 - Relationship of tasks in WP4 and the information and/or function that they provide

Following this introduction, the document presents the three main components of the Urban Circularity Assessment method. First, it describes the **material flow and stock accounting methods**, respectively presenting the main existing methods for flow as well as stock accounting that they build on, as well as the system boundaries that are in place. It also contains sub-chapters on inputs that are required for the accounting, satisfied through data collection and processing, and outputs that can be obtained. Secondly, it turns to the **analysis of those flows and stocks**, by introducing the ***circularity indicators*** and their measurements. Lastly, it presents the **analysis of the indicators**, needed to ***assess circularity***.

The document does not detail the practical necessities for the application of the method, such as use of the CityLoops Data Hub for data collection, processing and visualisation, or templates required, context specific assumptions etc. These are to be shared during the facilitation of the method application for five of the CityLoops cities (Apeldoorn (the Netherlands), Bodø (Norway), Mikkeli (Finland), Porto (Portugal) and Seville (Spain)), guided by the team of Metabolism of Cities. Based on the experience of this facilitation, a handbook will be produced in another deliverable, towards the end of the project, which can then be freely used by other cities or interested parties.

2. Material Flow and Stock Accounting

The first component of the UCA is the accounting of materials, both of their flows and stocks of the urban environment. This is the starting point and basis of the method, needed for an understanding of the city system as well as the necessary precondition for circularity indicators. This part of the method is the most time and resource intensive part, since data needs to be found, requested, and collected from various sources before getting processed, validated and analysed.

This chapter presents the material flow accounting (MFA) and material stock accounting (MSA) methods, to detail how they work when applied and how they are connected, particularly with regard to the method's final outputs.

2.1. Material Flow Accounting

A number of methods have been developed over the years with the goal to measure the material exchanges between a system (often territorial or economic) and its environment. As part of Deliverable 4.1, 29 methods were identified and studied, focusing specifically on the urban scale. MFA methods are applied on various scales, including supranational entities, such as the EU, national economies (countries), economic sectors, corporate organisations, regions or urban settlements. However, studies at the regional and local levels are still very limited compared to national empirical studies (Table 1) and a standardised method has yet to be developed (Niza, Rosado, and Ferrão 2009; Voskamp et al. 2017) for the former levels.

The two main differences between national and city-level studies are the way in which imports and exports of wastes are accounted for and the lack of data at a smaller spatial level, which requires additional steps for data collection and processing. For example, data availability at a regional or local level may be limited for certain material or product flows and, therefore, may have to be estimated from higher spatial scales or more aggregated data using proxy factors.

The lack of data does not inhibit the execution of material flow accounting in cities. To date, the majority of MFA studies on lower spatial scales are conducted on metropolitan areas (see Table 1), as opposed to just a city, as in Hamburg (Hammer and Giljum 2006), Lisbon (Pina et al. 2016; Rosado, Niza, and Ferrão 2014), Madrid (Sastre, Carpintero, and Lomas 2015), Paris (Barles 2009; Pina et al. 2016), and Stockholm (Rosado, Niza, and Ferrão 2014; Kalmykova, Sadagopan, and Rosado 2018), while (Niza, Rosado, and Ferrão 2009) mapped the metabolic profile of Lisbon city, which is a subset of the Lisbon metropolitan region.

Table 1 - MFA studies on spatial scales lower than the national economy

Study	Cities	Base year	Method	System boundary
(Hammer and Giljum 2006)	Hamburg, Leipzig, Vienna	1992-2003	EW-MFA	City and Metropolitan region; NUTS
(Barles 2009)	Paris	2003	EW-MFA	Paris municipality, metropolitan area and administrative region
(Kovanda, Weinzettel, and Hak 2009)	Czech Republic,	2003-2005	EW-MFA	NUTS3
(Niza, Rosado, and Ferrão 2009)	Lisbon	2004	EW-MFA	City
(Browne, O'Regan, and Moles 2011)	Limerick	1992-2002	EW-MFA	Limerick City Region
(Rosado, Niza, and Ferrão 2014)	Lisbon	2003-2009	UMAn	Lisbon city
(Kalmykova, Rosado, and Patrício 2015)	Sweden, Stockholm, and Gothenburg	1996–2011	UMAn	National and Metropolitan region areas. NUTS 1 and NUTS 3
(Sastre, Carpintero, and Lomas 2015)	Spanish regions	1996-2010	EW-MFA	NUTS2
(Duarte Quartin 2016)	Berlin, Frankfurt, Hamburg, Paris, Lyon, Lille, Manchester, Liverpool, Lisbon, Porto, Madrid and Stockholm	2000-2011	UMAn	Metropolitan regions (NUTS 3)
(Pina et al. 2016)	Lisbon, Paris, Seoul, Shanghai	2000	Input-Output	Metropolitan region
(Voskamp et al. 2017)	Amsterdam	2012	EW-MFA	Amsterdam
(Maarten and Vercalsteren 2021)	Flanders	2018	EW-MFA + Circularity	Flanders. NUTS1
(Noll et al. 2022)	Samothraki (Greek Island)	1929-2019	EW-MFA + Circularity	Island

2.1.1. EW-MFA - a standardised method (for a city?)

Over the last two decades, one MFA method has been adopted and adapted by the European Statistical Office (Eurostat 2001a), namely the EW-MFA, also called Eurostat method. Due to the relative ease of use and consistent format with other official statistics, this method has been consistently used by researchers and policy makers alike to measure the flows of economies.

The overall objective of EW-MFA is to characterise the domestic economy's relationship with the natural environment and the rest of the international economy in terms of material flows (excluding water, electricity and air). Only flows that enter or originate from economic processes (production, consumption) are considered as system inputs and outputs by this method without further specifying the processes that take place within the system mobilising these flows, see Figure 3. As such this method can be considered as a “black-box” approach.

While originally designed for national statistics, the EW-MFA method has also been applied to other territorial levels including urban cases (see Table 1). Nevertheless, due to data inconsistencies and specificities of the urban context, many researchers have developed various adaptations of the EW-MFA (Barles 2009; Browne, O’Regan, and Moles 2011; Hammer and Giljum 2006; Niza, Rosado, and Ferrão 2009).

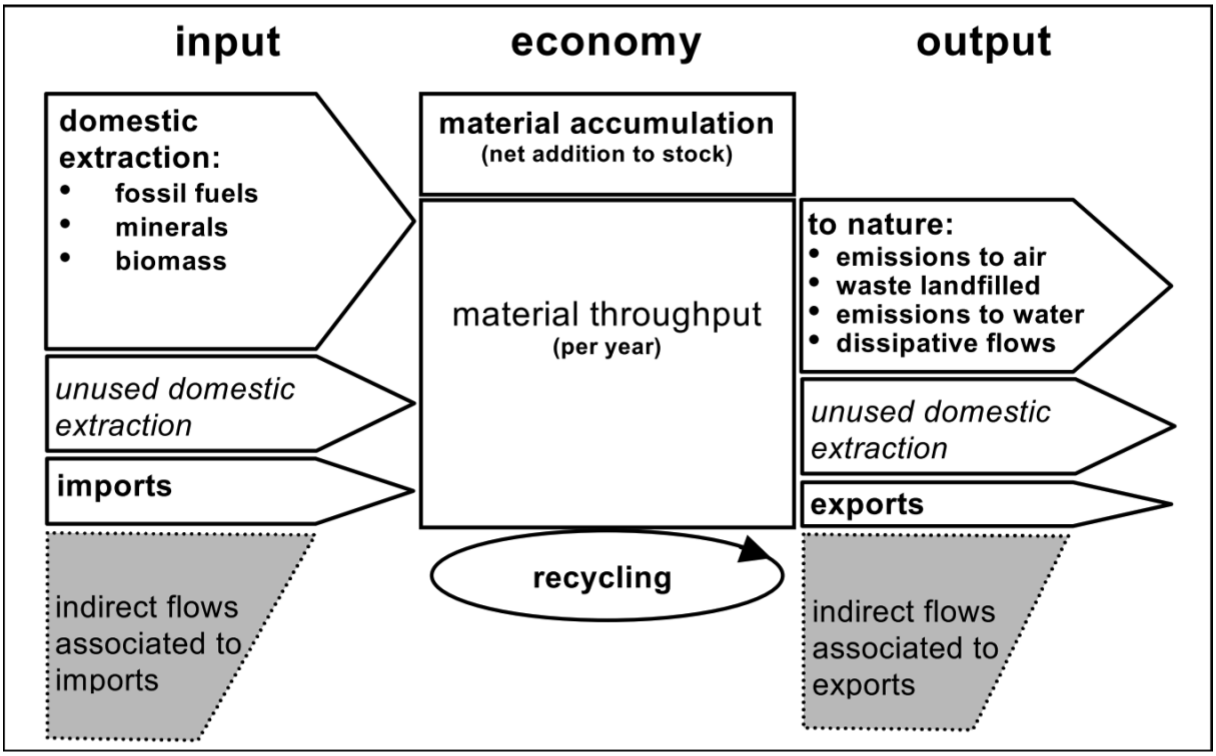

Figure 3 - General scheme for economy-wide MFA

One limitation of EW-MFA of the city is that it does not distinguish between flows related to the city's resource use and those that simply transit through the city, so-called throughflows. Making this distinction is critical to avoiding misclassifying trade-related flows through a city as consumption flows, which would result in an overestimation of a city's actual resource use. Another issue that can arise when adapting the method to the regional scale is the failure to take into account that waste treatment plants are often located outside the city boundaries. Using this approach would minimise flows to nature because they would be limited to the locally emitted part of those flows. Furthermore, it would also minimise or not properly reflect the recycling activities, efforts and rates, because the latter often occur outside the city boundaries.

2.1.2. EW-MFA + Circularity

As visible in the literature review in Deliverable 4.1, economy-wide flow accounting provides a high-level overview and comprehension of socioeconomic metabolisms. However, as mentioned beforehand, there are gaps in the literature when it comes to applying EW-MFA to the city scale (Table 1). In addition, only a few studies manage to overcome the black box approach of EW-MFA, enabling to understand and spatialise the processes that drive the mobilisation of flows within and outside cities. While the EW-MFA method provides a standardised way to quantify essential material flows and related indicators, it occasionally falls short in defining the link between all the datasets utilised and reconciling them.

To overcome some of these limitations, it was decided to conduct an EW-MFA study by adopting the framework proposed by (Mayer et al. 2019) and adapting it to the city scale. This framework links EW-MFA data with waste data in a systematic way, and applies mass balancing, thus enabling it to provide meaningful and impactful information for the development of circularity strategies.

This framework is built upon previous studies, mainly by Haas et al. (2015) where the circularity of the global economy was analysed. Subsequently, Jacobi et al. (2018) adapted the framework to the national scale (Austria) and Mayer et al. (2019) analysed the state of circularity and material loop closing in EU28. As for applications of the method on smaller spatial scales, there are two instances, namely that of Maarten & Vercalsteren (2021) for the Flanders region and to the Greek island of Samothraki by Noll et al. (2022), which complemented their study with the analysis of socioeconomic biophysical stocks. As detailed here, , this framework has been applied at various scales, from the global to the national and regional level. Going forward in this document, references made to the accounting framework, refer to that of (Mayer et al. 2019).

Figure 4 illustrates the path of flows considered by this framework including materials from import and domestic extraction (DE) as system inputs either to export or to material recovery or deposition as waste or emission. On top of inputs and flows, material transformations (processed materials; energetic use; material use, in-use stocks of materials; waste treatment; EoL waste) and the destination of outflows (exports, domestic processed output) are also analysed. Material flows are represented by arrows between boxes (processes), while the colours of the flows indicate the type of data source (e.g., orange for EW-MFA, blue for waste statistics).

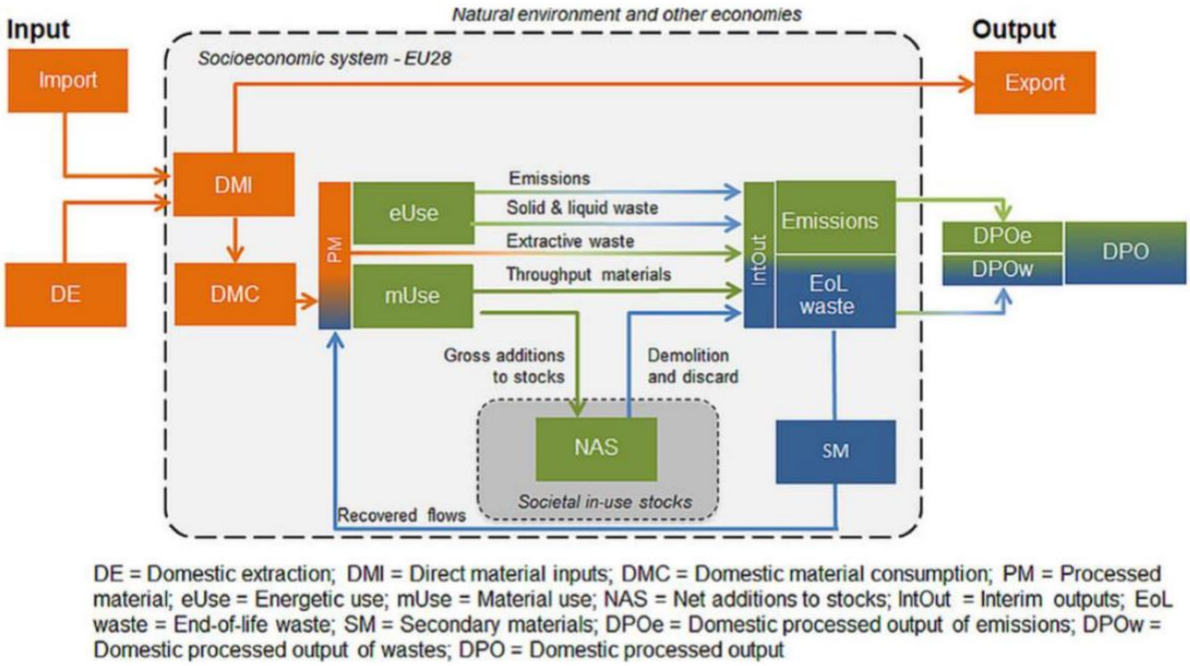

Figure 4 - "Framework and throughput indicators for an economy-wide CE assessment. This framework applies from individual materials (e.g., DE of corn or iron) to aggregated material categories (e.g., PM of biomass, fossil energy carriers) to the total material level (e.g., total DE). Colors indicate data sources used: orange = official data from economy-wide material flow accounts (Eurostat 2017c), blue = official waste and emissions statistics (Eurostat 2017b), green = mass-balanced modeling. Please note that a shift from green to blue color indicates a combination of statistical data and modelling" (Mayer et al. 2019, 64)

As for the boxes in the diagram, direct material input (DMI) into the socioeconomic system includes both domestic extraction, and imports of raw materials and manufactured goods. Exports to other economies are subtracted from domestic material consumption (DMC). To adjust the method to the city scale, DMCcorr (Barles 2009) will also be used. It is calculated by excluding exported wastes from exports and imported wastes from imports. Total DMC or DMCcorr and secondary material (SM) inputs include the definition of processed materials (PMs). Direct material input (DMI) into the socioeconomic system includes materials extracted from the domestic environment (domestic extraction [DE]) as well as raw materials and manufactured products imported from other places. The sum of DMC or DMCcorr and secondary material (SM) inputs is defined as processed materials (PMs).

PMs are classified as either energetic or material use. Energetic use (eUse) includes not just materials needed to generate technical energy, but also feed and food, which are the principal energy sources for livestock and people. Material use (mUse) includes all metal ores and metals, as well as non-metallic minerals and fractions of fossil and biomass resources that are not used for energy provision. Material use was divided into extractive waste, building material stock and throughput materials. All materials collected in buildings, infrastructures or durable commodities with a lifespan of more than one year are considered material building stock (e.g., concrete, asphalt, or steel).

Throughput materials are materials that do not accumulate in in-use stocks and can be divided into two types: materials utilised intentionally in a dissipative manner and losses that occur during material processing (wastage, not reported in waste statistics); and second, short-lived products.

Finally, as part of the accounting, combining statistical reporting and modelling helps balance input and output flows. This is accomplished independently for the eUse and mUse components via two balancing calculations:

1. **DPO emissions** = eUse − solid and liquid wastes
2. **Demolition and discard** = EoL waste from mUse − throughput materials in waste

All energy-producing elements are transformed into Domestic Processed Output (DPO) emissions and solid waste, within a year of extraction. Data for solid waste from combustion provided in waste statistics are used to estimate solid waste from human and animal metabolism (excrements) by applying appropriate coefficients indicating the non-digestible fraction of food and feed intake. eUse less solid waste outflow equals DPO emissions. The so-called balancing items (oxygen uptake during combustion and human/animal water use) are excluded. All outflows from eUse are comprised entirely of PM elements. This implies that all outflows from eUse consist solely of the components present in actual inputs as PM.

Because real in-use stocks (of all materials) are unknown, the following method is employed to close the material balance: First, total EoL waste from mUse should be consistently separated into discard and demolition, and throughput materials. Total EoL waste from mUse needs to be derived from waste statistics. Second, discard and demolition are determined as the difference between EoL waste from mUse reported in waste statistics, and the fraction of throughput materials. Third, NAS is the difference between additions to stock and discards and demolitions.

While the act of mass balancing is desirable from an accounting perspective, it cannot always be done, e.g. if data are missing. Therefore, for the UCA, depending on the city and the data availability, the assumptions that (Mayer et al. 2019) made, as well as the mass balancing can either be utilised or not. It will be decided on a case by case basis during the UCA facilitation.

2.1.3. System definition

In order to carry out the method presented, the system boundaries need to be defined. Three types of system boundaries are considered, namely spatial, temporal and material scope. The spatial boundary is aligned with the administrative boundaries of the city. The temporal boundary of this method is one year. To perform this method, a minimum of two points in time are required, spaced five years apart, for example, 2015 and 2020. However, cities can choose their reference years as per their data availability. This time series is done to be able to gauge the change of “circularity” over time.

The material boundary refers to the EW-MFA classification system defined by Eurostat. The material system is quite comprehensive and accounts for most economy-wide materials except water and energy. Mayer et al. (2019, 63) put the need for accounting of all materials perfectly by stating that:

> ***"Our proposal is to go beyond the level of individual products, substances, or industrial symbiosis but monitor progress towards a CE from an economy-wide perspective at the national or higher scale. Only at this scale is it possible to also capture system-wide effects such as displacement or rebound effects (Geyer et al. 2016) and to assess whether absolute reductions in resource use and waste flows were achieved."***

The applied Eurostat classification is hierarchical with four levels and three subcategories. At the most aggregated level are the main *material categories* (1-digit level) which vary from MF.1 to MF.8. Each material category is broken down into *material classes* (2-digit level), which are further broken down into *material groups* (3-digit level) and finally down to *material sub-groups* (4-digit-level) (Eurostat 2022). On the most detailed level, EW-MFA data is accessible for 45 material categories, which can be aggregated into 16 and eventually four major material groupings.

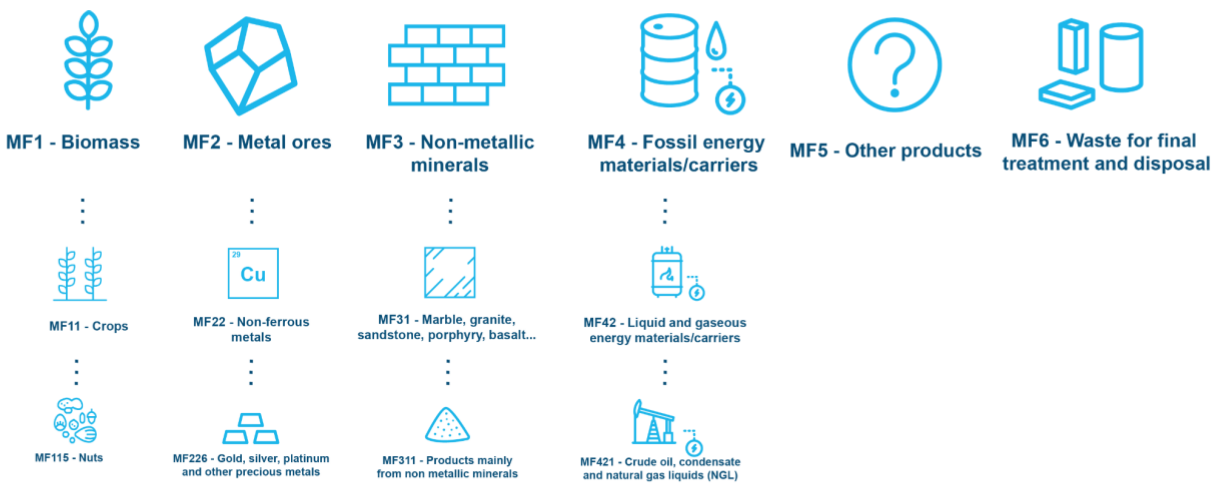

Figure 5 - Material scope for the UCA with exemplary items from MF material classes and groups

For the UCA method, materials categories MF1 to MF4, Biomass, Metal Ores, Non-metallic Minerals and Fossil Energy Materials/Carriers respectively, are at the centre of attention for the material boundaries. For the UCA, data for these categories and up until the 4-digit material group level are collected for domestic extraction, physical imports and exports, and DMC. Next to these general categories, the remaining big groups in the table of MF5 - Other products, MF6 - Waste for final treatment and disposal, SM_FIN - Stage of Manufacturing - finished products, and SM_SFIN - Stage of Manufacturing - semi-finished products are required in case a classification into the MF1-4 categories is unclear. Figure 5 illustrates the four big categories

(MF1-MF4) with some exemplary materials to get an understanding of the level of detail of the lower levels, while “Annex 1 - Material scope” provides the entire list of all materials.

Waste materials are also included in the material scope and draw their boundaries from the Eurostat waste treatment statistics. Major waste categories are following the classification of "Data from Eurostat waste treatment statistics [env_wastrt]" and include chemical and medical wastes, recyclable wastes, equipment, animal and vegetal waste, mixed ordinary waste, mineral and solidified waste, and metallic waste. See “Annex 2 - Waste material scope” for a complete list with all materials.

Once the system boundaries are defined, the selection of processes and flows included in the system definition have to be observed as well. The processes that are included in the MFA on the input side range from domestic extraction, imports and exports, to domestic material consumption. For the output side, the processes under study include the various different waste treatments subdivided by six treatment types: landfill disposal, deposit unto or into land, land treatment and release into water bodies, incineration/disposal, incineration with energy recovery, and recovery other than energy recovery.

2.1.4. Data collection

Having defined the system and its boundaries, data needs to be collected accordingly. Overall, preference is given to local, accurate and more recent data. If local data is not available, then Eurostat and EW-MFA data (env_ac_mfa) from the country level can be used or other regional data can be translated to the EW-MFA nomenclature and then be downscaled (the process will be detailed in the next chapter). It should be noted that if downscaling is needed, proxy data need to be collected as well. This holds true for waste data too.

Moreover, an alignment of statistics from material consumption to waste and emissions information is required for the EW-MFA assessment done here. While the relationship between MF codes and waste codes is important to match, this type of data is gathered using a variety of different scopes and definitions, without official concordances. However, in at least three publications, it was attempted to link them:

- Nuss et al. (2017) matched MF codes with Eurostat “Generation of waste by waste category, hazardousness and NACE Rev. 2 activity” statistics (env_wasgen).
- Jacobi et al. (2018) matched MF codes with waste (Austria) classified in NACE codes.
- Mayer et al. (2019) matched MF codes with Eurostat “Treatment of waste by waste category, hazardousness and waste management operations” data (env_wastrt).

To make the method work, the municipal waste data of the different cities will be linked as much as possible to the categories present in Eurostat (env_wastrt). Since the classification of municipal waste may vary between cities this linkage will have to be done ad-hoc.

The data collected is to be uploaded to the CityLoops Data Hub and entered in a template that is provided to the cities. A potential template could be the Eurostat questionnaire spreadsheet that countries have to fill in annually. However, Mayer et al. (2019) also provide an excel spreadsheet that they used for their data collection and framework, which can be found in their supporting information of the paper. It is seen as an enhancement of the EW-MFA questionnaire and has therefore been chosen as a template as it is more user-friendly and has indicators already built into it. After correcting some of the formulas and determining the numbers which are fixed, it is deemed ready to be filled in online by the cities. The template that provides ease of documentation of sources and assumptions will be adjusted for two reference years per study and extended by a tab to build the basis for the Sankey diagram.

2.1.5. Data processing

Following the data collection, the data needs to be processed. Through processing, the overall goal is to achieve mass balancing (see info box), which is not automatically included in a MFA by default, and to be able to then analyse the data (and prepare it for use in the CityLoops Data Hub). In order to achieve mass balancing and strive for a good level of data quality, a couple of conditions need to be met. Ideally, the data exists for the same reference year, the proper spatial scale, the correct materials and in weight-based units. If these conditions are not in place, or if this data does not exist for the needed system boundaries, then it needs to be obtained in a different manner.

MASS BALANCING

A foundational premise to conduct a MFA is the First Law of Thermodynamics, often known as the Law of Mass Conservation, asserts that matter is preserved after a physical transformation. As a result, calculations involving material and energy balances are necessary to arrive at final conclusions: total inputs in a city (import and domestic extraction) equals total outputs (waste and exports) plus net accumulation of materials in the system.

Based on this, MFA generally employs a mass balance approach (Eurostat, 2018) to quantify

1. inputs, such as domestic production and material imports;
2. intermediate products requiring further processing;
3. final products, such as consumer goods;
4. outputs, such as waste, direct and fugitive emissions, and exports; and
5. stock and durable goods accumulation within the economy.

The solution for getting data if units are not weight-based, but instead represent volumes, area, units or lengths, is to transform them with conversion factors into weight. When data does not fit to the system boundaries, then there are two ways to achieve that, namely (1) aggregation and disaggregation, and (2) downscaling. Both will be described in the following chapters.

Aggregation and disaggregation

Aggregation and disaggregation, as the names suggest, is the grouping or splitting up of data, respectively. Aggregation needs to occur if data exists on a more detailed level that is required or useful. For example, if the spatial data is on a neighbourhood level, then it has to be added up from all neighbourhoods to the city. Or if, e.g. trade data exists on a too detailed temporal scale such as quarterly or monthly, then it should be aggregated to a yearly time frame.

The same, but in reverse, goes for disaggregation. Disaggregation has to be carried out if the information is too general, e.g. if there is data on a material group that combines materials in a different way from the EW-MFA materials. Then informed assumptions have to be made, for example that this material group is made up of a certain percentage of the material of interest (e.g. 20% of imported food are cereals).

Downscaling

Aside from aggregation and disaggregation, downscaling is another means to adjust data from bigger spatial scales to the desired level. In doing so, it helps to surmount one of the major challenges faced when wanting to analyse the metabolic flows that pass through a city, namely the availability of statistical data at the required scale. The lack of statistical information on material flows at local and regional levels is also a difficult situation for applying the EW-MFA method at these levels (Sastre, Carpintero, and Lomas 2015; Voskamp et al. 2017). Due to the significant costs associated with data collecting at lower territorial levels, along with the limited incentives available to regional and local governments to monitor and minimise material consumption within their jurisdictions, official statistics on material flows at subnational levels are a rare occurrence. Additionally, the limited number of datasets accessible at these levels are not standardised, limiting their operability.

In order to overcome this situation, two approaches can be taken:

1. capture these data bottom-up, which in many cases are practically impossible due to their high cost and time required, and/or
2. top-down, taking data at a scale larger than that of the city and then, through statistical methods, downscaling it to the scale required for the study.

Putting aside the bottom-up approach as a sole pathway due to its impracticability, downscaling comes into focus. Statistical downscaling is the process whereby a statistical relationship is used to relate observed data at a larger geography to other variables at a smaller geography (Horta and Keirstead 2017), p. 296). Recent developments in statistical downscaling techniques have demonstrated that they can yield sufficiently robust EW-MFA estimates (Bianchi 2020; Bianchi, Cordella, and Menger 2022; Carlos Tapia et al. 2019; García-Guaita et al. 2018; Horta and Keirstead 2017; Rosado, Niza, and Ferrão 2014).

Given the difficulties of collecting data on suburban resource consumption in many cities, (Horta and Keirstead 2017) examined the possibility of applying statistical downscaling approaches to estimate local resource consumption from socioeconomic or other data sources. They evaluated six different types of downscaling methods: ratio-based normalisation; linear regression (both internally and externally calibrated); linear regression with spatial autocorrelation; multilevel linear regression; and a simple Bayesian analysis. Since some of these are very advanced in the calculations and assumptions that they require, and could not easily be carried out by cities themselves, the ratio-based downscaling method is deemed most suitable for the UCA.

Ratio-based downscaling

When researchers encounter a data lack during their local MFA investigation, they infer missing data using a single proxy (Barles 2009; Courtonne et al. 2015; Kovanda, Weinzettel, and Hak 2009; Niza, Rosado, and Ferrão 2009). This method is based on the premise that as resource consumption increases, production must increase to meet demand, resulting in a higher environmental impact. Therefore, ratio based indicators on production or consumption (so-called downscaling factors) are common in the literature due to their easy operability and effectiveness.

To give an example, by performing a combination of MFA and life cycle assessment method, (González-García and Dias 2019) quantified mass and energy flows within the city limits of Bilbao and Sevilla and derived urban environmental pressures. To do this, and because the data collected for Sevilla and Bilbao were not city-specific, average data were gathered at the national (building materials, except cement and sand) and regional (fossil fuels, water, food and drinks, cement and sand) levels and downscaled using proxies. A ratio-based downscaling approach was chosen due to its demonstrated simplicity and ability to aid in the understanding of resource consumption variations between cities. Thus, statistics at the regional level were downscaled to the city level, using the GDP as a typical measure of a city's citizens' purchasing power. Therefore, the regional level data were downscaled to city level based on the GDP of the city in relation to the average GDP of each region using the following equation:

$$Data_{city\ level} = \frac{GDP_{city}}{GDP_{regional}} * Data_{regional\ level}$$

Equation 1 - Downscaling equation based on GDP (González-García and Dias 2019)

In a simplified study of MFA combined with life cycle assessment, for the city of Santiago de Compostela, García-Guaita et al. (2018) also made use of the ratio-based downscaling method. To do so, they made use of different downscaling factors depending on the variable to be analysed:

- GDP was chosen to represent those resources that are inextricably linked to the city's economy: fossil fuels and energy consumption.
- The number of dwellings was used to calculate the consumption of products that are primarily consumed in households: food and beverages, including drinking water.

- Municipal water consumption was assessed by green surfaces (irrigation was considered as the only municipal water consumer).
- Road and air traffic were chosen as the primary modes of transport for the fossil fuels used in automobiles, and
- Municipal Solid Waste generation was downscaled using population.

Another interesting approach to downscale data on a regional scale is the use of the share of workers in a region. This approach has been used in several studies (Duarte Quartin 2016; Lavers Westin et al. 2020; Rosado, Niza, and Ferrão 2014) and is useful because it allows to analyse indicators for which data exists at a larger scale than the one under study and downscale them using the number of employees in a sector. For example, a linear relationship between DE and the number of workers for a particular economic activity might be assumed. In this case, the DE will be a percentage of the national DE that is equal to the percentage of national workers in that economic activity that are in the regional area If there is an absence of workers in an economic activity that maybe suggests that there is no extraction in that area (Rosado, Niza, and Ferrão 2014).

In a recent study, Lavers Westin et al. (2020) made use of the same downscaling approach and found that in addition to DE, the use of the number of employees can be used to estimate consumption. For this, they used data on imported products for which they had actual consumption values. For their calculation they made use of the following equation:

$$C_{x,r} = ER_{n,r} * DMC_x$$

Equation 2 - Consumption downscaling proxy (Lavers Westin et al. 2020)

where n = appropriate for product x sector, Cxr is the consumption of product x by NACE sector n in region r, ERnr is the employee ratio for NACE sector n and region r, and DMCx is the total domestic consumption of product x by NACE sector n in the country.

In light of the different downscaling approaches presented above, it was chosen to use ratio-based downscaling techniques due to their flexibility and ease of understanding, especially for use by less-advanced practitioners. The choice of the proxy to be used is conditioned by the availability of data, its scale and its intrinsic characteristics.

2.1.6. Output

The output from the material flow accounting is structured and documented data for a municipality/city, for two years, for a number of input and output materials and processes covering the entire system, from domestic extraction and imports to domestic processed outputs, waste and exports. Based on this foundation, further work products and results can be generated. One such important result is the use of the data for indicators, however these are presented in Chapter 3. The data can also be directly used for visualisations.

These data can be visualised in the form of Sankey diagrams. Depending on the data availability, these can be illustrated per single material group (MF1-4). Alternatively, they can also be colour-coded per stream and depicted in one Sankey diagram, much like the one from Eurostat (Figure 6).

Aside from the Sankey diagrams, other visualisations can be generated too. These typically focus more on single processes, e.g. the domestic material consumption or exports to represent the data in more detail or over several years, than what is possible in a Sankey diagram.

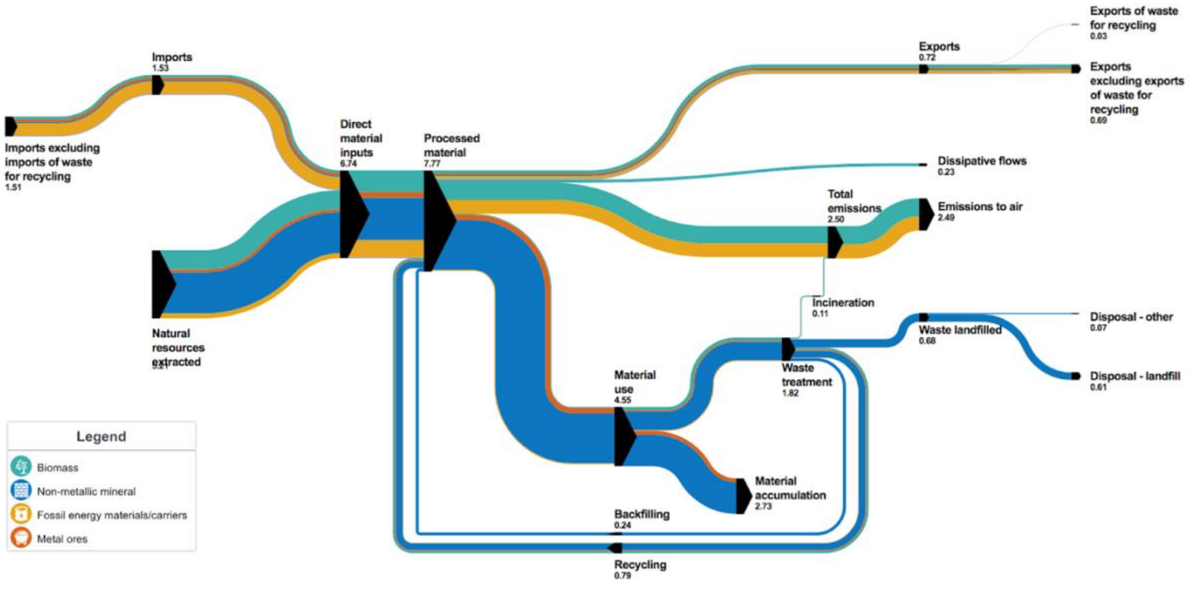

Figure 6 - Eurostat's Sankey diagram of four material groups (and values in Giga tonnes) for 27 countries in 2020 (Eurostat 2021)

2.2. Material Stock Accounting

Aside from the accounting of material flows, the material stock of cities will also be determined for the UCA. The motivation to complement the flow assessment with a stock assessment stems from the additional insights that can be extracted from the stock analysis as well as the unveiling of "real" circularity development that it might mask:

> ***"As long as additions to stocks grow at such high rates, even high EOL recycling rates will make a limited contribution to overall circularity. In order to be able to provide useful information for policy makers on how circularity can be increased, and where constraints to such aims are rooted, the inclusion of material stocks is required." (Joint Research Centre (European Commission) et al. 2017, 33)***

While the stock of many different materials, products or artefacts, e.g. vehicles, livestock, road network etc., can be assessed and provide respective actionable insights, the stock quantification in the UCA is limited to buildings (due to the focus of CityLoops on Construction flows). Due to time and work effort constraints of the cities carrying out the UCA, the stock assessment needs to be kept to a minimum. Since the built residential and non-residential housing stock is arguably one of the largest stocks that a city can have (for instance it is estimated to account for 84% of the total stock of Brussels (Athanassiadis et al. 2015, 111)), driving many inflows and outflows in the form of construction, renovation and demolition materials, it plays a vital role from a resource and circular economy perspective.

Specifically from the viewpoint of the CE, the analysis of the built environment stock brings various insights:

- To begin with, material stocks are a reservoir of materials. They absorb the additions of materials and act as a buffer until they are released once again. While the design of buildings for material reuse at their end-of-life is still quite rare, the CE strategy of overall building lifetime extension is taken advantage of and therefore materials are in use and stocks hold them for longer.
- The housing stock can be considered as a so-called urban mine. Instead of extracting materials from a traditional mine, buildings or parts thereof can be mined for their re-utilisation elsewhere. Consequently, by determining the material stock of cities, the reuse potential can also be assessed, working with building ages and estimations or assumptions of material lifetimes.
- Aside from the availability for reuse, the stock analysis can also help forecast the amounts (and quality) of construction and demolition materials. This way, it can help predict at which time and where certain kinds of materials become available and therefore plan waste management strategies.
- Finally, the analysis of stock can provide an estimation of materials that are going to be required in the form of future inflows, for renovations or new construction projects, informed by replacement rates and material lifetimes. This, together with the knowledge on outflowing materials has the potential to close material loops through local reuse.

2.2.1. Bottom-up material stock accounting

Following the elaboration on the importance of material stock assessment, this chapter will present the stock accounting method of the UCA. The method employed here is tried and tested and measures building stocks using a bottom-up approach (Stephan and Athanassiadis 2017). The method requires three main components (1) the location, land use and floor area of buildings, (2) building typologies and (3) building typologies' material composition. The next paragraphs present the four steps to quantify and spatialize the material stock, while under the chapter "Data collection and processing", it is specified how and where the respective data can be obtained.

Step 1: Find locations, land use and floor areas of buildings

The stock accounting method begins with finding the locations, land use specification and floor areas for all buildings of a municipality/city. The locations of the buildings enable the spatialisation of the material stock, meaning that it can be illustrated on a map (and by materials) for the entire municipality. Typically, the land use of the building, such as for use as retail, office, residential space etc., is provided with the location as well. (There may be cases where a building has multiple uses, but in this step a single, predominant land use for each building is identified). Further, the floor areas are needed to be able to calculate the amount of materials, together with the material composition (from step 3).

Step 2: Gather building typologies

In the second step, building typologies have to be defined. Building typologies, also known as archetypes, represent different types of construction technologies or methods and are classified by buildings' land use, height and year of construction. These typologies need to be found or defined, because each has its own material composition. For example, a single family house from the 1930s is very distinct from a high-rise apartment building of the 1960s, or a new low-rise office building (in terms of material composition (t/m^2)).

Step 3: Determine building typology's material composition

Building on Step 2, the material composition needs to be determined for each building typology. This essentially links typical types of materials and their amounts to typologies. The varying compositions need to be carefully accounted for, as the different construction methods (of the various building typologies) have different material needs and material "density". For instance, low rise and high rise residential buildings do not have the same structural needs. High rise buildings will have a tendency to be more material intensive per m^2 (especially for the structure). In addition, the year of construction can also be crucial, as for example certain materials such as asbestos or lead used to play a more significant role, compared with today or reinforced concrete may play a larger role than bricks now. Depending on the country, and even the region, the material composition can be quite distinct, depending on availability of local materials, stage of economic development, building methods, climate, etc. Therefore, each building typology has a material composition associated with it in t/m^2 that needs to be found.

Step 4: Calculate material stock and spatialise it

In the last step of the stock accounting method, data from all the previous steps are employed to obtain two main results: (1) The total quantity of materials in a typical building of each typology is determined by multiplying the gross floor area (per typology) in m^2 by the material composition (per typology) in t/m^2. (2) The results are spatialised, by combining the stock with the location and land use data to make choropleth maps. These results, can help with answering the question "where material stocks cause flows and [in what] volume?"

2.2.2. System definition

The system definition is, just like for the MFA, an essential part for the MSA in order to delineate the boundaries and processes that are included for the data collection and analysis. As for the spatial and temporal boundaries, the MSA of the UCA method branches the entire municipality and the accounting is done for one year. While the exact year is not of too great importance, since the building material stock typically does not change drastically over time, it should be close in time to the two reference years of the MFA, in order to get a sense of proportionality between the flows and stocks.

As for the object of study in material terms, the MSA focuses on the built environment and specifically on residential and non-residential buildings. Therefore, other urban infrastructure such as bridges, roads, railways etc. are excluded. The material scope that can be addressed within those buildings depends on data availability. In principle, the materials should mirror or be as close to reality as possible, which means that depending on the city and building styles, it could be between three or ten materials. Therefore, neither a set amount nor the kind of materials, e.g. concrete or wood are defined beforehand. Due to the unknown data availability in different contexts, the results between the EW-MFA nomenclature and the MSA part will not be consistent but rather similar. Materials that are excluded are those that are embodied, such as water, energy and GHGs emissions.

Finally, the processes that are included in the MSA are, by nature, more static than those of the MFA, since the existence of a stock is not active. This “passive process” does include the observation of the built-up area. An additional process that can be included, based on data availability, is that of renovations, to reflect the current state of the stock, as opposed to that of the original building plans.

2.2.3. Data collection and processing

To comply with the system definition and carry out the method, the corresponding data have to be collected. It is recommended that the data collection process follows the same sequence as the MSA method steps. This is to be able to quickly identify data gaps and determine if additional data collection and processing are required. Since the two steps of data collection and processing are intrinsically linked, due to their dependency on each other, they are described in this one chapter and schematically illustrated in Figure 7.

As was outlined before, what needs to be obtained overall are:

1. Locations, land use and floor areas of all buildings in the municipality
2. Building typologies: definition and assignment per building
3. Building typologies’ material composition
4. Calculation of material stock and spatialisation

The collected data can be uploaded in the CityLoops Data Hub. The processing of the data for the final output will be described during the UCA facilitation.

(1) Locations, land use and floor areas of buildings

The first step in the data collection should begin with contacting the local or national cadaster. From there, files on land use and building footprint/geometry should be obtained. In a number of cases, these two pieces of information are grouped in one database. Oftentimes, they come in the form of a GIS shapefile, containing land use (retail, office, residential etc.), gross floor area in m², height or number of stories, number of façades, date of construction and if possible, the latest year of renovation for each building in a city.

If such data does not exist or cannot be derived from the cadaster or a similar institution, building footprints and in some cases also the building use (residential, commercial, industrial etc.) can be extracted from the Open Street Map (OSM). It should be taken into account that data from this source will be bottom-up and collaborative and not an exhaustive list for all buildings, whose classification may conflict with urban planning.

(2) Building typologies: definition and assignment per building

Building typologies that exist for and within the city have to be identified next. This work probably has to be done on a country level, as it is unlikely that a city has its own list of typologies, but it is worth exploring that first with the respective department (e.g. urban planning).

If a city does not have its own building typologies, it can consult its national residential building typologies from the TABULA and EPISCOPE projects WebTool, see Figure 8 (TABULA 2022). (The webtool does have data for Denmark, the Netherlands, Norway and Spain, but not for Finland nor Portugal, the corresponding countries of the CityLoops cities.) When using the typologies of these two projects, they need to be matched with those of the cadaster's land use classification, for the correct calculation in method step 4.

For cities that do not have the building typologies in the TABULA WebTool, the next step of the search can be in looking for scientific articles or other publications on building typologies, for the respective city's country or with large cities of that country in the publication's title.

Finally, if this search is not fruitful, a more complex option remains, which is the creation of own typologies for the UCA. Using the information from the city's land use and building footprint database (from step 1) building typologies can be put together. These should have land use, height, and year of construction as their distinguishing parameters. For example, Stephan & Athanassiadis (2017) took advantage of the "Census of Land Use and Employment (CLUE) database" of Melbourne, Australia to create 47 archetypes, using "the floor area by land-use, the age and the number of stories for each of the 14,385 buildings within the city council" (Stephan and Athanassiadis 2017, 13). This many archetypes might not necessarily be needed for a smaller or younger city, but the applied approach for establishing them remains the same.

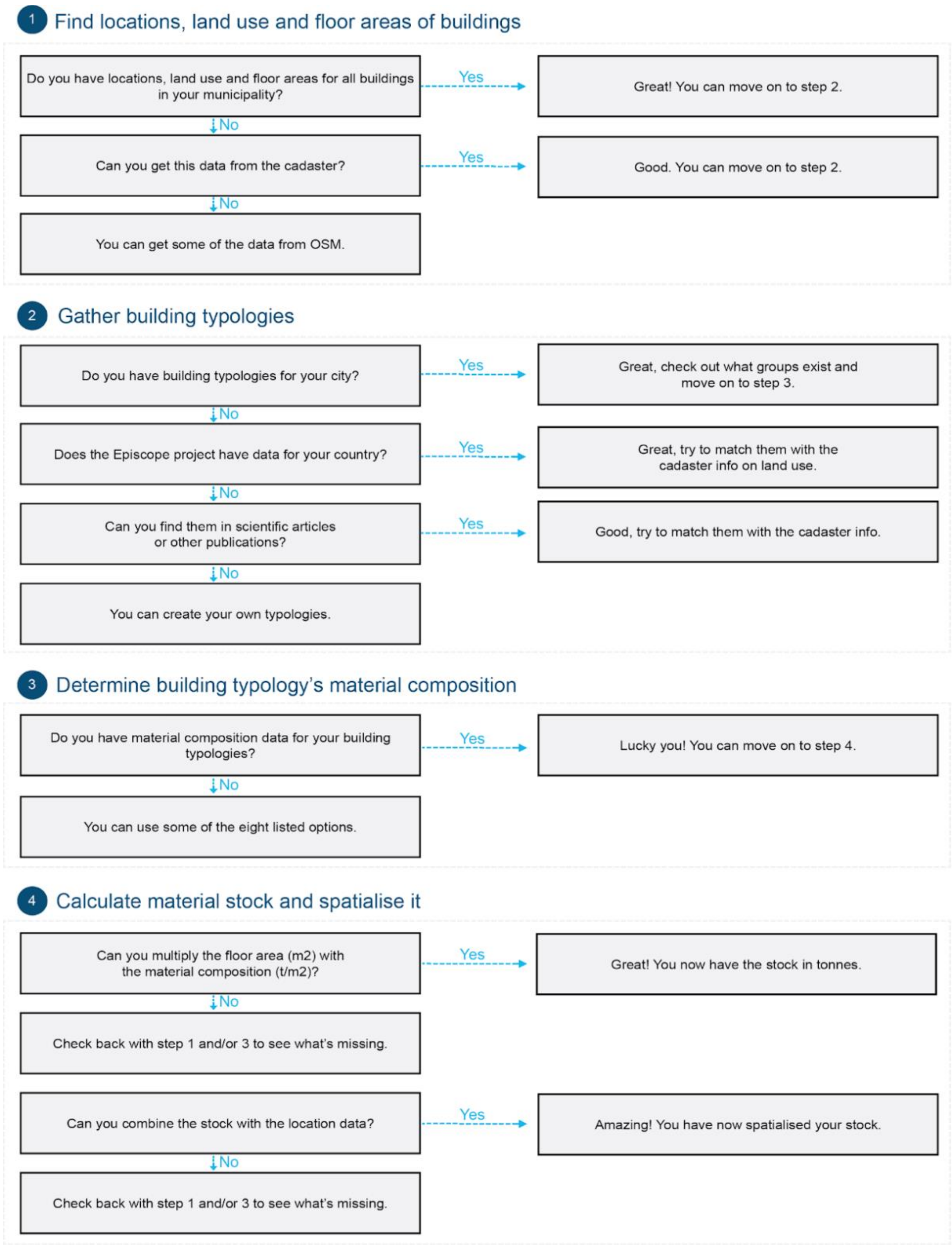

Figure 7 - The four data collection and processing steps of the MSA

Once the building typologies are established, they then need to be assigned to the buildings. In the end, each single building should have one corresponding building typology.

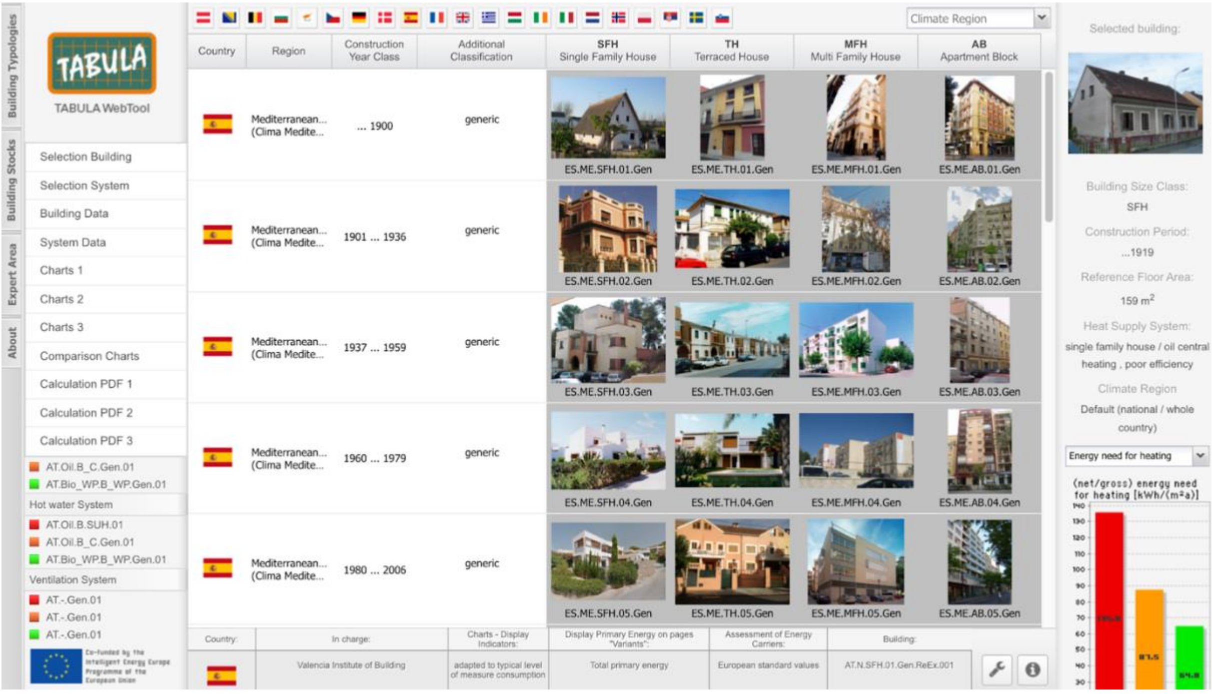

Figure 8 - Screenshot of the TABULA WebTool with building typologies of Spain

(3) Building typologies' material composition

Lastly, in terms of data collection, comes the finding of the building typologies' material composition. For determining the material composition or also material intensity, a couple of options exist:

- Obtaining the original bill of quantities of one building typology from large construction companies that have had a presence in the city for a long time.
- Getting architectural plans of a building typology and pictures to roughly estimate the materials used per m².
- Receiving architectural plans from new constructions, which may be more easily available, especially those built for the city departments or those that use newer typologies.
- Consulting existing scientific articles or case studies.
- For example, Sprecher et al. (2022), "present a database on the material intensity of the Dutch building stock, containing 61 large-scale demolition projects with a total of 781 datapoints, representing more than 306,000 square meters of built floor space".
- Using old architectural magazines or old urban development books that state which and how materials were used during a certain period of time.

- Performing a visual inspection and measuring surface area and thicknesses of materials.
- Employing good data of sorted waste from a building that was demolished from a certain typology and reverse engineering the material intensities (t/m²).
- If available, using material audits conducted by cooperatives or real estate companies of their buildings, preferably in a Building Information Modelling (BIM) format. These are different from pre-demolition audits, which often just focus on the small amount of materials that are going to be reused.

(4) Calculation of material stock and spatialisation

As was described in the method steps, the fourth and last step involves calculations and spatialisation. From a data collection and processing perspective, this means that the data gathered in the previous steps need to be prepared and aligned. Ideally, they are put into one excel sheet to link the information. The columns could look like in Table 2, where by adding up the material weight horizontally, the total weight of a single building can be derived, while the vertical summation reveals the total mass of one material (e.g steel) for all buildings and the entire “weight of the city’s buildings”.

For the spatialisation, the same data from Table 2 is then linked to a GIS shapefile that also contains the ID number of the buildings and their locations. This allows for the generation of maps, which are shown in the output chapter below. In principle this data can also be aggregated to a higher spatial scale, such as neighbourhoods or postcodes to produce other maps and obtain insights on a different level.

Table 2 - Material stock accounting structure for collating information, here with the example of two buildings, a single-family home (SFH) and a new bakery

ID of building	Land use	Construction year	Building typology	Floor area (m²)	Steel weight (tonnes)	Concrete weight (tonnes)	Total weight (tonnes)
1	Residential	1987	SFH [1980-2000]	120	5	8	13
2	Commercial	2022	Retail, low-rise [2015-2022[	90	10	16	26
Total	-	-	-	210	15	24	39

2.2.4. Output

The output from the material stock accounting is structured and documented data on building material stock for a municipality of one reference year, with the amount and kind of materials per building dependent on the local data. Based on this output, a number of visualisations can be generated to make the data better communicable and easier to understand.

The most comprehensive visualisations that are produced from the MSA data are choropleth maps. With the combination of spatial data, i.e. the location and outline of buildings, as well as building (material) data the information can be spatialised and therefore mapped, illustrating various details with the help of colour grading. Again, depending on the data, these maps are ideally produced on the building level, but the scales of postcodes or neighbourhoods are also possible when spatially accurate data are not available.

The online UCA report will include a live and interactive version of the map, while the PDF version of the report features images for the total mapped materials, single materials of interest (Figure 9) as well as maps of building age (Figure 10) and building typology distributions (Figure 11).

In addition to the choropleth maps, other charts can of course be produced with the building data as well. These include more common and easily generated visualisations in the form of bar or pie charts, for example. These will be employed in those cases where they can provide additional insights.

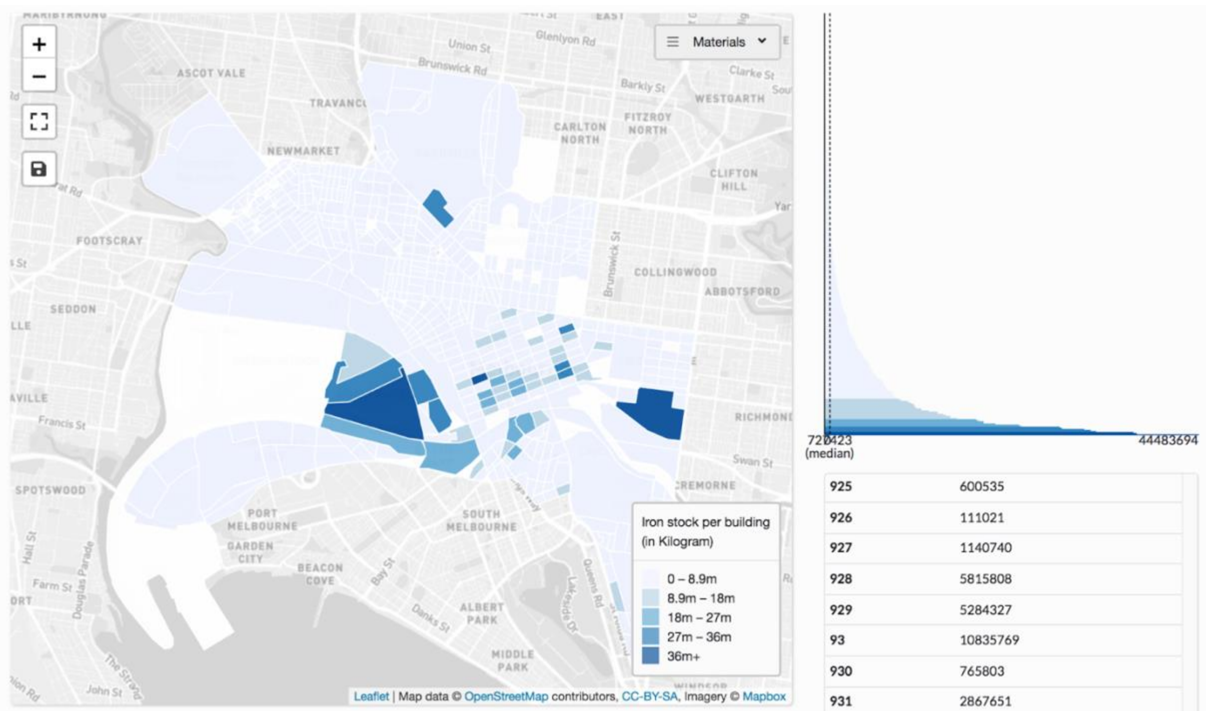

Figure 9 - Example of the material content map: iron content of building blocks in Melbourne, with bar chart on the right showing the distribution in quintiles (i.e. split into 20% of observations) (Metabolism of Cities 2022)

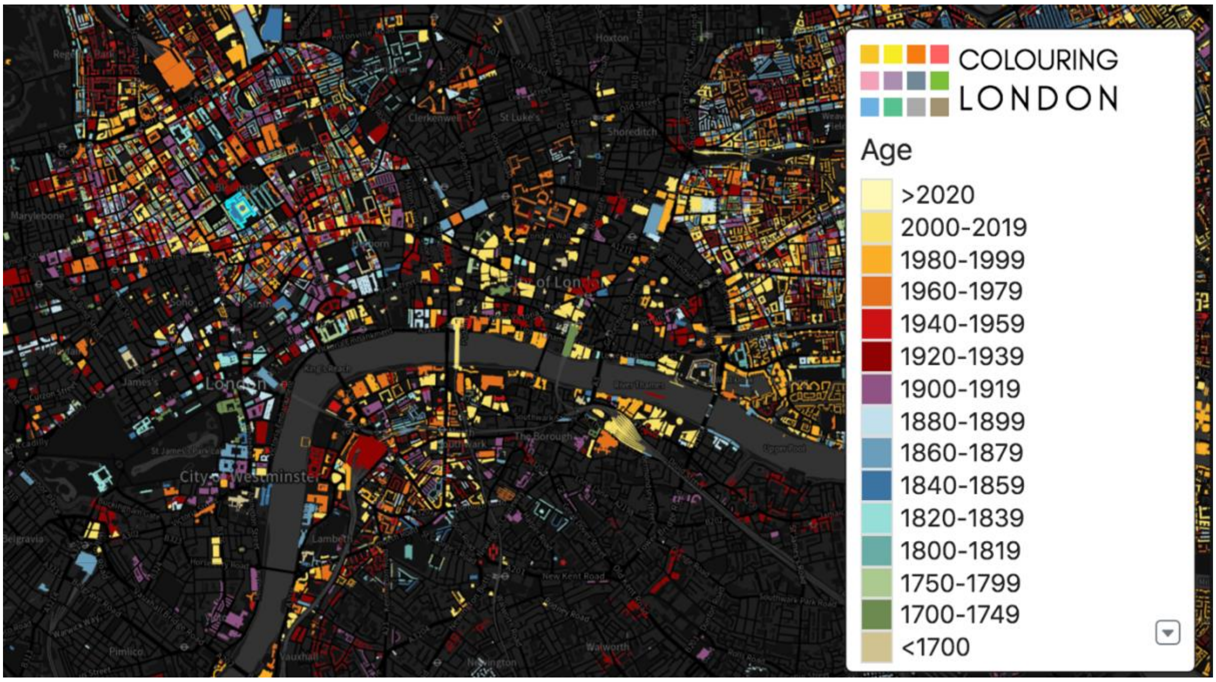

Figure 10 - Example of building age distribution map, in London (Colouring London 2022a)

Figure 11 - Example of building type distribution map, in London (Colouring London 2022b)

3. Analysis of Flows and Stocks: Measuring Indicators

The analysis of flows and stocks, after the materials have been quantified, is the next essential step of the UCA method. The assessment is supported by indicators, which use the output of the accounting and are calculated to reflect the status of progress towards a circular economy in the city. Fortunately, the definition of both a circular economy (CE) and a circular city already exist for this project, in Deliverable 6.1, as do a number of indicators. While the UCA builds on those, the indicator selection had to be re-evaluated and adjusted for the UCA.

This chapter first recapitulates the CE and circular city definition, to set the scene. It then describes the indicators for the UCA.

3.1. Circular Economy and Circular City definition

"As is commonly known among circular economy experts, there is a plethora of existing definitions of "circular economy" and with them, associated values, pathways, and schools of thought. While a lot of effort was put within this WP and WP6 to develop a common circular economy definition this report will not go into detail of this situation and simply presents definitions for circular economy and a circular city, which have been agreed upon for CityLoops. The work was first presented by Vangelsten et al. (2020, 11) in "D6.1 Circular City Indicator Set", where more information can be found on arriving at those" (Bellstedt, Athanassiadis, and Hoekman 2021, 7).

CIRCULAR ECONOMY DEFINITION
The Circular Economy is a regenerative system in which resource input, waste and emissions are minimised by slowing, closing, and narrowing material loops. This can be achieved by cooperative approaches, reuse, adaptation, resource stewardship, stock management, sharing, and other new business models that foster longevity, renewability, refurbishment, capacity sharing, dematerialisation and recycling and are induced by multi-stakeholder and multi-sectoral collaboration with the ultimate aim to increase resilience and maximize ecosystem functioning and human well-being.

CIRCULAR CITY DEFINITION

"A circular city is one in which

3. The local government, civil society, businesses, the research community and other local stakeholders collaborate to promote the transition from a linear to a circular economy. This means in practice:
4. fostering business models and economic behavioural patterns that maintain the value and utility of products, components, materials and nutrients for as long as sensible, in order to
5. close material loops and minimize as much as possible harmful resource use and waste generation locally, and thereby
6. improve human well-being, minimize net environmental impacts, protect and enhance biodiversity, and promote social inclusion, both within the city and globally, in line with the sustainable development goals."

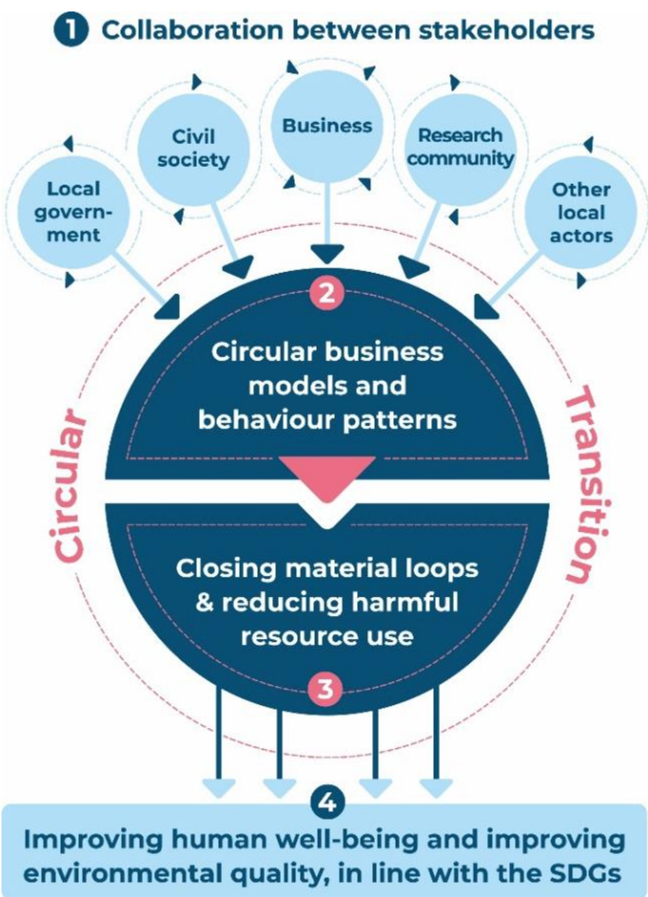

Figure 12 - The four Vision Elements of the Circular City vision and causal links for CE transition (Vangelsten et al. 2020)

“Studying both definitions, it can be seen that the circular city definition is derived from the circular economy definition. To better highlight the circular city definition, Figure 12 visualises it and its four Vision Elements, illustrating how they are connected and all needed to enable a circular transition” (Bellstedt, Athanassiadis, and Hoekman 2021, 8).

For the UCA method, just like for the SCA, the focus lies on Vision Element 3 “Closing material loops and reducing harmful resource use”. This objective can be supported by the accounting of the many different materials in the MFA and MSA, unveiling its status quo through respective indicators.

3.2. Indicators

Aside from a plethora of circular economy definitions, there are also a great number of circularity indicators and indicator frameworks that have been developed for several spatial scales and types of activities. After briefly presenting the function of circularity indicators, this chapter will present the indicators used for the UCA.

3.2.1. Function of circularity indicators

At its core, the role of indicators is to "simplify, focus, and compress the immense complexity of our changing environment to a manageable amount of relevant information" (Bîrgovan et al. 2022). Cities that are trying to adopt a circular economy strategy also have discovered the need for indicators to track and report their progress. However, the lack of data for such indicators is often an obstacle for towns implementing a circular economy strategy. Without this hindrance, cities could more easily self-assess their achievements, identify hurdles and possibilities, and adjust their growth trajectory towards circularity by measuring their performance.

Considering the above, a realistic framework of indicators for a circular economy transition in cities is required to assess progress and performance and, if necessary, alter ongoing activities. According to (Nigohosyan 2019), such a circular economy framework should aim to:

- **Support performance assessment:** Indicators are the foundation of monitoring as they quantify and aggregate data that helps track various elements of the Circular Economy;
- **Support policy-making:** Ensure evidence-based urban planning and management of the Circular Economy;
- **Support accountability and Circular Economy promotion:** Provide information on the progress of cities towards the Circular Economy and its benefits, which can be communicated to citizens
- **Support improvement:** Indicators can aid in identifying important success factors and best practices for the transition to a more circular economy.

Indicators that are based on the MFA serve to identify the inefficient use of natural resources, energy and materials at a macro-level. As a result, indicators are among the most important tools for monitoring the development of resource efficiency as well as long-term sustainability and policies related to those. Resource flows can provide a holistic picture of their movements through the economy, while associated indicators can mirror that situation in a way that is less abstract and more easily communicable. In addition, the indicators can illustrate how material flows shift within and between regions.

As has been described in the chapters above, an MFA can disclose not just the types and quantities of natural resources coming into the economy, but also what happens to materials as they travel inside and outside of the economy, and how this relates to resource productivity and environmental burdens. It can also allow for the analysis of a region's environmental impact from its economic operations and estimate how material-intensive its economy is.

3.2.2. Indicators for the UCA

For economy-wide material flow accounts, a large number of indicators can be derived and are already predetermined, as illustrated in Figure 3. They provide a comprehensive description of the biophysical metabolism of societies, describing material use at several stages of economic activity, from material extraction to international trade and material consumption to waste and emission production.

Furthermore, indicators can be classified depending on the scope of the material flows:

- Indicators based on accounts of direct material flows, i.e. domestic material extraction and physical imports and exports
- Indicators based on indirect material flows considering unused material extraction

Indicators based on direct material flows are the most often utilised MFA-based indicators in policy processes at present. Indicators of direct material flows do not account for all global material flows associated with final consumption in a country or region, as indirect (or embodied) materials of imported and exported products are not considered. In a globalised economy, supply chains are becoming increasingly far-reaching and complex, frequently including a significant number of countries throughout the life cycle of a product. As material flows can be located in different world locations, indicators of direct material flows cannot account for the actual environmental repercussions created by the consumption of certain products.

Regional material consumption, as assessed by the DMC indicator, can presumably be reduced by outsourcing material-intensive extraction and processing. In addition, it must be stressed that measures of direct material flows do not account for unusable materials from extraction, such as overburden from metal or coal mining or agricultural harvest wastes. However, these unutilised material flows result in a variety of environmental stresses, including water contamination and changes to the terrain. Due to the difficulty of gathering data on unutilised material extraction at the city size, only direct indications are utilised.

The EW-MFA method (Eurostat 2001b) and Mayer et al.'s framework (2019), which were also applied to the case of Flanders (Maarten and Vercalsteren 2020) provide a great variety of indicators. These examine two primary outputs when applied on a scale larger than the city scale: flows to nature (DPO) and exports. It then infers indirectly that flows to nature are domestic (at least at the time of their emission). On a regional or local scale, this assumption is no longer accurate. Cities rarely dispose or manage (all of) their liquid or solid wastes locally. Frequently, wastewater treatment plants, sanitary landfills, and waste incinerators are situated many kilometres away from the administrative borders of cities. Consequently, wastes can be termed exports, and so can flows to nature, at least partially. Carrying out a EW-MFA, without taking this into account, would create a bias by minimising flows to nature, as they would be limited to the locally emitted portion of those flows; it would also minimise recycling, as it often occurs outside the city; and it could minimise total exported wastes, as they are not accounted for in trade exports (wastes + other exports), as some of the statistics that are frequently used to evaluate exports do not account for wastes (for instance wastewater transported outside the city by sewage pipes). Thus, certain flows had to be characterised for the analysis:

- exports were separated into wastes exported and other exports,
- flows to nature were separated into local and remote flows,
- and recycling was separated into local and remote recycling.

According to (Barles 2009), an adjustment is also required for the DMC when assessed at the regional scale.When DMC is studied at the local scale it does not accurately reflect in a socio-economic sense being minimised due to the increase in exports due to waste exports. To overcome this problem waste exports can be subtracted from total exports as well as subtracting waste imports from DMI.

Consequently, in addition to taking these characteristics into account, it is proposed to add two indicators that (Barles 2009) designed for this purpose, DMCcorr and LEPO.

Taking into account the definition of the circular city and, in particular, vision element 3 "Closing material loops and reducing harmful resource use", a set of indicators has been selected to measure this purpose. For this purpose, the indicators that best fit to the object of study and scale, measuring circularity at the city scale, have been selected and adapted according to the existing literature. To this end, several EW-MFA indicators as well as some of those proposed by Mayer et al. (Mayer et al. 2019) and additional one for material stock have been selected, as shown in Table 3.

They have been classified into two main categories: indicators of scale and indicators of circularity. Indicators of scale allow dimensioning urban metabolic flows, while indicators of circularity allow analysing the degree of loop closing and its efficiency. Furthermore, the indicators have been classified into input/output-side indicators to facilitate their understanding and into eight different dimensions: Input and output, City correction, Interim flows, Material loop closing, Balance, Rates, Efficiency and Intensity.

Table 3 - CityLoops circularity indicators for the UCA

CityLoops indicators	Dimension	Input side indicator	Output side indicator
Scale indicators	**Input and output**	Direct Material Input (DMI)	Domestic Processed Output (DPO)
		Domestic Material Consumption (DMC)	-
	City correction	Domestic Material Consumption corrected (DMCcorr)	Local and Exported Processed Output (LEPO)
	Interim flows	Processed materials (PM)	Interim outputs (IntOut)
	Material loop closing	Secondary Materials (SM)	
	Balance	Net Addition to Stock (NAS)	
		Physical Trade Balance (PTB)	
Circularity	**Rates**	Input socioeconomic cycling rate (ISCr)	Output socioeconomic cycling rate (OSCr)
		Input ecological cycling rate potential (IECrp)	Output ecological cycling rate potential (OECrp)
		Input non-circularity rate (INCr)	Output non-circularity rate (ONCr)
	Efficiency	Material productivity (MP)	
	Intensity	Material intensity (MI)	

3.2.3. Indicator definitions and accounting rules

The indicators that were selected for the UCA (Table 3) are all quantitative indicators that are aligned with the data collection for the MFA. They are either measured in tonnes or expressed as ratios. To understand them better, each definition of the indicator as well as their accounting formulas are stated below in Table 4.

Table 4 - CityLoops circularity indicators for the UCA, with their definition and formulas

Indicator name	Description	Formula
Direct Material Input (DMI)	Consists of domestically extracted materials (domestic extraction [DE]) and imported raw materials and manufactured goods.	DMI = DE + Import
Domestic Processed Output (DPO)	DPO measures the total mass of materials removed from the domestic environment or imported that are returned to the environment after usage in the economy. These flows take place at the processing, manufacturing, use, and disposal stages of the production-consumption chain. Included are air pollutants, industrial and household wastes deposited in landfills, material loads in wastewater, and materials spread as a result of product use (dissipative flows).	DPO = DPOemissions + DPOwaste DPOemissions = eUse − solid and liquid wastes DPOwaste = EoL waste - SM
Domestic Material Consumption (DMC)	DMC quantifies the entire amount of material utilised directly in an economy (i.e. excluding indirect flows).	DMC = DMI - Exports
Domestic Material Consumption corrected (DMCcorr)	Modified DMC that is calculated by excluding exported wastes from exports and imported wastes from DMI.	DMCcorr = DMI - imported wastes - exports except waste
Local and Exported Processed Output (LEPO)	LEPO is a measure of the local and exported flows to nature. For its calculation, solid and liquid wastes are separated into two categories: locally treated (or discharged to nature) and exported. The flow was further separated into flows to nature (emissions to air and water, landfilling, and dissipative use) and recycling for each category. Locally treated solid and liquid waste flows were joined to other local flows to measure domestic processed output (DPO). The sum of the exported processed outputs to nature from remote treatment was calculated. This flow was added to DPO to get LEPO.	LEPO = DPO + exported flows to nature
Processed materials (PM)	PMs are defined as the sum of DMC and secondary material (SM) inputs. PMs were either designated for energetic or material use. It further indirectly denotes recycled materials. The terms PM and DMC are used in this method specifically to describe either the inclusion or exclusion of secondary materials respectively.	PM = DMC + SM
Interim outputs (IntOut)	Measures wastes and emissions before diversion of materials for recycling and downcycling.	IntOuts = EoL waste + DPO emissions

Secondary Materials (SM)	Secondary materials refers to the amount of materials, which undergo material recovery including downcycling and cascadic use of materials.	SM = EoL waste - waste after recycling
Net Addition to Stock (NAS)	Net Addition to Stock is used to close the material balance in the absence of known in-use stock. There are two ways of determining it. (1) The following three steps are necessary for its calculation: 1. Total EoL waste from mUse needs to be consistently separated into discard, demolition, and throughput waste flows. The total EoL waste from mUse can be calculated. While waste statistics include building and demolition debris, they do not include EoL waste, which includes abandoned long-lived objects like furniture, automobiles, and appliances. 2. Determine the quantity of discard and demolition as the difference between the fraction of throughput materials (i.e., materials with a life duration 1 year) and the EoL waste from mUse (e.g., waste from packaging, paper, food waste, etc.). 3. NAS is then calculated as the difference between "Gross additions to stock" and "Demolition and discard". (2) NAS can be also calculated as the residual of the identity for the material balance. Consequently, NAS would contain all inaccuracies in the calculation. It is possible to immediately calculate material stock and changes in material stock using a combination of bottom-up and top-down accounting principles, allowing for material balance quality checks. The material balance also exposes crucial relationships between the various indicators and indicates whether an economy invests in developing physical stockpiles or is fueled by a high throughput of materials (UNEP, 2021).	(1) NAS = Gross addition to stock - Demolition and discard (2) NAS = DMC + Balancing items input - Balancing items output
Physical Trade Balance (PTB)	Physical Trade Balance of a region. Net imports indicate greater imports than exports, whereas net exports indicate greater exports than imports.	PTB = Import - Export
Input socioeconomic cycling rate (ISCr)	Input Socioeconomic Cycling rate measure the contribution of secondary materials to PM	ISCr = Share of secondary materials in PM

Output socioeconomic cycling rate (OSCr)	Output Socioeconomic Cycling rate measure the contribution of secondary materials to IntOut	OSCr = Share of secondary materials in IntOut
Input ecological cycling rate potential (IECrp)	Input Ecological Cycling rate potential measure the contribution of DMC of primary biomass in PM	IECrp = Share of DMC of primary biomass in PM
Output ecological cycling rate potential (OECrp)	Output Ecological Cycling rate measures the contribution of DPO from biomass in IntOut	OECrp = Share of DPO of primary biomass in IntOut
Input non-circularity rate (INCr)	Input Non-Circularity rate measures the contribution of eUse of fossil energy carriers in PM	INCr = Share of eUse of fossil energy carriers in PM
Output non-circularity rate (ONCr)	Output Non-Circularity rate measures the contribution of eUse of fossil energy carriers in IntOut	ONCr = Share of eUse of fossil energy carriers in IntOut
Material productivity (MP)	Material productivity is defined as the ratio between GDP and DMC. It indicates the economic value generated per unit of material consumption. Over time, the indicator illustrates whether decoupling of material use from economic growth is achieved. This indicator is also called resource efficiency.	MP = GDP/DMC
Material intensity (MI)	Material intensity is defined as the ratio between DMC and GDP. It indicates the unit of material consumption required per unit of economic value.	MI = DMC/GDP

4. Analysis of Indicators: Assessing Circularity

Following the second main method step and chapter on the measuring of indicators, this chapter will be the last chapter and present the third step of the UCA method: The assessment of circularity through the analysis of indicators. The overall idea of this step is to analyse and understand the data. The nature of the analysis is rather qualitative, due to the restraints of resources, as a more quantitative assessment would require more data for comparison. The following sub-chapters introduce the ways in which benchmarking, focusing on trends, by comparing data in time and relating data to the local context assist with the interpretation of indicators.

4.1. Interpretation of indicators

Since "one cannot improve what cannot be assessed," policymakers, practitioners, and scholars emphasise the importance of monitoring frameworks for the circular economy. Indicators help us to understand the raw data. They help us to make sense of it and give it context, as well as to understand its possible relationships in a systemic way.

To determine whether an indicator shows progress towards a desirable state, it must contain at least one of two characteristics: either (1) evolution over time; otherwise, it is merely a snapshot in time; or (2) a certain proportion or rate that may be compared to official goals, such as EU targets.

1. **Evolution over time**: To analyse evolution over time, data from at least two periods in time (in the past) that are at least five years apart are necessary. Even better would be to have data for a longer period, such as every five years for twenty years, for a total of four data points.
2. **Goals:** Numerous indicators can be tied to EU or national objectives. This provides a clear sense of the city's standing and contribution.

In general, it is also beneficial to collect and analyse both direct and indirect indicators. Since indirect indicators are frequently presented as a percentage (share), which is not indicative of the amount or significance of a flow but is instead influenced by direct indicators, both sorts of indicators provide context for one another (Bellstedt, Athanassiadis, and Hoekman 2021).

A framework of indicators has been proposed, consisting of nine indicators of scale (direct indicators) and eight indicators of circularity (indirect indicators). Since at least two time periods will be analysed for all indicators, it will be possible to analyse their evolution over time, allowing for the analysis of trends. Unfortunately, due to the lack of EW-MFA at a city scale there are no goals or benchmarking of the direct indicators at the city scale. However, as the selected scale indicators are aligned with the EU monitoring framework for the circular economy, they can be compared with those calculated at the national scale making use of a population proxy. The performance of cities can then be compared with the country they are part of, as well as with other countries.

4.2. Relating findings to local situation

When an urban circularity assessment is carried out, it is necessary to not only analyse flows and stocks and calculate indicators, but also to understand the context in which they take place. This is because the context, in this case, the cities and their hinterland, provide a crucial and unique set of circumstances and situations.

Cities play an important role in the transition to a circular economy. It is here where most of the impacts associated with their high appetite for materials and energy occur, by being growth engines that require monitoring and control. Cities act as aggregators of materials and energy consuming more than 70% of global natural resources, emitting more than 70% of global emissions and generating almost 50% of global waste (Bîrgovan et al. 2022).

Despite the fact that cities are one of the primary causes of the unsustainable scenario in which we find ourselves, they are also one of the best places where circularity strategies can be formulated and implemented. This is because cities act as magnets for creative potential and innovation. Furthermore, they have the ability to respond more rapidly to pressing local issues compared to a national government, thereby facilitating the transition of society towards a circular economy bottom-up. Therefore, they are among the most influential actors that can positively affect their sphere of influence, if they adopt circular strategies.

After carrying out the diagnostic phase of the UCA by capturing all available data, processing and analysing them, the proposed indicators can give us an idea of both the material and energy dimension of the city, as well as metrics that allow us to understand the state of circularity of the region. While this is done with top-down and quantitative approaches and encourages data-driven decision-making, it is necessary to combine this with bottom-up and qualitative approaches that allow to understand the nature and size of the problem under study. It enriches the analysis, but more importantly, it provides a better understanding in order to be able to subsequently outline the best suitable strategy to meet the local challenge.

For example, if a municipality has abundant resources, e.g. timber from new forestation and also a demand for construction materials that normally have high embodied environmental requirements, it could use local sources instead. To be more specific in the example, there could be substitution of steel beams with wooden beams in the renovation of the built environment or use for new housing to replace higher environmental impact materials with wood, where feasible. It could also have the added side-effect of bringing back into focus cultural and social aspects of vernacular architecture and traditional, less harmful building methods and materials.

Thus, when conducting an analysis and interpreting the indicators, the context of a city and its associated strategy need to be taken into account. This is to say, data helps us to size the problem, but knowledge of local circumstances helps to enrich the analysis and the search for solutions. As a result, when the quantified stocks and flows are integrated with qualitative information, actionable knowledge is created. Finally, as an urban circularity analysis should be context dependent, the collaboration of all stakeholders in both the analysis and implementation of the strategy will help in achieving a more just and circular city.

4.3. Assessing the circularity of a city

A city can never be fully "sustainable" as it cannot rely on the self-sufficiency of nearby resources. Analysing a city as a living organism is a popular approach to examining the environmental sustainability of a city, to at least measure its trajectory towards goals such as material circularity (circular economy), Sustainable Development Goals (SDGs), or constraints of planetary boundaries. The complex systems that a city possesses are observable in terms of the matter and energy that it consumes to maintain its vital activities, thereby characterising its metabolism, the accumulation of materials, and the numerous discharges of residuals. These assessments, referred to as urban metabolism studies, employ material flow accounting techniques.

MFA is typically conducted with a focus on a certain point or period of time, as well as a particular geographical region or industrial sector. It seeks to measure or account for the movement of raw materials, resources, and/or intermediate or finished products in physical units from extraction through disposal. It is also used to document material and energy flows between natural and socioeconomic systems, as well as to monitor the types and quantities of waste produced. As a result, an MFA enables a thorough understanding of and approach to resource management.

These accounting methods are used to determine the material inputs and waste outputs of a city or municipality at the urban scale. The study of the measured materials enables the detection of inefficient resource consumption throughout the system, hence revealing opportunities for resource minimisation, waste prevention, reduction, and recycling that are not limited to the end-of-pipe.

In an extension with an emphasis on environmental or economic impact assessment, the studies can be used to identify both positive and negative environmental consequences, as well as the economic costs associated with the growth of inputs (resources) and the management of outputs (mainly urban wastes). Eventually, they can serve as the foundation for more effective urban planning initiatives.

The UCA method proposed here helps to detect and monitor economy-wide improvements and trade-offs for circularity across a city. To do so, a socio-metabolic approach, proposed by (Mayer et al. 2019), was adopted with the aim of developing a better understanding of material, waste and emissions flows in a region by using a mass balance between input of resources and outputs of waste and emission, understanding them with the help of circularity-focused indicators in a systemic and linked way.

The UCA method can support public administrators, waste companies, and practitioners in comprehending and enhancing urban resource utilisation, thereby enabling them to reduce environmental degradation and identify the environmental impacts of energy, material, and waste flows. As the importance and urgency of cities and their worldwide implications increase, a comprehensive framework that captures the material flows and stocks associated with a city is essential. The suggested approach is well-grounded in existing academic literature and aligned with current efforts by cities. Therefore, it is time for cities to begin to assess their urban circularity.

5. Applying the UCA method

Following the presentation of the UCA method, this section briefly summarises the most important action points for the application of the UCA method and its three main parts: (1) (a) material flow and (b) stock accounting (MFSA), (2) indicators and (3) CE assessment. As stated in the introduction chapter, there will be a separate handbook for UCA practitioners that provides detailed steps, assumptions, data sources, etc.

The data collection and processing for the MFA can be accomplished in eight steps, as illustrated in Figure 13. In a first step, it needs to be selected for each of the materials in “Annex 1 - Material scope”, if these are extracted, imported and/or exported. Depending on the data availability from (1) the Sector-wide Circularity Assessment of the construction and/or biomass sector that some CityLoops cities have carried out, (2) local data or (3) national data, the next respective steps have to be carried out, although not in a consecutive order (per materials) as could be understood from Figure 13. For example, if local data exists for cereals it can be used right away and does not have to be searched and possibly downscaled from a higher spatial scale. However, in the overall approach for all materials, the steps should be taken in the indicated order, not least to also include the waste data in the end. The goal and output of these steps are weight-based data for the extracted, imported, exported and wasted materials for two points in time. These feed into a prepared template that automatically produces the circularity indicators and the Sankey diagram.

As for the stock accounting, Figure 7 shows the four data collection and processing steps of the MSA and the respective chapter more clearly outlines the resources that can be applied for the analysis. Again, output of the MSA is the calculated and spatialised material stock of all residential and non-residential buildings in the municipality.

After the MFSA, the UCA practitioner should assess and benchmark the indicators. Then, in the overall circularity assessment, the interpretation of all results, including indicators, Sankey diagrams, as well as other visualisations, needs to be carried out and documented, along with an evaluation of the data quality.

The final output are the processed data on the CityLoops Data Hub and the presentation and analysis of results in an Urban Circularity Assessment report.

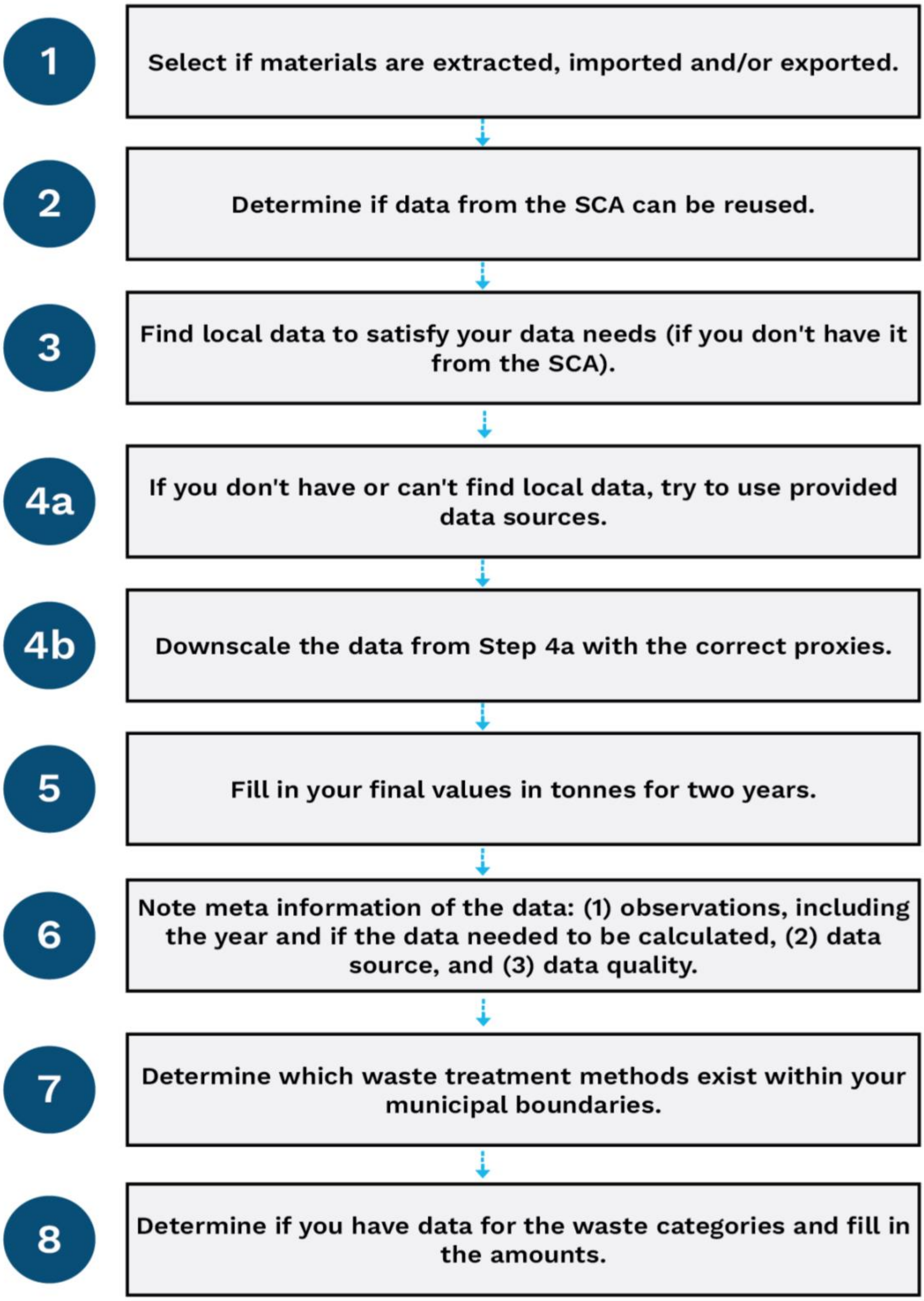

Figure 13 - The eight data collection and processing steps of the MFA

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Annex

Annex 1 - Material scope

MF1 - Biomass	**MF11 - Crops (excluding fodder crops)**
	MF111 - Cereals
	MF112 - Roots, tubers
	MF113 - Sugar crops
	MF114 - Pulses
	MF115 - Nuts
	MF116 - Oil-bearing crops
	MF117 - Vegetables
	MF118 - Fruits
	MF119 - Fibres
	MF1110 - Other crops n.e.c.
	MF12 - Crop residues (used), fodder crops and grazed biomass
	MF121 - Crop residues (used)
	MF1211 - Straw
	MF1212 - Other crop residues (sugar and fodder beet leaves, other)
	MF122 - Fodder crops and grazed biomass
	MF1221 - Fodder crops (including biomass harvest from grassland)
	MF1222 - Grazed biomass
	MF13 - Wood
	MF131 - Timber (industrial roundwood)
	MF132 - Wood fuel and other extraction
	MF14 - Wild fish catch, aquatic plants/animals, hunting and gathering
	MF141 - Wild fish catch
	MF142 - All other aquatic animals and plants
	MF143 - Hunting and gathering
	MF15 - Live animals other than in 1.4, and animal products
	MF151 - Live animals other than in 1.4
	MF152 - Meat and meat preparations
	MF153 - Dairy products, birds' eggs, and honey
	MF154 - Other products from animals (animal fibres, skins, furs, leather, etc.)
	MF16 - Products mainly from biomass
MF2 - Metal ores (gross ores)	**MF21 - Iron**
	MF22 - Non-ferrous metal
	MF221 - Copper
	MF222 - Nickel
	MF223 - Lead

	MF224 - Zinc
	MF225 - Tin
	MF226 - Gold, silver, platinum and other precious metals
	MF227 - Bauxite and other aluminium
	MF228 - Uranium and thorium
	MF229 - Other metals n.e.c.
	MF23 - Products mainly from metals
MF3 - Non-metallic minerals	**MF31 - Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)**
	MF32 - Chalk and dolomite
	MF33 - Slate
	MF34 - Chemical and fertiliser minerals
	MF35 - Salt
	MF36 - Limestone and gypsum
	MF37 - Clays and kaolin
	MF38 - Sand and gravel
	MF39 - Other non-metallic minerals n.e.c.
	MF311 - Products mainly from non metallic minerals
MF4 - Fossil energy materials / carriers	**MF41 - Coal and other solid energy materials/carriers**
	MF411 - Lignite (brown coal)
	MF412 - Hard coal
	MF413 - Oil shale and tar sands
	MF414 - Peat
	MF42 - Liquid and gaseous energy materials/carriers
	MF421 - Crude oil, condensate and natural gas liquids (NGL)
	MF422 - Natural gas
	MF423 - Fuels bunkered (Imports: by resident units abroad); (Exports: by non-resident units domestically)
	MF4231 - Fuel for land transport
	MF4232 - Fuel for water transport
	MF4233 - Fuel for air transport
	MF43 - Products mainly from fossil energy products
MF5 - Other products	
MF6 - Waste for final treatment and disposal	
SM_FIN - Stage of Manufacturing - finished products	
SM_SFIN - Stage of Manufacturing - semi-finished products	
SM_RAW - Stage of Manufacturing - raw products	

Annex 2 - Waste material scope

TOTAL - Total Waste
W01-05 - Chemical and medical wastes (subtotal)
W011 - Spent solvents
W012 - Acid, alkaline or saline wastes
W013 - Used oils
W02A - Chemical wastes
W032 - Industrial effluent sludges
W033 - Sludges and liquid wastes from waste treatment
W05 - Health care and biological wastes
W06_07A - Recyclable wastes (subtotal, W06+W07 except W077)
W061 - Metal wastes, ferrous
W062 - Metal wastes, non-ferrous
W063 - Metal wastes, mixed ferrous and non-ferrous
W071 - Glass wastes
W072 - Paper and cardboard wastes
W073 - Rubber wastes
W074 - Plastic wastes
W075 - Wood wastes
W076 - Textile wastes
W077_08 - Equipment (subtotal, W077+W08A+W081+W0841)
W077 - Waste containing PCB
W08A - Discarded equipment (except discarded vehicles and batteries and accumulators waste) (W08 except W081, W0841)
W081 - Discarded vehicles
W0841 - Batteries and accumulators wastes
W09 - Animal and vegetal wastes (subtotal, W091+W092+W093)
W091 - Animal and mixed food waste
W092 - Vegetal wastes
W093 - Animal faeces, urine and manure
W10 - Mixed ordinary wastes (subtotal, W101+W102+W103)
W101 - Household and similar wastes
W102 - Mixed and undifferentiated materials
W103 - Sorting residues
W11 - Common sludges
W12-13 - Mineral and solidified wastes (subtotal)
W121 - Mineral waste from construction and demolition
W12B - Other mineral wastes (W122+W123+W125)
W124 - Combustion wastes
W126 - Soils
W127 - Dredging spoils
W128_13 - Mineral wastes from waste treatment and stabilised wastes
W06 - Metallic wastes (W061+W062+W063)
W091_092 - Animal and mixed food waste; vegetal wastes (W091+W092)
W11_127 - Common sludges and dredging spoils (W11+W127, valid up to 2008)

W12_X_127NH - Mineral waste (except non-hazardous dredging spoils, valid up to 2008)
RCV_OTH - Other recovered wastes (valid up to 2008)
DSP_OTH - Other disposed wastes (valid up to 2008)
INC_OTH - Other incinerated wastes (valid up to 2008)
TOT_X_MIN - Waste excluding major mineral wastes

Annex 3 - Data collection tables

Input side: EW-MFA data

7	MATERIAL/INDIC_NV	DE - Domestic Extraction	IMP_XEU - Extra EU Imports	EXP_XEU - Extra EU Exports	DMC - Domestic Material Consumption
8	TOTAL - Total	5,784,397	1,539,118	629,735	6,693,781
9	MF1 - Biomass	1,801,860	178,613	156,867	1,823,606
10	MF11 - Crops (excluding fodder crops)	715,581	70,761	63,110	723,231
11	MF111 - Cereals	332,859	21,533	44,791	309,601
12	MF112 - Roots, tubers	63,324	288	2,662	60,950
13	MF113 - Sugar crops	133,512	5,427	1,618	137,321
14	MF114 - Pulses	3,183	1,034	531	3,687
15	MF115 - Nuts	774	913	86	1,600
16	MF116 - Oil-bearing crops	44,760	18,353	1,434	61,679
17	MF117 - Vegetables	61,882	3,332	4,220	60,993
18	MF118 - Fruits	69,730	13,605	5,212	78,123
19	MF119 - Fibres	1,060	406	469	997
20	MF1110 - Other crops n.e.c.	4,498	5,871	2,088	8,281
21	MF12 - Crop residues (used), fodder crops and grazed biomas	789,890	58	1,941	788,007
22	MF121 - Crop residues (used)	225,338	7	378	224,967
23	MF1211 - Straw	169,464	7	378	169,093
24	MF1212 - Other crop residues (sugar and fodder beet leaves, c	55,875	-	-	55,875
25	MF122 - Fodder crops and grazed biomass	564,551	51	1,563	563,039
26	MF1221 - Fodder crops (including biomass harvest from grassl	388,472	51	1,563	386,960
27	MF1222 - Grazed biomass	173,504	-	-	173,504
28	MF13 - Wood	290,218	38,307	23,561	304,964
29	MF131 - Timber (industrial roundwood)	230,537	34,748	23,037	242,248
30	MF132 - Wood fuel and other extraction	59,681	3,559	524	62,716
31	MF14 - Wild fish catch, aquatic plants/animals, hunting and gat	6,171	4,799	1,847	9,123
32	MF141 - Wild fish catch	5,153	3,532	1,684	7,001
33	MF142 - All other aquatic animals and plants	454	1,267	163	1,558
34	MF143 - Hunting and gathering	564	-	-	564
35	MF15 - Live animals other than in 1.4, and animal products	-	4,095	10,587	(6,492)
36	MF151 - Live animals other than in 1.4	-	8	329	(321)
37	MF152 - Meat and meat preparations	-	1,246	4,651	(3,404)
38	MF153 - Dairy products, birds eggs, and honey	-	421	3,832	(3,411)
39	MF154 - Other products from animals (animal fibres, skins, furs	-	2,419	1,775	644

rawData_ewMFA_input_side | rawData_WasteStat_output_side | Input_side_step1 | Input_side_step2 | Output_side_step1

Input side: Waste data

12		Data from Eurostat waste treatment statistics [env_wastrt]							
14	WASTE/WST_OPER	TRT - Total waste treatment	DSP_L - Landfill / disposal (D1-D7, D12)	DSP_D - Deposit onto or into land	DSP_O - Land treatment and release into water bodies	INC - Incineration / disposal (D10)	RCV_E - Incineration / energy recovery (R1)	RCV_NE - Recovery other than energy recovery	RCV_B - Recovery other than energy recovery - backfilling
15	TOTAL - Total Waste	2,324,390,000	1,101,500,000	946,270,000	155,220,000	35,700,000	106,770,000	1,080,420,000	236,520,000
16	**W01-05 - Chemical and medical wastes (subtotal)**	30,010,000	7,170,000	6,470,000	690,000	4,110,000	5,030,000	13,710,000	150,000
17	W011 - Spent solvents	1,770,000	10,000	10,000	0	580,000	520,000	650,000	0
18	W012 - Acid, alkaline or saline wastes	4,430,000	1,190,000	630,000	560,000	40,000	60,000	3,140,000	60,000
19	W013 - Used oils	2,370,000	20,000	10,000	0	90,000	230,000	2,020,000	0
20	W02A - Chemical wastes	9,550,000	1,480,000	1,460,000	20,000	1,900,000	1,510,000	4,670,000	10,000
21	W032 - Industrial effluent sludges	7,480,000	2,780,000	2,700,000	80,000	560,000	1,950,000	2,190,000	50,000
22	W033 - Sludges and liquid wastes from waste treatment	3,020,000	1,510,000	1,470,000	40,000	120,000	380,000	1,010,000	10,000
23	W05 - Health care and biological wastes	1,390,000	190,000	190,000	0	810,000	370,000	20,000	0
24	**W06_07A - Recyclable wastes (subtotal, W06+W07**	202,470,000	1,830,000	1,830,000	0	530,000	26,150,000	173,950,000	210,000
25	W061 - Metal wastes, ferrous	74,550,000	60,000	60,000	0	0	80,000	74,400,000	20,000
26	W062 - Metal wastes, non-ferrous	8,440,000	30,000	30,000	0	0	0	8,410,000	0
27	W063 - Metal wastes, mixed ferrous and non-ferrous	7,140,000	10,000	10,000	0	0	0	7,130,000	0
28	W071 - Glass wastes	16,100,000	230,000	230,000	0	0	0	15,860,000	20,000
29	W072 - Paper and cardboard wastes	35,260,000	130,000	130,000	0	20,000	380,000	34,740,000	0
30	W073 - Rubber wastes	2,640,000	20,000	20,000	0	20,000	1,180,000	1,420,000	10,000
31	W074 - Plastic wastes	12,820,000	730,000	730,000	0	80,000	1,730,000	10,270,000	40,000
32	W075 - Wood wastes	43,680,000	460,000	460,000	0	390,000	22,630,000	20,200,000	100,000
33	W076 - Textile wastes	1,840,000	150,000	150,000	0	20,000	150,000	1,520,000	10,000
34	**W077_08 - Equipment (subtotal,**	11,030,000	170,000	170,000	0	20,000	60,000	10,780,000	0
35	W077 - Waste containing PCB	40,000	10,000	10,000	0	10,000	0	10,000	0
36	W08A - Discarded equipment (except discarded vehicles	3,840,000	90,000	90,000	0	10,000	50,000	3,700,000	0
37	W081 - Discarded vehicles	5,660,000	30,000	30,000	0	0	0	5,620,000	0

rawData_ewMFA_input_side | rawData_WasteStat_output_side | Input_side_step1 | Input_side_step2 | Output_side_step1 | CE_Calculation

CityLoops is an EU-funded project focusing on construction and demolition waste (CDW), including soil, and organic waste (OW), where seven European cities are piloting solutions to be more circular.

Høje-Taastrup and Roskilde (Denmark), Mikkeli (Finland), Apeldoorn (the Netherlands), Bodø (Norway), Porto (Portugal) and Seville (Spain) are the seven cities implementing a series of demonstration actions on CDW and soil, and OW, and developing and testing over 30 new tools and processes.

Alongside these, a sector-wide circularity assessment and an urban circularity assessment are to be carried out in each of the cities. The former, to optimise the demonstration activities, whereas the latter to enable cities to effectively integrate circularity into planning and decision making. Another two key aspects of CityLoops are stakeholder engagement and circular procurement.

CityLoops started in October 2019 and will run until September 2023.

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