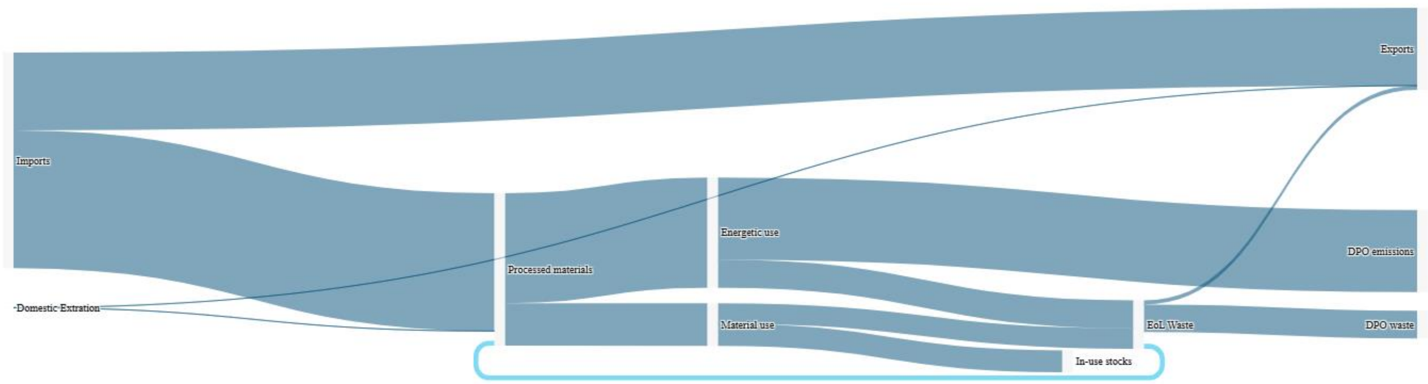
URBAN CIRCULARITY ASSESSMENT PORTO

Deliverable 7.8

2GO OUT Consulting



Version	1.0
WP	7
Deliverable	7.8
Date	April 4, 2023
Dissemination level	Public
Deliverable lead	2GO OUT Consulting, geral@2goout-consulting.com
Authors	Carla Santos, 2GO OUT Consulting
Reviewers	Pedro Santos (2GO OUT Consulting), Sara Velho (CMP), Manuel Semedo (CMP), Marta Pinto (CMP), Pedro Pombeiro (CMP) Susana Freitas (LIPOR), Emanuel Monteiro (LIPOR), Helder Claro (Porto Ambiente), Carolin Bellstedt (MoC), Gerardo Ezequiel Martín Carreño (MoC), Aristide Athanassiadis (MoC), Deniz Çelik (MoC), Tiffany Nicoli (MoC).
Abstract	This report on the Urban Circularity Assessment for Porto presents the gathered information and main findings on the material flows of the local economy for 2009 and 2019, as well as the building stock accounting. It provides contextual information of the city and the local economy under study and then illustrates the quantities of flows in the single parts of the supply chain, summarised by a Sankey diagram, followed by a map of the material stock. Both of the accounted materials are evaluated in the form of circularity indicators and their data quality. Finally, the results are analysed and interpreted to determine a status quo, considering limitations of the data used, before recommendations are offered on how to achieve greater material circularity in the municipality of Porto.
Keywords	Urban circularity assessment; Material flow accounting; Building stock; Circularity indicators; Urban metabolism; Circular city
License	This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0). See: https://creativecommons.org/licenses/by/4.0/

Contents

Executive Summary

The transition from a linear to a circular economy is an ambition for Porto and a great opportunity to tackle the actual environmental, social and economic challenges that they are facing out today. Close the loops of the materials and minimise harmful resource use and waste generation locally is a work that needs to be done and upscaled to achieve the goal of a circular city.

To analyse which is the Porto's material circularity level, the Urban Circularity Assessment (UCA) was conducted for the municipality in 2022. The study followed the UCA method (Bellstedt, *et al.*, 2022) developed under the CityLoops H2020 Project and was carried out for the years 2009 and 2019, due to data availability. The Porto's UCA Report consists in six main parts: (1) urban and economic context; (2) material flow assessment; (3) material stock assessment; (4) analysis of flows and stocks; (5) data quality assessment; and (6) analysis of data and indicators.

For comprehensive analysis of the UCA Report, it is important to note that numerous data sources were analysed and processed to carry out the UCA analysis, being possible, in the case of Porto, to obtain data at the city-level scale for almost all material flows which increases the accuracy and reliability of the results, however it is important highlight there is data (e.g. imports & exports) that is related with financial data, i.e. data related to where the headquarters of the company that transacts the goods are geographically located, which means that some goods could not entry or leave physically the municipality. The same does not apply to the building material stock where it was necessary to make numerous assumptions to get some results and that compromised the quality of the final results. Still, despite data gaps and limitations, the UCA provides a basis for understanding, using an accounting method that has been validated and used in a national and European context.

Porto has a high urban density with 232,753 inhabitants spreading over 41 km^2, it is the second most dense municipality in Portugal in terms of population as well as businesses. Its local economy is mainly based on "wholesale and retail trade" (17%), "accommodation and food service activities" (16%) and "professional, scientific and technical activities" (13%) in terms of number of employees, in 2019.

The UCA demonstrates that Porto is yet a linear and carbon-rich city, processing yearly around 856 kt of materials, adding 201 kt of additional stock (buildings, infrastructures, and durable goods) and reinjecting 54 kt in their economy. The results also shows that Porto has a high ecological cycling rates potentials (74%) that makes it an opportunity to move forward to achieve circular economy through circular bioeconomy strategies. In addition, the material stock assessment (MSA) illustrates the weight of Porto, whose building stock amounts to 28,000 kt (or around 130 t *per capita*).

Main circular economy indicators for Porto in 2019

CITYLOOPS INDICATORS	INPUT-SIDE INDICATOR		OUTPUT-SIDE INDICATOR	
Scale indicators (kt/yr)	Domestic material consumption (DMC)	856.2	Domestic processed outputs (DPO)	654.7
	Processed materials (PM)	910.0	Interim Outputs (IntOut)	708.5
	Secondary Materials	53.8		
	Net Addition to Stock (NAS)	201.5		
Circularity rates (%)	Input socioeconomic cycling rate (ISCr; share of PM)	5.9	Output socioeconomic cycling rate (OSCr; share of IntOut)	7.6
	Input ecological cycling rate potential (IECrp)	74.4	Output ecological cycling rate potential (OECrp)	74.0
	Input non-circularity rate (INCr)	10.8	Output non-circularity rate (ONCr)	13.9

Note: scale indicators presented in kt/yr, circularity rates in percentage. (kt/yr = kilotons per year)

Porto is already running its 2030 Roadmap for a Circular City, and several projects and efforts have already been implemented towards circularity, however, most of them are not reflected in this study since it is hard to quantify its impacts. UCA presents an opportunity for identify and implement new actions to move towards city's circularity as well to improve and update this study.

Main Recommendations for Making Porto More Circular

- Develop of a monitoring system for the city's circularity to follow the ongoing circular projects.
- Improve the building cadastre for better analysis of the material stock.
- Support new scientific research opportunities.
- Develop a bioeconomy.

- Develop a municipal policy of circular public procurement.

It is suggested to browse the online version of UCA report where charts, Sankey Diagram and the material stock map can be interacted with: https://cityloops.metabolismofcities.org/city/porto/uca-report/.

1. Introduction

The EU Horizon 2020 funded [CityLoops project](#) focuses on closing the material loops of cities in terms of material flows, societal needs and employment. Cities, depending on their magnitude and types of economic activities, possess considerable opportunities and various levers to transform their metabolism and economy towards a more environmentally sustainable and circular state.

Within this project, seven European cities, amongst those also the city of Porto are (planning to) implement demonstration actions to kickstart their circularity journey. To better understand what the current circularity status quo is, as well as the impact of these actions, and the efforts needed to transform their cities, an Urban Circularity Assessment (UCA) method was developed. The method consists of urban material flow and stock accounting that paired with system-wide indicators assesses the material circularity of a city.

The material flows are accounted economy-wide for two separate years, applying a city-level adjusted Mayer et al. (2019) framework, which in itself builds on the EW-MFA[1] method, including a wide material scope (specified below), while optimised for a circular economy assessment. The material stock accounting is limited to the buildings of the municipality, with the exact material scope depending on data availability in each city. Finally, the mass-based, "circularity" indicators cover the entire system and enable the assessment of a city's circularity. As such, a balance between comprehensiveness and scientific rigour on the one hand, and operability by urban policy makers and practitioners on the other is sought by the UCA method.

The material scope of the flow accounting aims to cover the entire local economy and is divided into a total of six material groups. These material groups are depicted as icons here and were studied each with more specific materials in sub-categories and along the supply chain of domestic extraction, imports & exports, domestic material consumption and waste. When studying these materials and the entire supply chain, together, these elements help to set a solid knowledge and analytical foundation to develop future circularity roadmaps and action plans.

[1] Economy-wide material flow accounts (EW-MFA) "are a statistical accounting framework describing the physical interaction of the economy with the natural environment and with the rest of the world economy in terms of flows of materials" (source: Eurostat)

Within the CityLoops project, the Urban Circularity Assessment was carried out by three of the seven cities (Mikkeli, Porto and Sevilla) themselves after having previously successfully completed their Sector-wide Circularity Assessments and Reports. They could build on extensive training that they had received in the form of courses on data collection for the construction and biomass sectors and data processing. The cities were accompanied and supported in their work by the Metabolism of Cities team, who conducted the UCA for two further cities (Apeldoorn and Bodø). Numerous additional insights can be found in the individual Data Hubs of each city.

This current Urban Circularity Assessment report presents the gathered information in seven sections:

- *Urban Context*
- *Economic Context of Porto*
- *Material Flows in Porto*
- *Material Stock in Porto*
- *Analysis of Flows and Stocks: Measuring Indicators*
- *Data Quality Assessment*
- *Analysis of Data and Indicators: Assessing Circularity*

It provides contextual information of the city and the local economy under study. It then illustrates the quantities of flows in the single parts of the supply chain, summarised by a Sankey diagram, followed by a map of the material stock. Both of the accounted materials are evaluated in the form of circularity indicators and their data quality. Finally, the results are analysed and interpreted to determine a status quo, taking into account limitations of the data used, before recommendations are offered on how to achieve greater material circularity in the municipality of Porto.

(The italic texts in this report were written by Metabolism of Cities' Aristide Athanassiadis and Carolin Bellstedt. They provide relevant general information and serve as connecting elements of the single report parts.)*

2. Urban Context

To contextualise the results of the Urban Circularity Assessment, this section provides population and land use information data for Porto. In addition, population numbers and area size of the city under study, as well as its corresponding NUTS3, NUTS2 and country were included, as can be seen to the right of the Porto map. Data for these scales were added to better understand how relevant and important the approximations are when downscaling data from these scales to the city level.

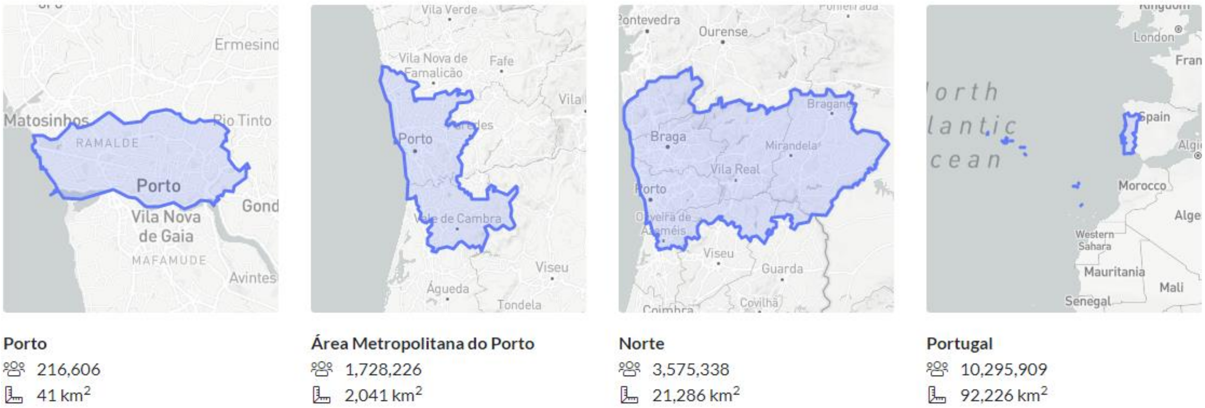


Figure 1. Population and area of Porto (2019) [source: Pordata, 2022]

2.1. Population of Porto

The population of Porto declined from 328,788 inhabitants in 1981 to 232,753 in 2021, a decrease of 29.21% in 40 years. It presents around 13% of the inhabitants of Porto Metropolitan Area and 7% of the North Region of Portugal. Despite the fact that Porto has suffered a high population decline in recent decades, it looks like it has seen a small population growth (8.70%) since 2016, in part as a result of the city's rising reputation as a place to live and work.

Between 2009 and 2019, the two reference years of this study, the number of inhabitants in the municipality of Porto has decreased by 24,648 persons from 241,254 in 2009 to 216,606 in 2019, a decrease of 10.2%.

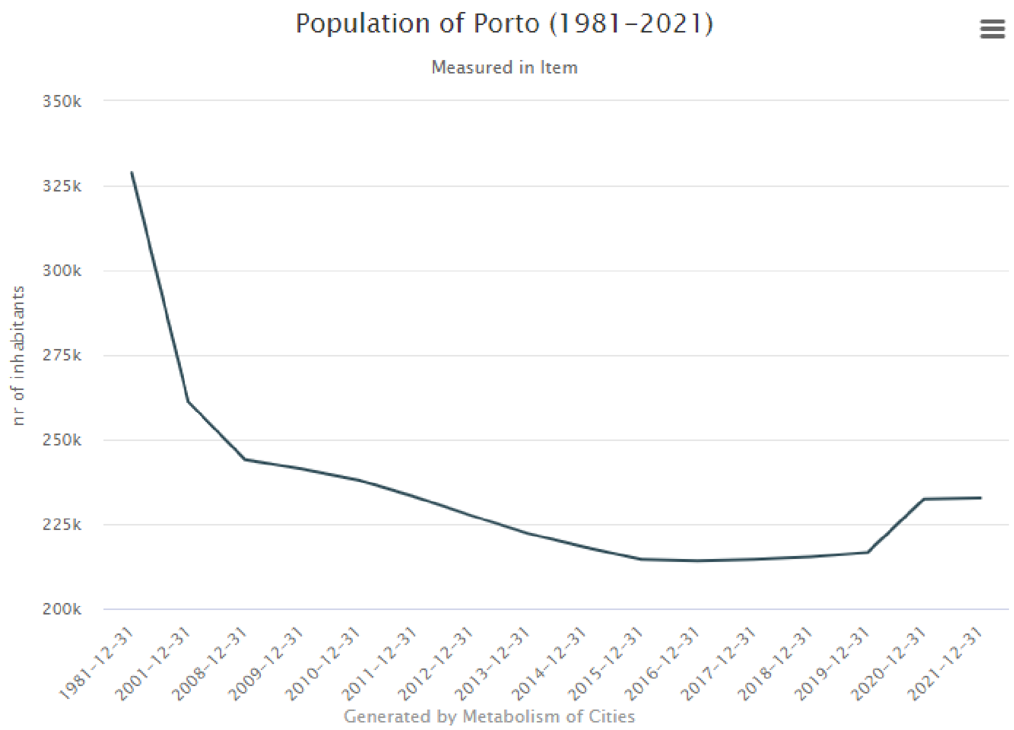


Figure 2 - Population of Porto (interactive graphic) [source: Pordata, 2022]

Nowadays, around 232,753 people live in the city. According to the gender distribution, the city is majority female with 54.2% of the population and 45.8% being male, following the trend of the regions (Northern Region [NUTS2] and Porto Metropolitan Area [NUTS3]) where it is located and of the country itself.

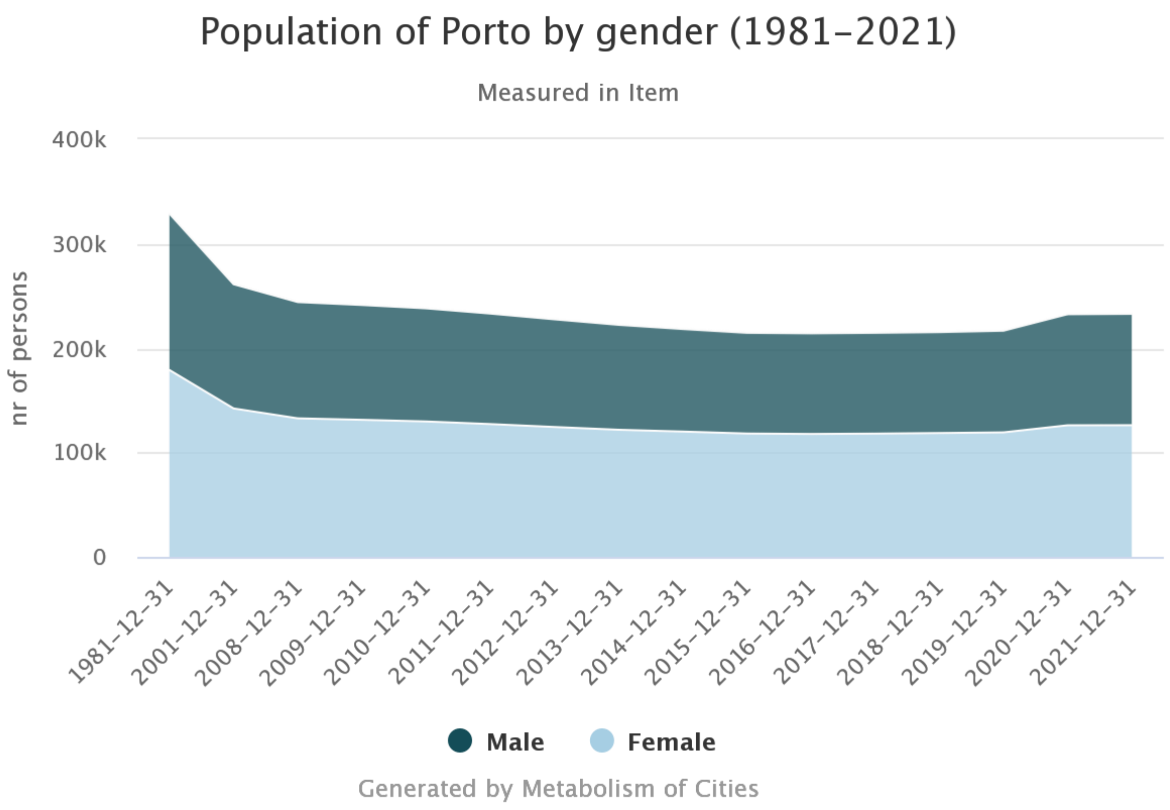


Figure 3. Population of Porto by gender (interactive graphic) [source: Pordata, 2022]

In terms of age, as shown in the 2021 data, the majority of the population is between ages 20 and 64 years, accounting for 57.9% of the total population. The elderly population (above the age of 65) represents 26.1% of the total population and the young population (below the age of 19) only represents 16%. It reflects a population aging, like what is happening across the country.

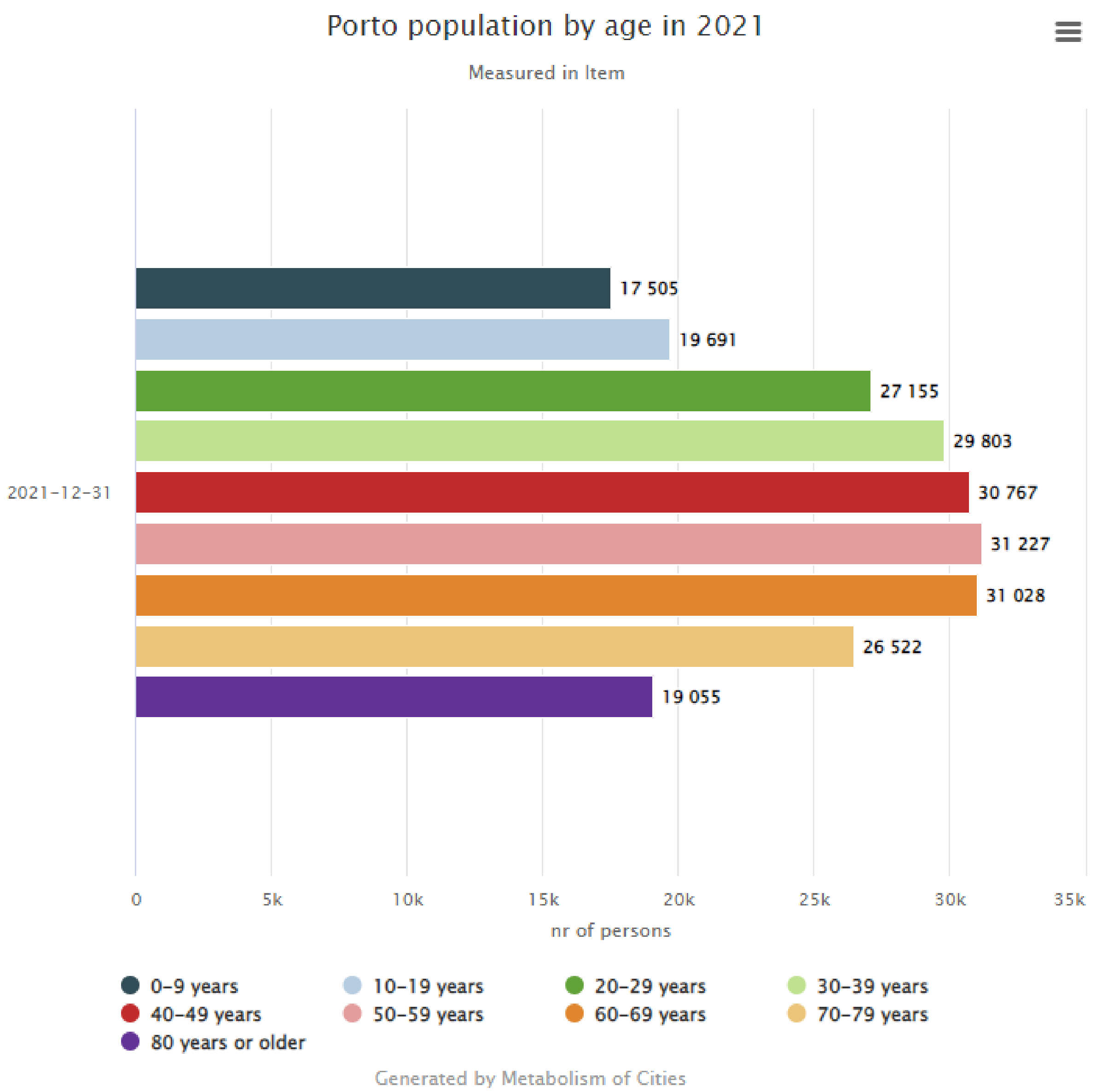


Figure 4. Population of Porto by age (interactive graphic) [source: INE, 2022]

2.2. Land Use

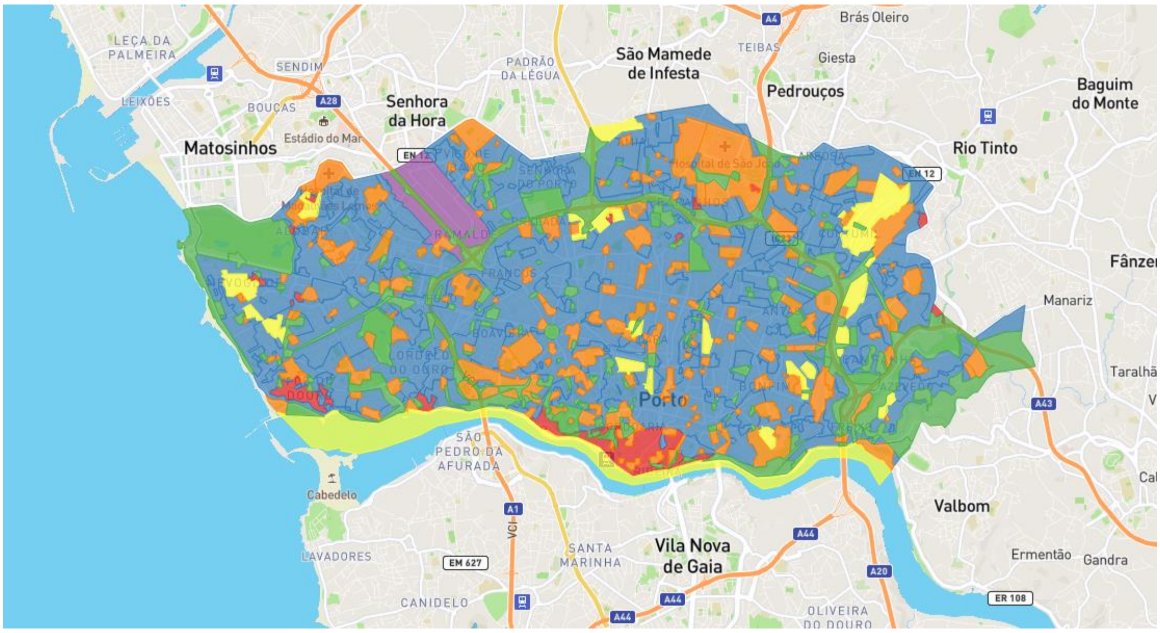


Figure 5 - Land use map (interactive graphic) [source: DGT, 2022]

From the total area (41 km^2) of the municipality of Porto, 21.4 km^2 (54%) is classified as residential space. According to statistical data, Porto is the second most dense municipality in Portugal after Amadora, with a population density of 5,596.3 persons/km^2, higher than the Portuguese capital (Lisbon) density (5,455.2 inhab/km^2) (PORDATA, 2022a).

The green spaces are the second usage of the land, covering 18% of the municipality (6.95 km^2), and it corresponds to 22 m^2 of green spaces per inhabitant. Space for economic activities only occupies 2% of the territory (0.91 km^2).

3. Economic Context of Porto

This section puts into perspective the economic context of the city under study. It describes its significance in terms of GDP or GVA and provides information on the number of people employed, as well as the main economic activities. Main actors that play a significant importance may also be highlighted.

	GVA (MONETARY VALUE, IN €) (2019)	EMPLOYEES (2019)
Porto	4,119,324	151,943
Área Metropolitana do Porto	17,590,879	737,577
Norte	30,652,956	1,418,707
Portugal	104,417,694	4,225,538

[source: INE, 2022b and INE, 2022g]

Porto's economic dynamics have changed during the last decades, with some economic activities moving to neighbouring municipalities. This could be seen, particularly, in the "manufacturing" industry that sought more favourable spaces from the point of view of cost, availability of space and accessibility to logistics and transport infrastructures. The "wholesale and retail trade" sector has followed a similar strategy. Each one lost 16% of their employees between 2009 and 2020 (CMP, 2018; INE, 2022g). Also the "construction" sector has lost almost 60% of their employees during this period, which can also be related to the intensely urbanized area of Porto's territory (Figure 5), leaving little opportunity for the evolution of the sector in Porto.

Despite the job losses, during the last decade, in the economic sectors identified above, in total, the number of jobs in Porto increased by around 4.27%, from 137,479 employees in 2009 to 143,352 employees in 2020. The main economic sectors that contributed to this growth were "accommodation and food service activities" (more 7,902 employees in 2020), "information and communication activities" (more 6,279 employees), "consultancy, scientific and technical activities" (more 3,644 employees), "human health and social work activities" (more 2,263 employees) and "real estate activities" (more 1,363 employees) (INE, 2022g).

In 2019, year of reference of UCA, there were **151,943 employees** in total, and the three economic sectors with the highest number of employees were **"wholesale and retail trade; repair of motor vehicles and motorcycles" (17%), "accommodation and food service activities" (16%) and "administrative and support service activities" (13%)** (INE, 2022g). This distribution differs from that of the Porto Metropolitan Area (AMP) and the country, where besides "wholesale and retail trade" and "administrative and support service activities", the prevailing economic sectors were "manufacture" and "education". In the northern region (NUTS2) the "construction" sector also has a high weight in number of employees.

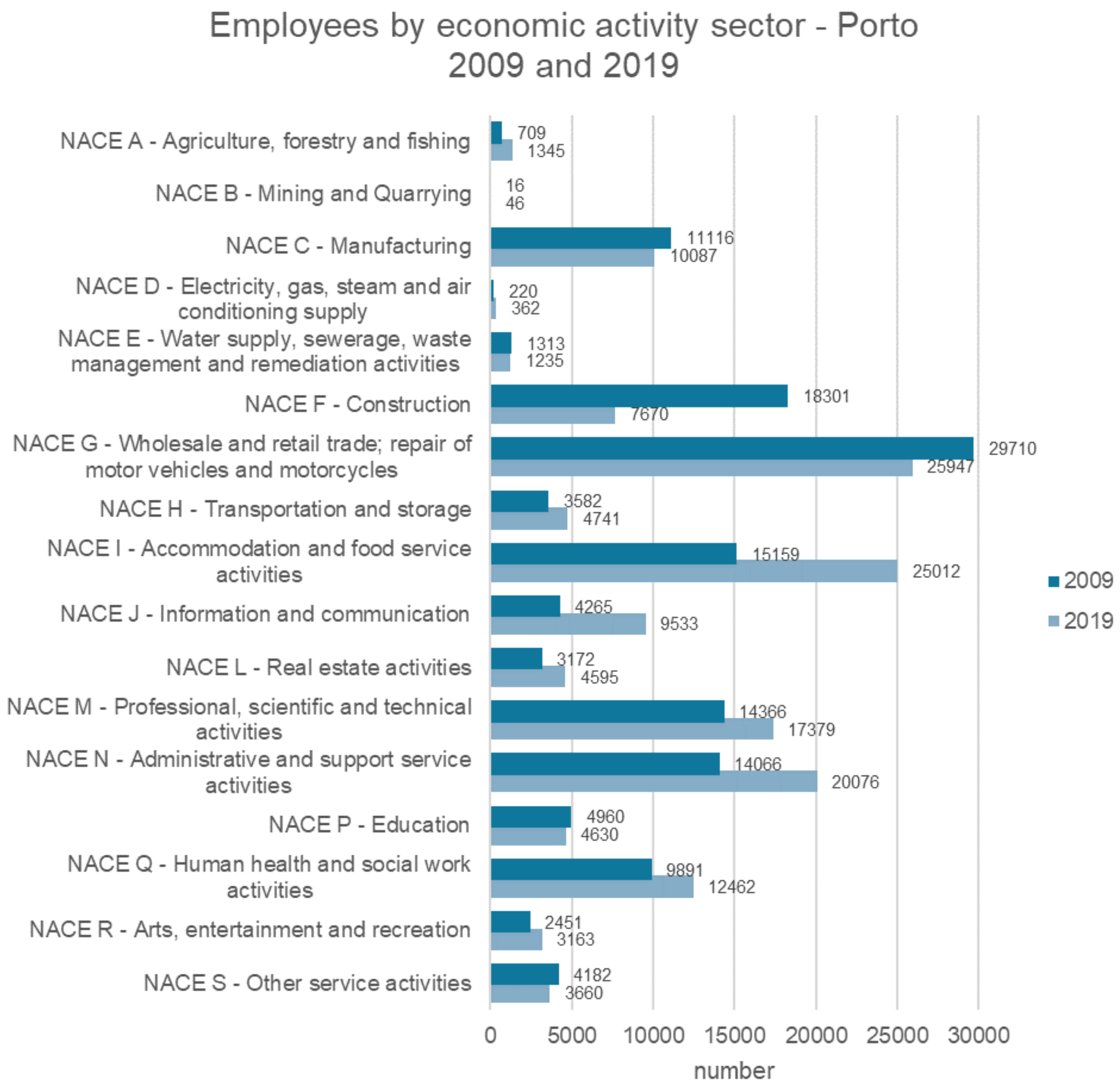


Figure 6 - Porto employment numbers (interactive graphic) [source: INE, 2022g]

In the last decade, between 2009 and 2019, there has been a growth in terms of number of employees in the economic sectors of “agriculture, forestry and fishing” (90%), from 709 employees in 2009 to 1,345 employees in 2019, and “mining and quarrying” (188%), from 16 employees in 2009 to 46 employees in 2019. However, this growth does not reflect the growth of the activity itself within the city, since there is no record of domestic extraction related with these both sectors or the existing one is extremely low. This is probably a consequence of the growing of these sectors (especially the agricultural sector), which in some cases has translated into the establishment of the headquarters of the companies in urban contexts (CMP, 2018).

The economic sector "information and communication" also had a high growth between 2009 and 2019, doubling its number of employees (from 4,625 to 9,533 employees). In fact, it has been verified that Porto has also found market "niches" in technological activities, either in the less demanding component of online shared services in nearshore, or in the more qualified model of conception and production of new products and services, mainly IDE (Integrated Development Environment) projects, often in close articulation with the higher education institutions located in the city (CMP, 2018).

In general, the numbers show that the services provided to companies generate 43% of jobs in Porto (2019), mostly administrative and support activities, consulting, scientific and technical activities, and information and communication technology-related activities (ICT). This transforms Porto into a very attractive city to multinational companies in ICT sector (CMP, 2022a).

In terms of number of enterprises, Porto had a total of **42,927 enterprises** in 2019, mostly SMEs (Small and Medium Enterprises), of which 95.3% (40,876 enterprises) are micro-enterprises (less than 10 employees) and only 55 are large enterprises (INE, 2022a). Porto is the second most business dense municipality in Portugal (1,036.4 enterprises *per* km^2), right after Lisbon (1,206.4 enterprises *per* km^2) (PORDATA, 2022) and detains 19.9% of the enterprises in Porto Metropolitan Area.

Most of the Porto's enterprises are from "consultancy, scientific and technical activities" (17.4%), "wholesale and retail trade; repair of motor vehicles and motorcycles" (15.2%) "administrative and support service activities" (13.1%), "human health and social work activities" (12.2%) and "accommodation and food service activities" (10.2%) (INE, 2022). A total of 2.2% of enterprises are involved in "agriculture, forestry and fisheries" with the highest concentration in "agriculture, farming of animals, hunting and forestry". The extractive industry has 8 enterprises, representing only 0.02% of the total, these are mainly related to "mining and preparation of metal ores" and "other mining and quarrying".

A mention should be made to the number of start-ups and their size in terms of business volume that has increased in Porto, from around 26.2% to 28%, between 2016 and 2018, and also a significant number of interface centres, poles and competitiveness clusters consolidated, supported by a favourable dynamic in the areas of: Talent and Teaching, Science and Technology (S&T), Research and Development (R&D) and Entrepreneurship and Innovation (CMP, 2022a).

In monetary terms, Porto generated approximately **4,120 million Euros in Gross Value Added** (GVA) in 2019, making up 23.4% of the Porto Metropolitan Area GVA and about 3.9% of the Portuguese GVA (INE, 2022b). At a city level, the sectors that stand out the most in value are **"wholesale and retail trade" (570 million Euro)**, **"professional, scientific and technical activities" (440 million Euro)** and **"accommodation and food service activities" (423 million Euro**), which together totalled 1,424 million Euro (34.8%) in 2019. This differs from Portugal's distribution where "manufacturing" is the sector with the highest value (INE, 2022b).

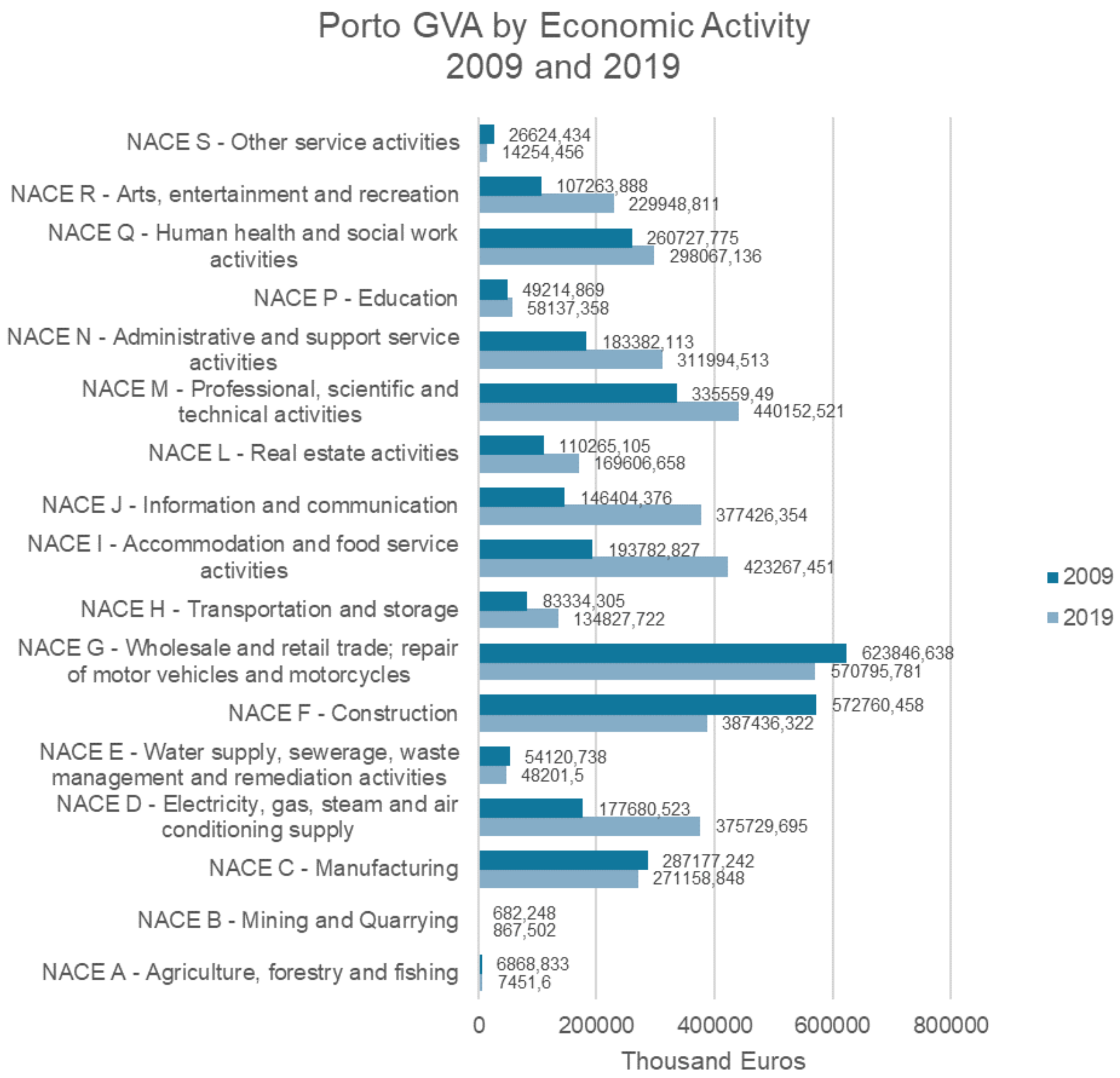


Figure 7. Porto GVA by Economic Activity (interactive graphic) [source: INE, 2022b]

Porto takes on the role of the main employment pole in the Porto Metropolitan Area and the largest city economic dimension in the Northwest of the country, reflecting in a specialization profile in activities that tend to be concentrated in major urban centers, such as business services, business, hospitality, education, health and social support.

Tourism Sector

The tourism sector is one of the most relevant economic activities in Porto, remaining in the top 3 largest employers since 2009, beside the "wholesale and retail trade". The Porto's tourism sector represented in 2019 more than 16% of the employment in the city (25,012 persons employed), and 10.3% of its economic value in GVA (423,267 million Euros) (INE, 2022g; INE, 2022b). Moreover, this is the main driver of the city's economy, also influencing the development of other economic activities such as commerce, creative industries, real estate and transport, reflected in the urban rehabilitation, of the appearance of numerous hotels and local accommodation, new entertainment venues, in the intensification of nightlife and offering a wide range of services to the visitors (CMP, 2018).

Porto is the main attraction of Porto Metropolitan Area tourists, one of the most relevant from Northwest Portugal and distinguished with numerous awards of international tourism, which intensity increased considerably from 3.3 guests by inhabitants in 2009 (INE, 2016) to 10.4 guests by inhabitants in 2019 (INE, 2022c). In terms of number of nights in tourist accommodation establishments, there were more 2,803,456 nights in 2019 when compared to 2011, meaning a growth of more than 157% between both years (INE, 2022f). The proportion of non-resident tourists has also been increasing, and by 2019 they accounted for about 79.1% of the city's total tourists (INE, 2022h). The same happen with the growth of the lodging capacity available in the city's tourist accommodation establishments, which in 2019 was already approximately 108 beds *per* 1,000 inhabitants, compared to 66 beds *per* 1,000 inhabitants in 2014 (INE, 2022e).

By 2019, this reflected some tourism pressure in some specific locals of Porto, such as the historic center of Porto, so the Municipality has been investing in measures to mitigate negative impacts of intense tourism, for example, by decentralizing economic and culture activities to less explored areas, such as the eastern part of the city, and by applying the Municipal Tourism Tax and Local Accommodation since 2018, as a financing so that the municipality can follow this growth and, at the same time, manage this same growth in tourism, namely in terms of security, hygiene, maintenance of public space and promotion of entertainment activities. Although the measures in place to mitigate the pressure of tourism in certain parts of the city, it is expected that tourism will continue to grow beyond the values presented until 2019.

In 2021, the Porto Declaration on Sustainable Tourism presented the commitment to establish target goals on the umbrella objective of attaining a sustainable urban tourism, including an inclusive and more sustainable tourism sector in the cities' agendas, while fostering job and wealth creation, social inclusion and cultural preservation (CMP, 2021).

4. Material Flows in Porto

Measuring material flows and circularity is a data heavy exercise. Numerous datasets were collected and visualised throughout the Urban Circularity Assessment process. To synthesise these findings, a Sankey diagram illustrates how material flows of the local economy of Porto are circulating from one lifecycle stage to another. The height of each line is proportional to the weight of the flow. This diagram, therefore, helps to quickly have an overview of all the materials flows that compose the economy and their respective shares. The flows that are coloured in light blue in the Sankey diagram, are return flows. This means that they flow in the opposite direction of the lifecycle stages and are subject to reuse, redistribution, or remanufacturing. Their size relative to the others is a good indication of a material's circularity.

The Material Flow Accounting followed the UCA method that combines the EW-MFA method with the adapted framework proposed by Mayer, *et al*., 2019 which was adapting to the city scale (Bellstedt, Carreño, Athanassiadis, & Chaudhry, 2022).

To perform the Porto's UCA study it was defined three types of systems boundaries:

- Spatial boundary: administrative boundaries of the Porto Municipality.
- Temporal boundary: two years were considered with 10 years apart – 2009 and 2019. These reference years was chosen considering the data availability, especially those related with agricultural data.
- Material boundary: hierarchical classification system of the EW-MFA[2] was used in UCA. Data for materials categories MF1 to MF4 and up until 4-digit material group level was collected for domestic extraction, physical imports and exports. The remaining big groups (MF5 – Other products and MF6 – Waste for final treatment and disposal) are also required in case a classification into MF1-4 categories is unclear. Waste materials are also included in the material scope and draw their boundaries from the Eurostat waste treatment statistics (Annex 2 – Waste material scope).

Figure 8 shows us the four big categories (MF1-MF4) with some examples of material classes and material groups to understand the level of detail of the lower levels. In Annex 1 – Material scope you can find the entire list of all materials. All this information also can be consultant in the CityLoops – D4.4 Urban Circularity Assessment Method.

[2] The EW-MFA classification system defined by Eurostat was used. The 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 MF1 to MF8. Each material category is broken down into material classes (2-digit-level), which are further broken into material groups (3-digit-level) and finally down to material sub-groups (4-digit-level). 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 (Bellstedt, Carreño, Athanassiadis, & Chaudhry, 2022).

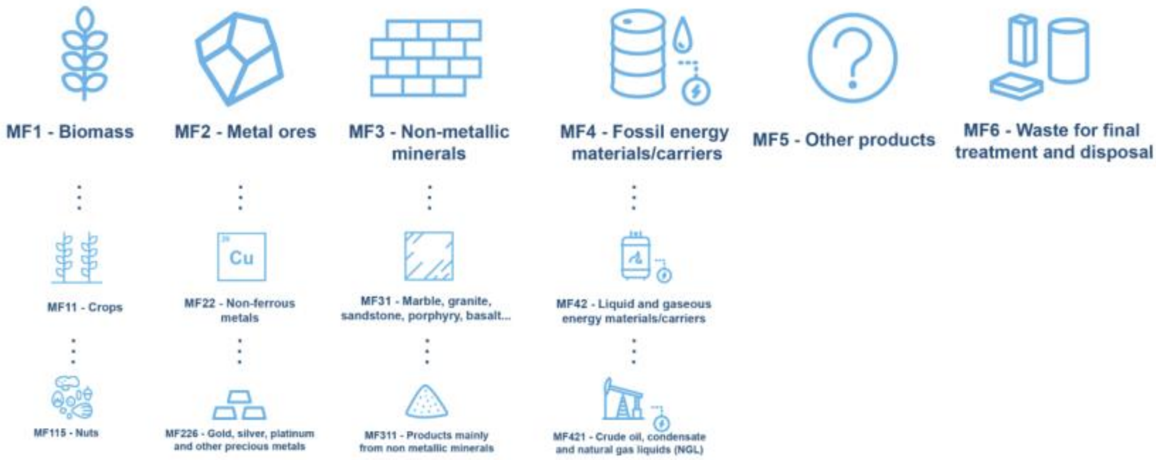


Figure 8. Material scope for the UCA with examples of material classes and material groups [source: Bellstedt, Carreño, Athanassiadis, & Chaudhry, 2022]

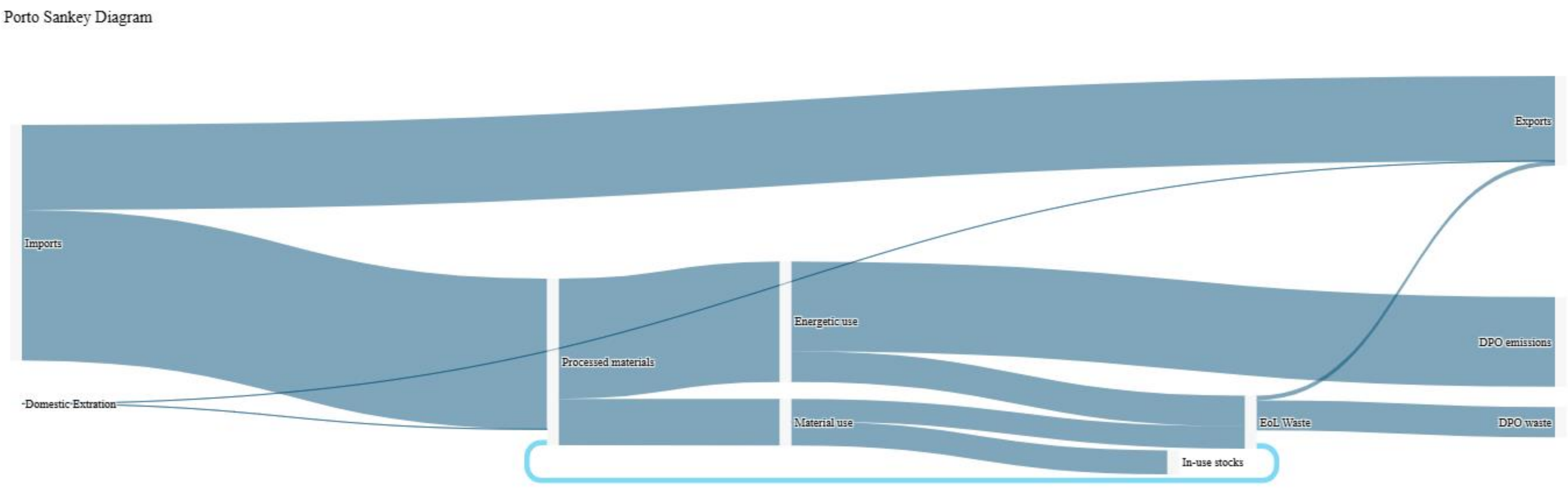


Figure 9. Porto Sankey diagram (interactive diagram in online report)

4.1. Domestic Extraction

As can be observed in the Sankey diagram, domestic extraction, i.e. the material originating from the domestic environment, does not have a large expression in Porto. The city only has a few domestic extraction of biomass[3]. In terms of metal ores and non-metallic minerals, from the knowledge of the author, none of these were expected in Porto, despite the existence of companies in this economic sector in the city. Fossil fuel extraction is non-existent in Portugal (INE, 2021), therefore, there is no extraction in Porto either.

The agricultural census conducted every 10 years by National Statistics Office (INE) reveals few agricultural data for the city of Porto. The biomass extracted locally was 831 tonnes in 2009 and 244 tonnes in 2019, which represents **a decrease of 70.7%**. Overall, fodder crops dominated this material group in 2009, however in 2019 the distribution is more balanced with a predominance of vegetable extraction (80 tonnes) followed by fodder crops (53 tonnes) and roots and tubers (45 tonnes), representing almost 73% of the biomass domestic extraction (Figure 10).

A mention should be made to the ‘Horta à Porta’ Project, an initiative with 14 urban vegetable gardens spread throughout the city, that owns 4.5 hectares, and allows local people to produce for themselves locally. Since their annual production was unknown and the land was very small, they were not included in the UCA analysis.

[3] Domestic extraction of biomass records material flows from the environment to the economy related to the human appropriation of cultivated and non-cultivated biomass.

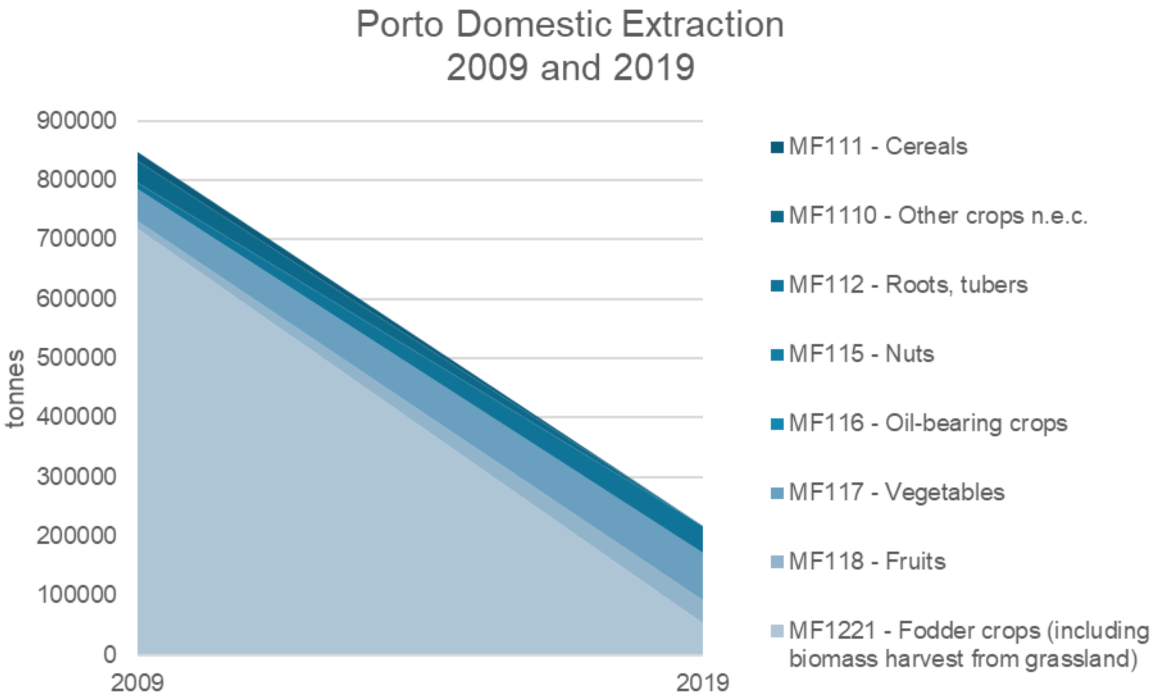


Figure 10 - Domestic Extraction in Porto (interactive chart) [source: Agricultural Census, INE]

4.2. Imports & Exports

The data related with imports & exports is usually very hard to obtain for city-level and most of the time, lacking data may lead to misleading results. The imports & exports, i.e. materials originating from other economies and that goes to other economies, should be analysed through two ways: 1. international trade, it means materials/goods that entry/leave in the local economy from/to other countries; and, 2. national trade, it means materials/goods that entry/leave in the local economy (municipality) from/to other local economies (municipalities) of the same country.

For Porto, the only data used for imports & exports analysis was the international trade, provided by INE, since these data are available at the city-scale. Nevertheless, it is important highlight that the data is related with the municipality where the headquarters of the company that transacts the good are located geographically, which means that some goods could not entry or leave physically the municipality, since has referred in the chapter 3, there is a lot of companies that chose Porto for their headquarters.

For national trade data (i.e. the internal movement of goods between the different municipalities of the country) the most reliable information for this analysis is regional data (NUTS2) and at MF 1-digit-level. As MF 1-digit-level data can't be used in the UCA method in order to match with the Mayer *et al*. framework, due to the lack of detail of the information made available, the data related to national trade was excluded from the study (as will be explained in the data quality part).

Imports

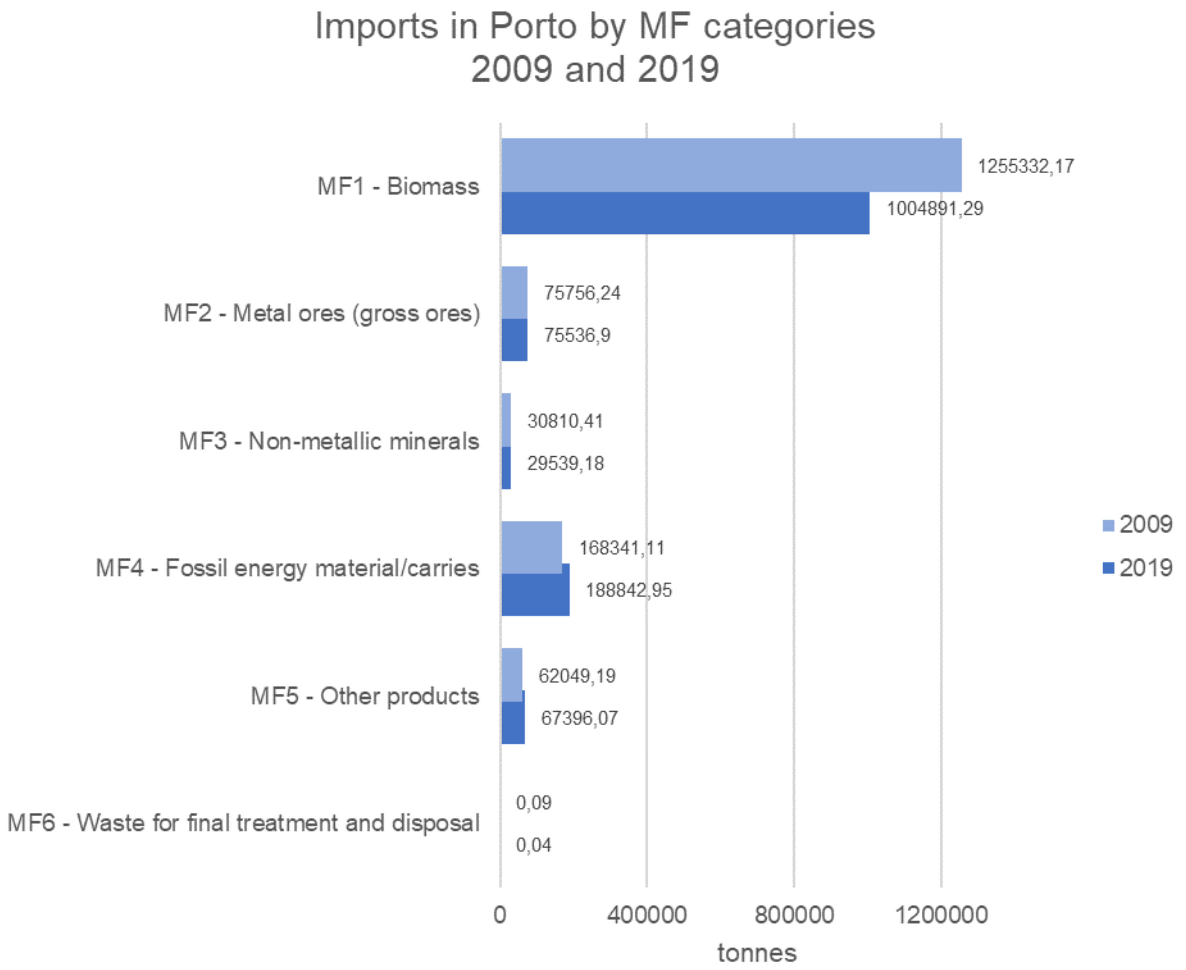


Figure 11 - Imports to Porto by MF Categories in 2009 and 2019 (interactive graphic) [source: INE, 2022]

The City of Porto imported a total of 1,592,289 tonnes of materials in 2009 and 1,366,206 tonnes in 2019. A decrease of 14% which is consistent with the decrease in population and supported by the decreased of import of biomass (MF1) by 19.95% and non-metallic minerals (MF3) by 4.13%. The imports of fossil energy materials/carriers (MF4) has increased by 12.18% which can be explained by, on the one hand, by the growing trend in the number of light passenger vehicles, not only in the city of Porto where the indicator of new vehicles per 1,000 inhabitants rose from 26.29 (2009) to 28.60 (2019) (INE, 2022j), but also throughout the country with records of growth of over 13% in vehicles presumed to be in circulation (IMT, 2022). On the other hand, the fact that the city has become extremely attractive for tourism, as well as a place to work and study in the last years, means that every day the city witnesses the equivalent of more than 70% of its resident population entering the city, to work or study, mostly with their private vehicles. And this has increased between the last two census available (INE, 2013; INE, 2022i). Even those that live and work in the municipality have their own private vehicle as their main commuting preference. Related to the tourist population in 2019, there were 2,245,291 people that visited the city (INE, 2022c), the equivalent of 10.4 guests by inhabitants (INE, 2022d).

As can be seen in the Figure 11, biomass is the main material imported by Porto with 79% (2009) and 74% (2019), followed by fossil fuels with 11-14%. The metals, non-metallic minerals, other products and waste together made up 11% in 2009 and 13% in 2019.

Related with biomass, the most relevant materials imported are cereals (64.8% of biomass imported) followed by sugar crops (13.4% of biomass imported), this is in line with the existence of a sugar refining industry and two others that operate at the cereal milling level (Santos, Castro, & Santos, 2021).

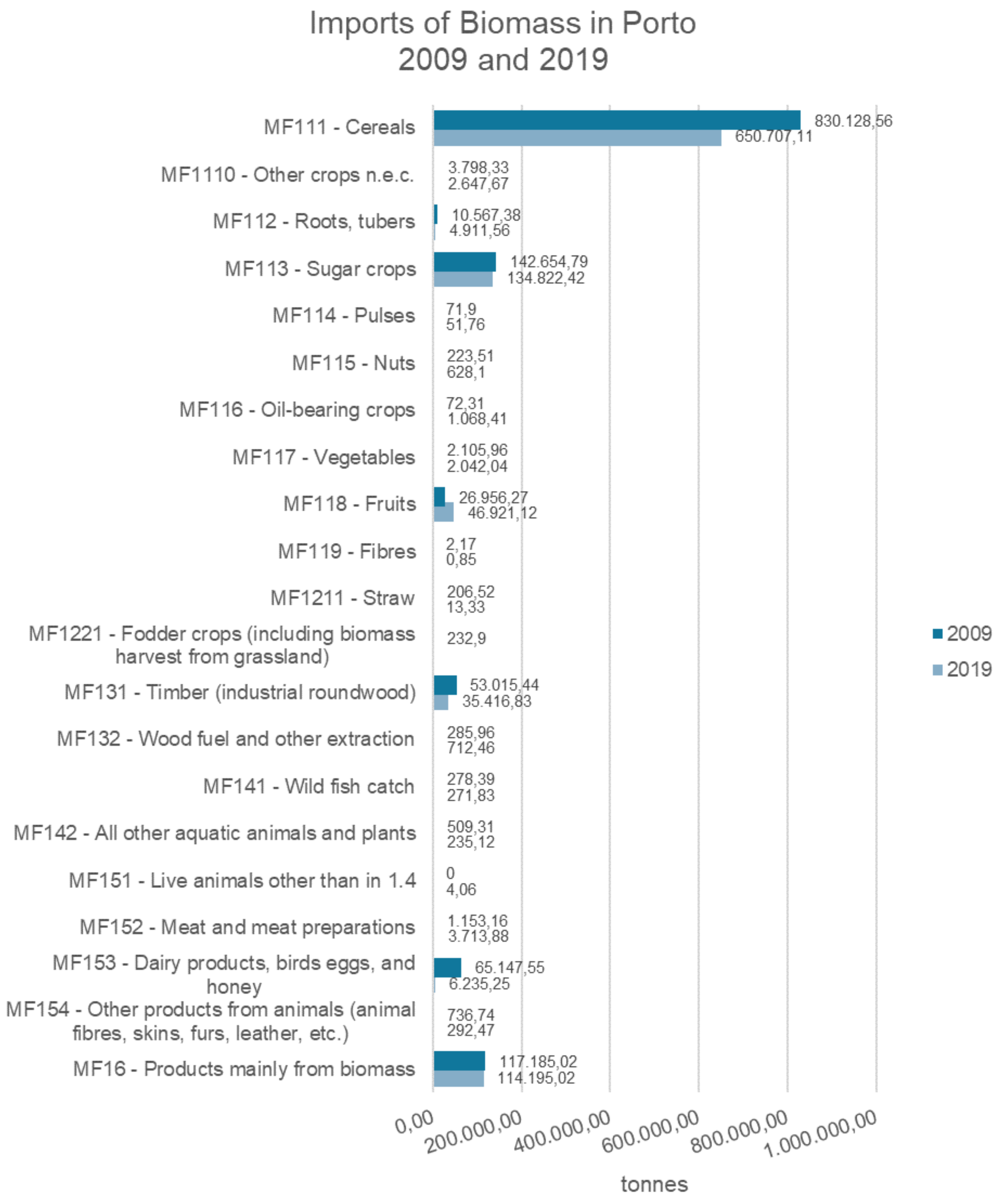


Figure 12. Imports of biomass materials to Porto, in 2009 and 2019 (interactive graphic) [source: INE, 2022]

Exports

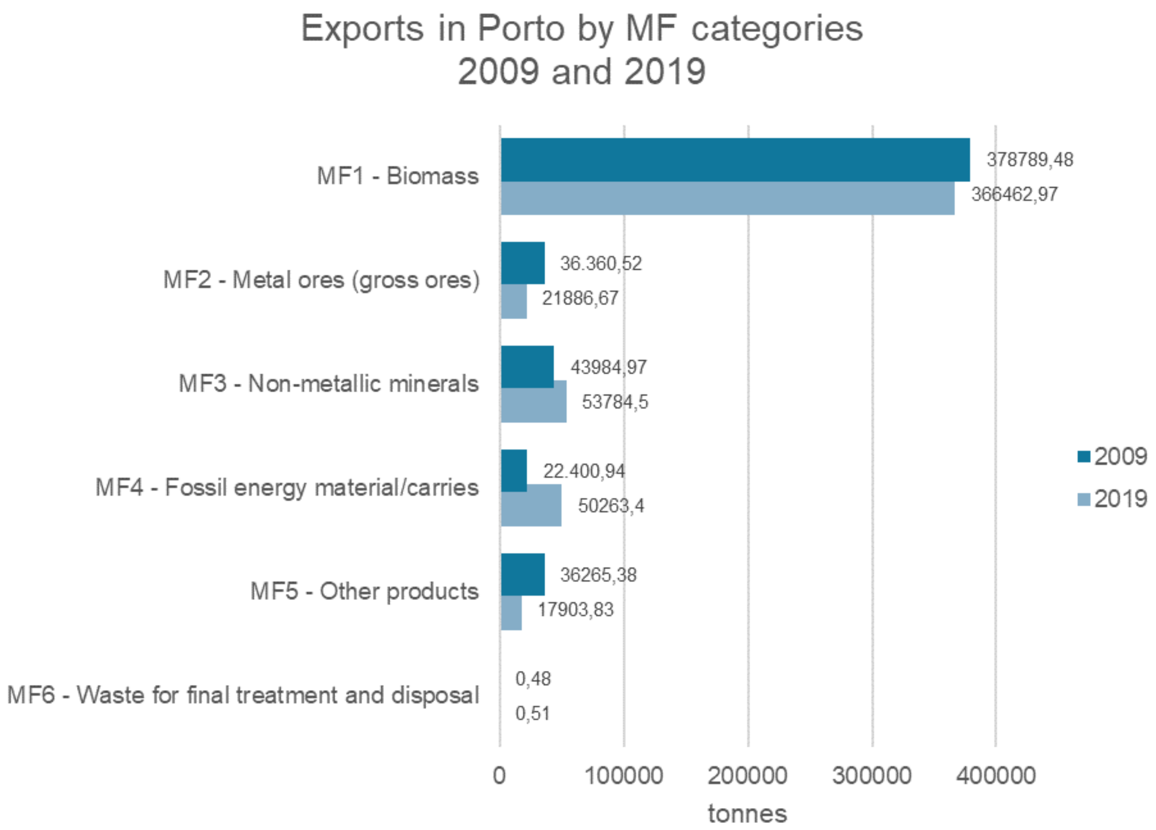


Figure 13 – Exports from Porto by MF Categories (interactive chart) [source: INE, 2022]

The city of Porto exported a total of 517,801.77 tonnes in 2009 and 510,289.88 tonnes in 2019. Also, in exports there was a slight decrease (1.45%) between both years, more specifically, the export of metal ores (MF2) decreased by 40% and other products (MF5) by 51%. Nevertheless, the exports of fossil fuels (MF4) increased by 124% and non-metallic minerals (MF3) by 22%.

As can be seen in the charts, biomass makes up the main share of exports with more than 70%, followed by non-metallic minerals (11%) and fossil fuels (10%), during 2019. Metal ores (MF2) and waste (MF6) together made up 8% in 2009 and 5% in 2019.

The Figure 14 represents the distribution of exports of biomass and shows us that the most relevant materials exported are timber – industrial roundwood (MF131), dairy products, birds, eggs and honey (MF153) and sugar crops (MF113). Since there is no domestic extraction of these materials in the city and the importation is lower maybe these materials came from other municipalities.

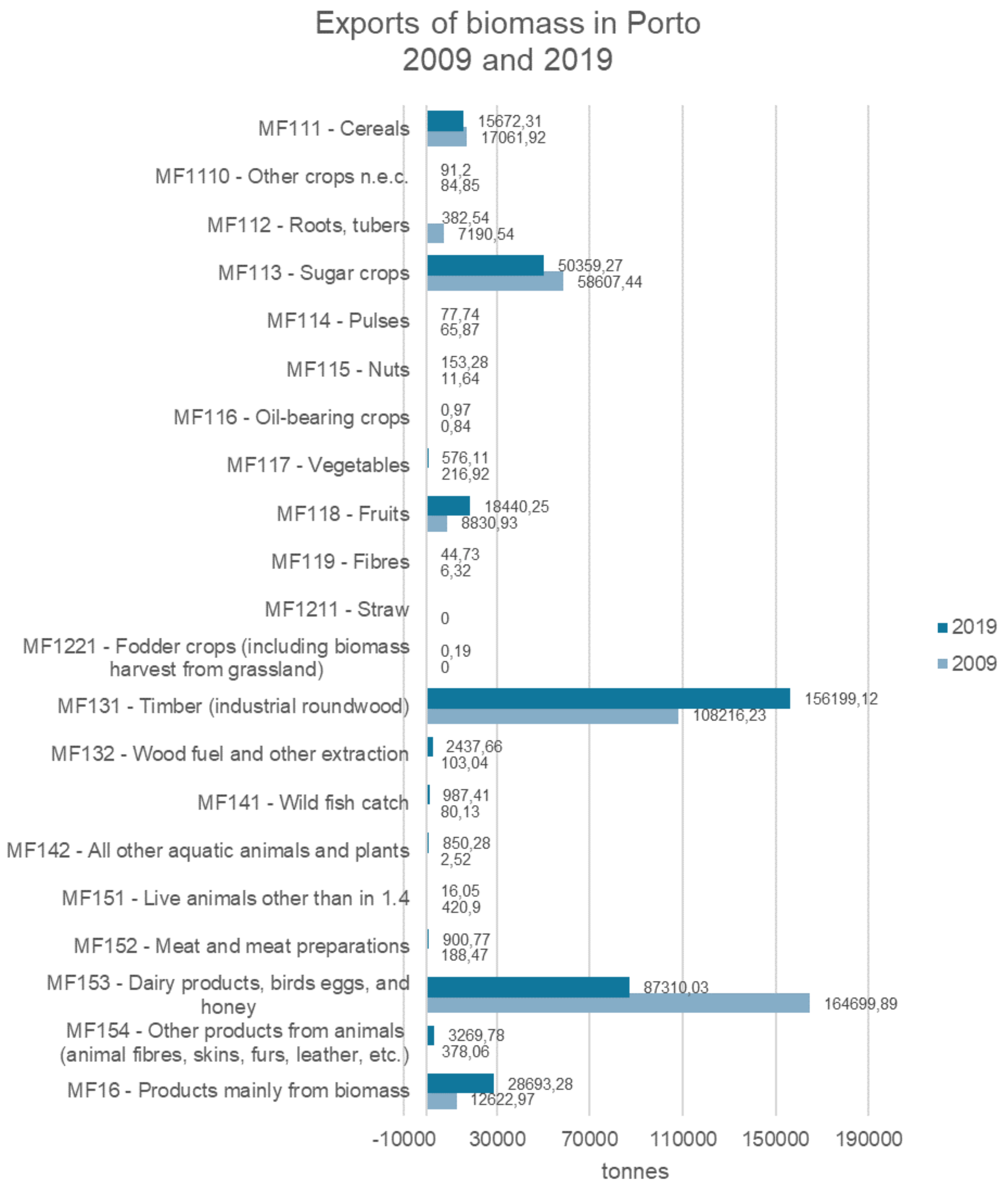


Figure 14. Exports of biomass in Porto (interactive chart) [source: INE, 2022]

As most of the companies has only their headquarters in the city, lot of these materials do not have a transformation phase in Porto but are just transiting through the city, with exception of sugar crops and cereals.

4.3. Domestic Material Consumption

The domestic material consumption (DMC) represents the quantities that are consumed in the City of Porto, and it is calculated by adding the domestic extraction with imports and subtracting exports. **In 2019, the DMC of Porto was 856,160.7 tonnes in total, representing a DMC *per capita* of 3,95 tonnes**. This amount added up with 53,854 tonnes of secondary materials forms the input flow to the processed materials (910,014.9 tonnes in 2019), which was split up into energetic use (72.17%) and material use (27.83%), 656,799 tonnes and 253,216 tonnes, respectively.

The energetic use (eUse) powers the local economy, it includes not just materials needed to generate technical energy, but also feed and food, which are the principal energy sources for livestock and people (Bellstedt, Carreño, Athanassiadis, & Chaudhry, 2022).

The eUse results in emissions to air (DPO emissions with 489,464 tonnes), as well as to land, in the form of solid and liquid wastes – 167,336 tonnes that ended up at the end-of-life (EoL) waste.

The material use (mUse), with 253,216 tonnes, split up evenly (almost 50% each) in gross additions to stock (131,758 tonnes), such as infrastructures and goods that stay in the city for more than one year and throughput materials (121,458 tonnes) that ended up at EoL waste. Material use 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. The throughput materials are material 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 provision (Bellstedt, Carreño, Athanassiadis, & Chaudhry, 2022).

4.4. Waste

The waste output of Porto, found on the right side of the Sankey Diagram, is the last component of the material flow accounting. For this analysis only urban waste (which includes mixed waste, food and vegetal waste and recyclables [paper, metal, plastics, glass, WEEE and batteries] from residential sector and some commercial sectors such as restaurants, hospitals, etc.) was included in the accounting, since the industrial waste information only exists at country scale and its downscale does not reflect the reality of the municipality of Porto, as it will be explained in the data quality part.

Thus, waste totalled 143,071.78 tonnes in 2019, a decrease of 2.9% from 2009 (147,296.59 tonnes), this decrease corresponds with a period of economic decline and decreasing purchasing power. During this period the waste collection system also had some adjustments that exlcluded some of the large waste producers from the municipal waste collection system.

The waste was classified in accordance with the EWC-Stat Categories from Eurostat[4], following the guidance for statistical waste nomenclature and the UCA methodology (Annex 2 – Waste material scope).

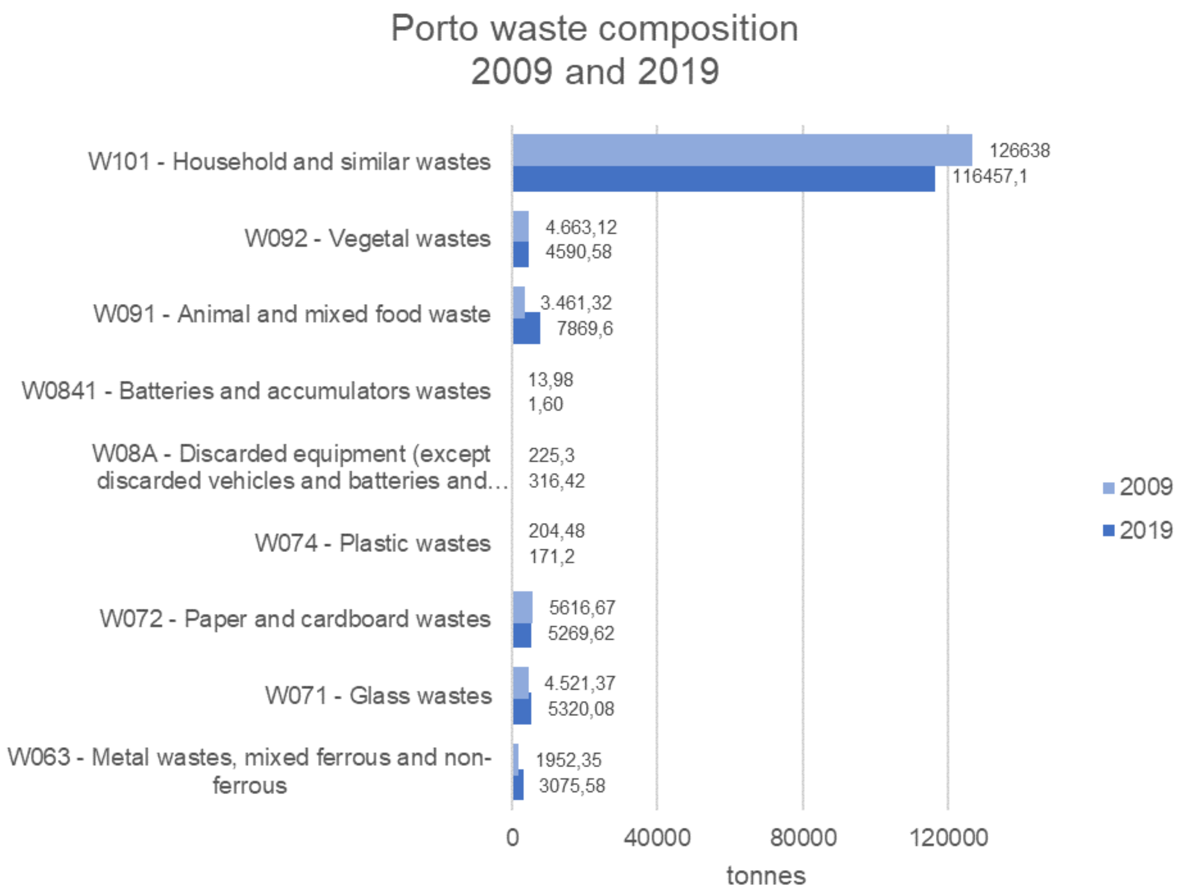


Figure 15 - Waste composition (interactive chart) [source: LIPOR and Porto Ambiente, 2022]

The largest fraction was classified as "household and similar wastes" (EWC-Stat categories) with more than 80% in both years. In this fraction was included the mixed waste collected, and other waste streams that doesn't fit into other EWC-Stat categories, such as furniture, scrap iron, polystyrene, light bulbs and ink cartridges/toners. **The recyclable waste, namely mixed food waste, vegetable/green waste, metal wastes, paper & cardboard, glass, plastic packaging and electric and electronic equipment (WEEE) totalled 26,614.68 tonnes**

[4] Eurostat (2010), Guidance on EWC-Stat Categories

(2019), with mixed food waste (7,869.60 tonnes), glass (5,320.08 tonnes) and paper & cardboard (5,269.62 tonnes) as the three largest streams.

The total end-of-life waste in 2019, was 219,080 tonnes. This splits up as DPO waste (165,226 tonnes) as well as secondary materials totalling 53,854 tonnes. The first one corresponds to the material left after recycling or not subjected to it in the first place, and the second one consists of materials from recycling, where 54.74% (29,482 tonnes) made it back to processed materials and 45.26% (24,372 tonnes) were exported.

Regarding waste treatment, urban waste collected in the City of Porto is almost all subjected to recycling and incineration with energy recovery (waste-to-energy), at LIPOR[5] facilities, outside the city boundaries. Recycling (RCV_O in the Figure 16) in the UCA method bundles into one group various operations that take place outside of Porto such as organic valorisation (industrially) and sorting or separation facilities. To those is added the organic valorisation (local composting) that is the only waste treatment operation that happens inside the city.

Although waste-to-energy still prevails over recycling, during the two reference years there was a growth in recycling (26.6%) and a decrease in waste sent to waste-to-energy facilities (-7.8%).

Regarding the waste sent to landfill, only the refuse of composting plant (42 tonnes) and waste-to-energy (11.938 tonnes) were sent to landfill, from a total of 530,930 tonnes produced in LIPOR's region (8 municipalities where Porto is included) in 2019, the equivalent to 2.26%, according to the official data included in the report published by the Portuguese Environmental Agency (APA, 2020). Since this data is only available at the regional-level and corresponds to indirect waste that is the end result of waste treatment processes, it has not been included in the UCA study.

[5] LIPOR is an association of municipalities of the Greater Porto Region which is responsible for the management, recovery and treatment of the municipal waste of its eight associated municipalities, where Porto is included.

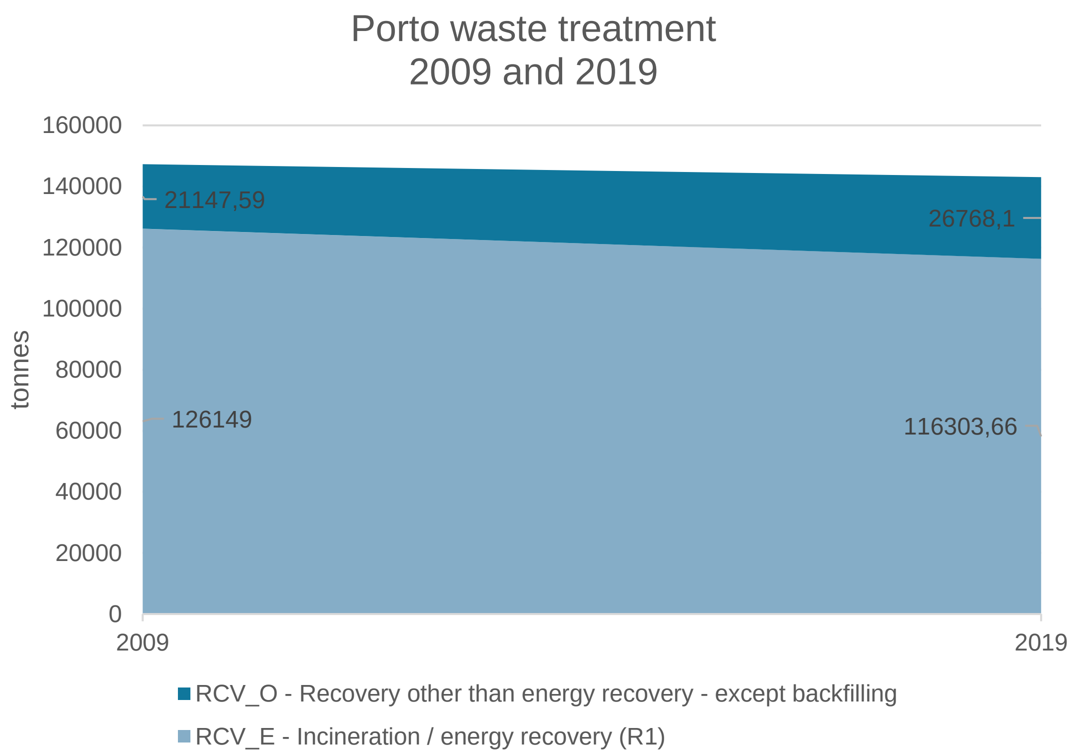
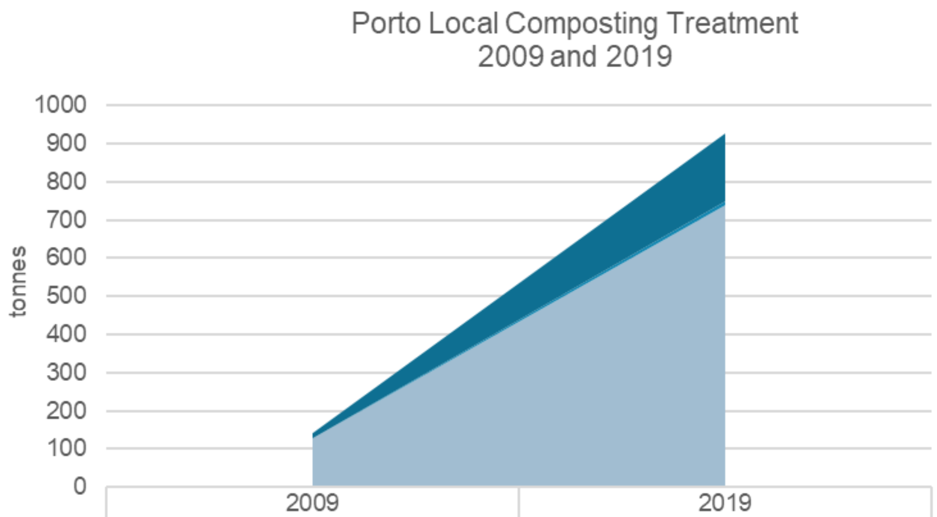


Figure 16 - Waste treatment distribution ([interactive chart]) [source: LIPOR and Porto Ambiente, 2022]

Regarding biowaste local treatment there was in the city, in 2019, three types of composting: home composting, with more than 1,850 residential compost bins in residential houses; voluntary community composting[6], with 8 compost bins available in 5 locals of voluntary community composting; and urban vegetable gardens composting with 440 compost bins. The biowaste local treatment grew more than 500% between 2009 and 2019, from 142 tonnes in 2009 to 927 tonnes in 2019. This growth reflects the strategy of promoting local treatment instead of waste collection in order to minimise waste transport and consequently, associated operational costs and GHG emissions.

[6] Voluntary community composting is different from City community composting. The first one is managed by a volunteer, while the second is managed by a composting master hired to support maintain and manage the composting system, answer and clarification of doubts and dissemination of the project.



	2009	2019
Urban Vegetable Gardens Composting	14,4	176
Community Composting	0	11
Home Composting	127,6	740

Figure 17. Local composting treatment ([interactive graphic](#)) [source: LIPOR and Porto Ambiente, 2022]

5. Material stock in Porto

Determining and analysing the material stock of a city can, similarly to the material flow accounting, also be a data intensive endeavor. The intensity depends on the scope and the data availability. For the Urban Circularity Assessment, the scope includes all residential and some non-residential buildings in the municipality. Unlike the material flow quantification, the analysis is not done for one or several specific reference years, but considers all buildings that have been constructed and still exist, up until and including 2022 (year of study). The aim is to quantify the materials that every single building contains and represent them spatially on a map. Depending on the data availability around building typologies, age cohorts, building height and material intensities, different, specific quantifications and investigations can be made.

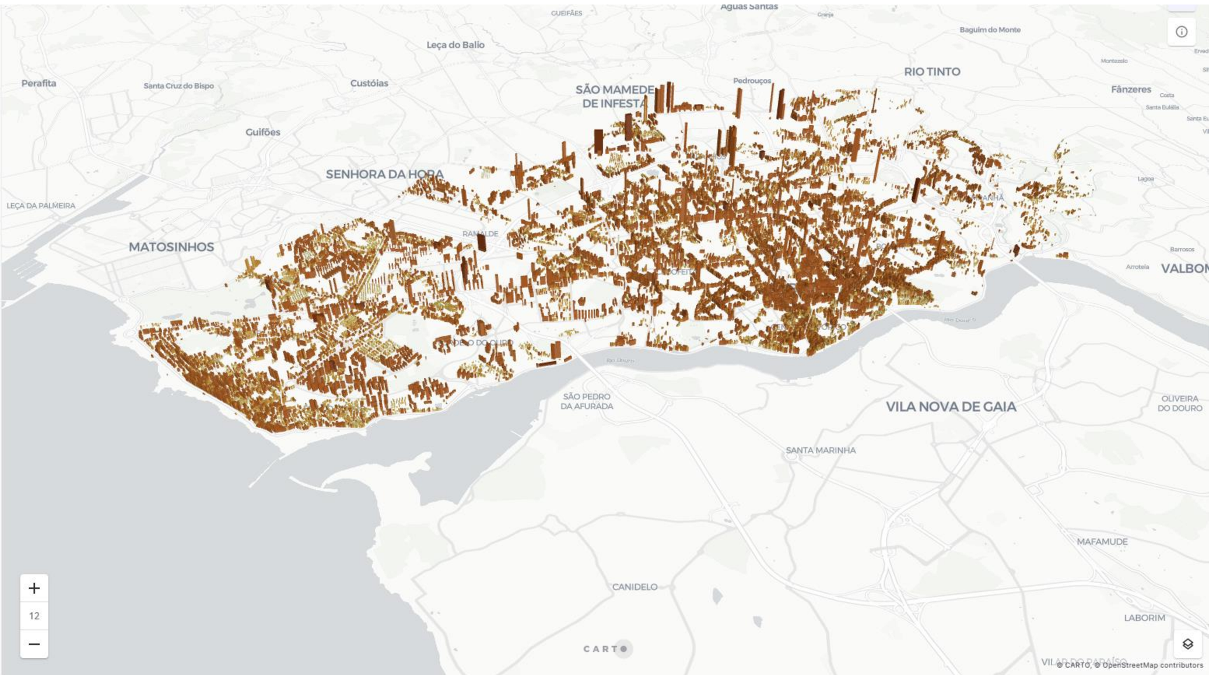


Figure 18 - Map of Building Material Stock in Porto expressed in tonnes

5.1. Building typologies in Porto

Typologies are an essential component of material stock of buildings. For Porto it was defined taking into account the description of the building in the attributes of shapefiles provided by the Municipality of Porto, and the number of floors (estimated as described in data quality part).

The building typologies were developed to fit the ones available in the material intensity database of Miatoo, *et al*. (2019) study (more detailed information in the data quality part) where four typologies are defined:

- Detached houses (when the description is 'Vivenda-casa' or 'Palácio Particular');
- Residential apartment buildings (when the description is 'Prédio' and is below or equal to 4 storeys);
- Residential high-rise buildings (when the description is 'Prédio' and is above 5 storeys);
- Non-residential (all other buildings, such hotels and houses for elderly people).

In total, **45,035 buildings** were analysed in the municipality of Porto, which corresponds to residential and some non-residential buildings, and comprises 69.5% of the buildings identified in its Municipal Master Plan. Most of the buildings (62.3%) are residential detached houses. This is followed by residential apartment buildings (23.3%) and residential high-rise buildings (13.6%). Only 0.7% of the buildings here analysed are non-residential, such as hotels and houses for elderly people.

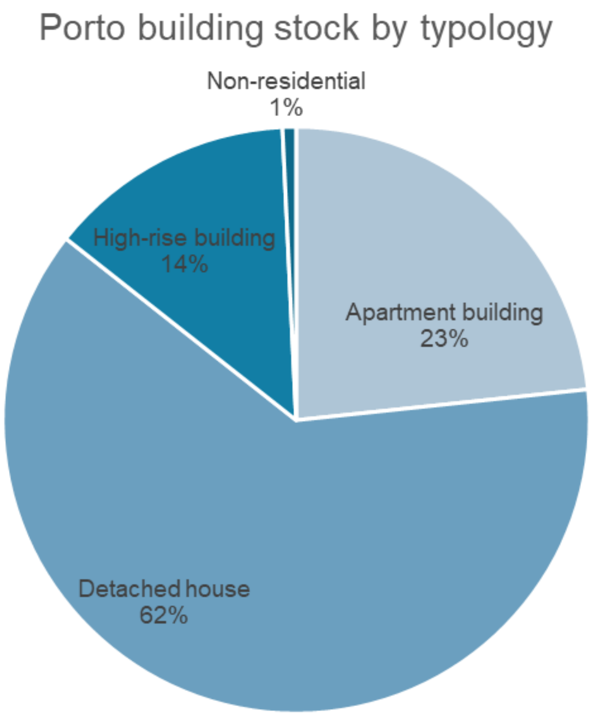


Figure 19 - Porto building stock by type of building (interactive chart) [source: Municipal buildings database, 2022]

5.2. Analysis of Material Stock

Many assumptions needed to be made in order to get some overview of the material stock accounting for Porto, so the analysis of its results should be careful (more detailed information in the data quality part). However, an estimation was made to show the potential of the analysis and also to demonstrate what kind of information we can take from it.

The material stock of Porto's buildings was estimated with the building typologies developed in the previous part and the material intensities of 13 construction materials (mortar/plaster, lightweight concrete, concrete, steel, bricks, timber, glass, synthetic insulation materials, mineral insulation materials, other insulation materials, bituminous waterproofing materials, flooring materials and other materials n.e.) from Miatoo, *et al.* (2019). To obtain it, the gross floor area (estimated) for each building was multiplied by its associated material intensity, which depends on the typology of that building. In the end, it is estimated that Porto's **building stock weighs approximately 28 million tonnes**.

By spatialization of the material stock, it is possible to map the materials stored within the city and identify some zones with higher material intensity, however, this representation for Porto is not accurate since the building data does not have the main features needed for the analysis and they had to be estimated and take assumptions to get it (see data quality part).

The map at the beginning of this section shows us that the greater material intensity of buildings seems to be in the historical city (older area of the city), where even a number of renovation and reconstruction projects are already underway and where a high potential for renovation or demolition can be seen in the coming years. It means that a lot of material could soon become available to be reintegrated into the economy and satisfy future resource use demands. This kind of analysis allows us to understand the quantities and the location of Porto's resources.

Considering the materials assessed, bricks represent the vast majority of the material stock approximating 55% of the total mass. Together with mortar/plaster and concrete (lightweight concrete and concrete), they represent the most representative materials in terms of mass (93%).

From a circular economy perspective, perhaps the most important strategy would be to maintain the building stock, however when this is not possible, it is important to know what kind of materials could be reused or recycled. According to the analysis made for Porto, the reuse of bricks and the reuse or recycling of mortar/plaster and concrete would be the most desirable.

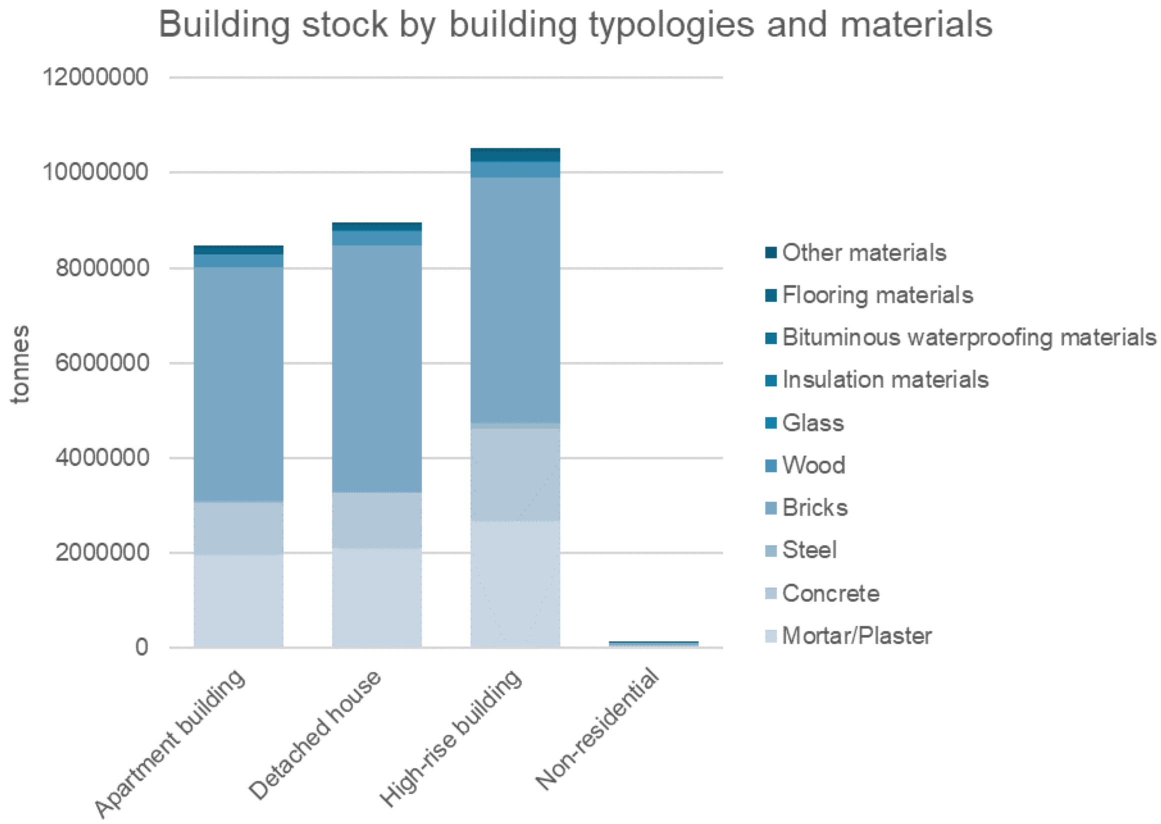


Figure 20 - Building stock by building typologies and materials [source: own calculations from municipal buildings database and material intensities from Miatoo et al]

From the point of view of building typologies, the high-rise buildings (buildings with more than 5 storeys) are responsible for the highest share of the material stock (37.46%) in Porto, followed by detached houses with 31.90%.

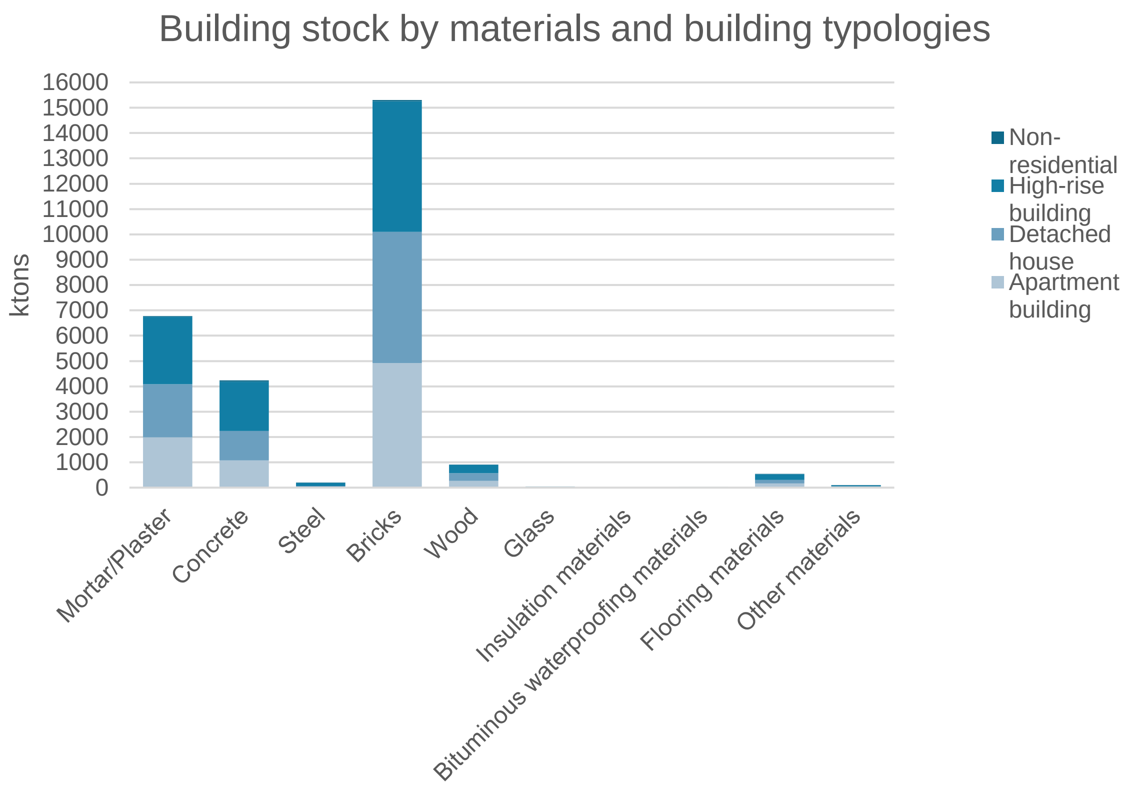


Figure 21 - Building stock by materials and building typologies [source: own calculations from municipal buildings database and material intensities from Miatoo et al)

6. Analysis of Flows and Stocks: Measuring Indicators

To monitor the progress of the local economy towards circularity, a number of indicators were proposed and measured. Altogether, these indicators depict several facets of circularity of the sector. As such, they need to be considered in combination rather than in isolation when assessing circularity. In addition, these indicators can be compared to other cities or spatial scales (such as the country level). However, this has to be done with great care and use of the contextual elements in the previous sections of the report. Finally, the value measured from these indicators can be traced over time to track the city's progress towards circularity. The below table provides the value for two reference years, where possible, and the percentage change between the two.

Indicator	Description	Formula
Input Socioeconomic Cycling Rates (ISCr)	Input Socioeconomic Cycling rate measures 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
Remaining non-renewable primary resources	This is calculated balancing indicators (so that the MFA inflows equals outflows)	
Remaining interim outputs	This is calculated balancing indicators (so that the MFA inflows equals outflows)	
Material recovery		Material recovery = (recycling + backfilling)/ EoL waste
Direct Material Input (DMI)	Consists of domestically extracted materials (domestic extraction [DE]) and imported raw material 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	DPO = DPOemissions + DPO waste

	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 result of product use (dissipative flows)	DPOemissions = eUse – solid and liquid wastes DPOwaste = EoL waste - SM
Domestic Material Consumption (DMC)	DMC quantifies the entire amount of material utilized 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 natures. 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 floes 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 Material (PM)	PMs are defined as the sum of DMC and secondary materials (SM) inputs. PMs were wither 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 Material (SM)	Secondaru materials refers to the amount of materials, which undergo material recovey 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	(1) NAS = Gross addition to stock – Demolition and discard (2) NAS = DMC + Balancing items input – Balancing items output

	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).	
Physical Trade Balance (PTB)	PTB of a region. Net imports indicate greated imports than exports, whereas net exports indicate greater exports than imports	PTB = Import - Export

Indicator table

Indicator	2009	2019	Unit	Change from 2009 to 2019 (%)
Input Socioeconomic Cycling Rates (ISCr)	2.0	5.9	%	203.5%
Output Socioeconomic Cycling Rate (OSCr)	2.5	7.6	%	206.7%
Input Ecological Cycling Rate Potential (IECrp)	82.0	74.4	%	-9.3%
Output Ecological Cycling Rate Potential (OECrp)	81.5	74.0	%	-9.2%
Input Non-circularity Rate (INCr)	8.9	10.8	%	21.5%
Output Non-circularity Rate (ONCr)	11.3	13.9	%	22.8%
Remaining non-renewable primary resources	7.1	8.8	%	24.1%
Remaining interim outputs	4.7	4.5	%	-3.8%
Material recovery	8.8	24.6	%	180.6%
Direct Material Input (DMI)	1,593,120.1	1,286,883.5	tonnes / year	-19.2%
Domestic Processed Output (DPO)	841,533.6	654,689.8	tonnes / year	-22.2%
Domestic Material Consumption (DMC)	1,075,318.9	856,160.7	tonnes / year	-20.4%
Domestic Material Consumption Corrected (DMCcorr)	1,075,318.8	776,704.1	tonnes / year	-27.8%

Local and Exported Processed Output (LEPO)	841,534.0	654,690.3	tonnes / year	-22.2%
Processed Material (PM)	1,096,705.7	910,014.9	tonnes / year	-17.0%
Interim Outputs (IntOut)	862,920.4	708,544.0	tonnes / year	-17.9%
Secondary Material (SM)	21,386.9	53,854.2	tonnes / year	151.8%
Net Addition to Stock (NAS)	233,785.3	201,470.9	tonnes / year	-13.8%
Physical Trade Balance (PTB)	1,074,487.4	855,916.5	tonnes / year	-20.3%

Indicators that were chosen and their development over time

The indicators here analysed were selected under [CityLoops D4.4. Urban Circularity Assessment Method](), developed by Metabolism of Cities, and they allow to measure how much a city is circular, accordingly it was defined in the CityLoops Project, in particular, vision element 3 "Closing material loops and reducing harmful resource use".

The indicators are distinguished between indicators of scale, which allow dimensioning urban metabolism flows, and indicators of circularity which allow analysing the degree of loop closing and its efficiency (Bellstedt, Carreño, Athanassiadis, & Chaudhry, 2022). For better understanding of each indicator the CityLoops D4.4. Urban Circularity Assessment Method should be consulted.

In 2019, the processed materials (PM) were converted by around 77.86% (708,544 tonnes) into interim outputs (IntOut), decreasing just 1% from 2009. The remaining, 201,470 tonnes (22.14%) were added to in-use stocks of buildings, infrastructure, and durable goods (NAS) (Mayer, et al., 2018). The material recovered in 2019 represents 24.6% of the total End-of-Life (EoL) that was used as secondary resources, while in 2009, it was only 8.8%.

The indicators of circularity chosen to analyse the achievement of the degree of loop closing, measure material flows relative to interim flows PM and IntOut (Mayer, et al., 2018). The input socioeconomic cycling rate (IScr) that measures the recycled and downcycled materials reprocessed as secondary material remained low in 2019, at 5.9%, however increasing by 203.5% from 2009. The contribution of the secondary materials to IntOut, represented by the indicator OSCr (Output Socioeconomic Cycling Rate) was also too low in 2019, at 7.6%, however also registering an increase of 206.7% from 2009, revealing a great improvement in the substitution of virgin materials.

In terms of ecological cycling, although indicated only as theoretical potential (Mayer, et al., 2018), was very high: the input ecological cycling rate potential (IECrp), indicating the contribution of domestic material consumption (DMC) of primary biomass in PM, was 74.4% in 2019, and the Output Ecological Cycling Rate Potential (OECrp) which measures the contribution of Domestic Processed Output (DPO) from biomass in IntOut was 74.0%, however both ecological cycling rates has decreased by 9.3% and 9.2% from 2009, respectively. Notwithstanding the observed decrease of these indicators, their high values show the potential for moving forward circular economy through developing and implementing a circular bioeconomy strategy.

The non-circularity indicators measure the contribution of eUse of fossil energy carriers in PM and IntOut thus quantifying the share of material flows that do not qualify neither for socioeconomic and ecological loop closing (Mayer, et al., 2018). It means that the input non-circularity rate (INCr) measures the flows that cannot be recycled or reused, and although its value was not very high (10.8%), it suffered an increase of 21.5% between 2009 and 2019. Moreover, it resulted in an Output Non-circularity Rate (ONCr) of 13.9% which also grew from 2009 (22.8%).

Between 2009 and 2019, Porto has decreased its domestic material consumption (DMC) by 219,158 tonnes (-20.4%) with a high increase (151.8%) of secondary materials (SM), which resulted in a great increase (203.5%) of the Input Socioeconomic Cycling Rate (ISCr). However, the consumption of fossil or non-circular resources has increased in the period analysed, possibly due to the growth of tourism intensity that tripled in the last decade, as well as the growth of people who seek the city to work or study and that consume resources in the city. Adding to this its dependence on imports, the city can lead to an unsustainable situation due to its external dependence on materials and energy.

The material productivity and material intensity indicators could not be determined due to the absence of GDP data at the municipal level.

8. Data Quality Assessment

Numerous datasets were collected and considered in the Urban Circularity Assessment and this section qualitatively assesses how reliable the data used is. In some cases, datasets were not available for some materials or for some lifecycle stages at the city level. Therefore, estimations needed to be done by looking at data at higher spatial scales (region or country) and downscaling it with proxies, described in the part on data gaps and assumptions.

The overall data quality is considered as well and depicted in the data quality matrix below. It is expressed through four data quality dimensions: reliability, completeness, temporal correlation, and spatial correlation. Each dimension has its criteria for the ranking of high (green), medium (yellow) and low (red), which is based on this [Pedigree report]() and shown in the table here. There may be additional explanations in some cells, as supporting information.

Rating	*Reliability*	*Completeness*	*Temporal correlation*	*Spatial correlation*
high	*Reviewed or measured data*	*Data exists for all of the single sub-material groups and/or materials*	*1 data less than 3 years difference to the time period of the data set*	*City-level data*
medium	*Estimated data*	*Data exists for most of the single sub-material groups and/or materials*	*2 data less than 6 years difference to the time period of the data set*	*Regional-level data (NUTS 3)*
low	*Provisional data*	*Data exists for the main material group only*	*3 data less than 10 years difference to the time period of the data set*	*NUTS 2 and country-level data*

Data quality matrix

Lifecycle stage	Reliability	Completeness	Temporal correlation	Spatial correlation
Domestic extraction - MF1 Biomass	Estimated data	Data was found for most single materials that are extracted locally	Data from 2009 and 2019	City-level data of cropland area but regional-level data (NUTS 2) for crops yields
Imports & Exports				
MF1 - Biomass	Reviewed and measured data	Only considered international trade	Data from 2009 and 2019	City-level data
MF2 - Metal ores (gross ores)	Reviewed and measured data	Only considered international trade	Data from 2009 and 2019	City-level data

MF3 - Non-metallic minerals	Reviewed and measured data	Only considered international trade	Data from 2009 and 2019	City-level data
MF4 - Fossil energy materials/carriers	Reviewed and measured data	Only considered international trade	Data from 2009 and 2019	City-level data
MF5 - Other products	Reviewed and measured data	Only considered international trade	Data from 2009 and 2019	City-level data
MF6 - Waste for final treatment and disposal	Reviewed and measured data	Only considered international trade	Data from 2009 and 2019	City-level data
Waste	Reviewed and measured data	Industrial and commercial waste wasn't considered	Data from 2009 and 2019	City-level data
Material stock	Good material intensities but do not adequately represent Porto buildings and scarce cadastral material	Scarce attributes for each building, namely gross floor area and year of construction	Data material intensities available from 1900-2007	Statistic subsection data for some essential data like year of construction

8.1. Data Quality

The data gathered for this study is mainly public and some municipal data from:

- National Statistics Office (INE): biomass domestic extraction (temporary and permanent crops and olive production) and international trade data (imports & exports);
- Directorate-General of Energy and Geology (DGEG): energy consumption (fossil energy material) assumed as imports;
- LIPOR and Porto Ambiente: household waste collection and treatment;
- Municipality of Porto: material building stock.

Most of the data is at local scale which to some extent allows for some reliability of the results presented. The exception goes for material stock where a lot of work must be done to improve the Material Stock Assessment (MSA) and get a more reliable picture of the city.

As the data quality matrix can show us, the quality of the data is good for almost all lifecycle stages (LCS) and material groups:

- **Reliability** – very acceptable data. For half of the LCS the data were measured (imports & exports and waste), for domestic extraction the data were estimated and for material stock the data was provisional.
- **Completeness** - for domestic extraction and imports & exports the data scores is medium, while for material stock is low.
- **Temporal correlation** - the data was always from the reference years (2009 and 2019) what qualifies it as very good, except for stocks where available material intensities data only until 2007.
- **Spatial correlation** - The data is very good for all LCS with city-level data employed. The exception goes to material stock in which some information, such as the year of construction of each building, was aggregated by statistical subsection.

8.2. Data Gaps and Assumptions

Domestic Extraction

Porto only has a few biomass domestic extraction. The SCA data was used for 2019. To measure this data in Porto for 2009, the same approach was applied, e.g. cultivated land use area and yield information were used. From 2009 Agricultural Census - INE, at city-level, data of cultivated land use area (including fodder crops and grazed biomass) was multiplied by information on crop yield at a NUTS2 level to calculate the weight of extracted crops.

Material Flow Accounts from INE were used to determine which materials could be extracted in Porto, if there isn't extraction in the country so they can't be extracted in the city at all. That is the case with fossil energy materials /carriers (INE, 2021).

For mining extraction, satellite analysis was carried out and there wasn't any area of extraction identified in the city. Despite that, there are some companies registered in Porto with NACE Code of Extractive Industry ("other service activities related to extractive industries"; "extraction and preparation of metal ores"; "other extractive industries"), that we assume to be from headquarters, since from the report author's knowledge of the territory, the mineral extraction activity itself does not exist in Porto.

Additional data or information was not found about other types of domestic extraction taking place in the City of Porto.

Imports & Exports

Data on imports & exports at the city level is very hard to obtain. For Porto, only international trade data was used. This was provided by National Statistics Office (INE) at city-level for all material categories, including information regarding the stage of manufacturing. The original data was disaggregated by product into the Combined Nomenclature (8 digits) which was converted to the EW-MFA material categories through the information in Annex 4 of the EW-MFA Questionnaire and to the EW-MFA stage of manufacturing by the Annex 5 of the EW-MFA Questionnaire.

For imports of fossil energy materials (MF4) the data from this database wasn't considered since we have more accurate data and specific data from DGEG (Directorate-General for Energy and Geology) that has statistical data for Natural Gas consumption and sales of petroleum products at city-level. Since Porto does not have domestic extraction of fossil energy materials, all energy consumption was considered import. The data from the international trade database, related to these materials, only was considered the export data, to avoid double counting.

To the report author's knowledge, Porto obtains many of the products it consumes from neighbouring municipalities, mainly biomass products, which arrive in the city by road or rail. The data related with the national trade (i.e. goods transported inside the country between municipalities) is available at NUTS2 level from "Communications and Transportation Statistics" (INE) disaggregated by goods transported at NST 2007 codes (first level). These codes only can be converted to MF 1-digit-level. More detailed information was necessary to match with the Mayer *et al*. framework. Since it wasn't possible to get more detailed information (MF 3-digit-level) this data was excluded from the UCA in order not to distort the final results.

Domestic Material Consumption

As DMC is a measured indicator (DMC = DE+IMP-EXP) no extra assumptions were made, neither data needs to be collected to calculate this indicator. However, it inherits all assumptions and uncertainties from the two previous sections.

Waste

The City of Porto only has biowaste local treatment schemes (home, community and urban vegetable gardens composting). For this reason, almost all the urban waste produced inside the boundaries of the city is exported to LIPOR facilities (outside Porto's boundaries) for treatment and valorization (the City of Porto is part of LIPOR, sharing their facilities to urban waste valorization). In terms of importation of waste, the data provided by international trade presents a very low value that must correspond to throughflows.

The data used in this study was only urban waste (that includes mixed waste, food and vegetable waste and recyclables [paper, metal, plastics, glass, WEEE and batteries] from residential sector and some commercial sectors such as restaurants, hospitals, etc.) collected by Porto Ambiente (municipal waste collection company) and treated or valued at the facilities of LIPOR (waste treatment company), located in the neighbouring municipalities, outside the city boundaries. The data provided for these two companies (type of waste collected and type of treatment) is at city-level and covers selective and mixed waste collection, providing the amount of different waste streams (food waste, green/vegetable waste, glass, paper, package, between others), that were classified as EWC-Stat categories (taking in account the Eurostat

Guidance on classification of waste according to EWC-Stat categories) to corresponding to categories needed for the UCA method.

Additional information was provided by LIPOR regarding biowaste local treatment schemes (home, community and urban vegetable gardens composting). The biowaste treated locally, inside the city boundaries, was estimated by the number of composter bins and their capacity of treatment.

For non-household waste (industrial waste) there is data at the country level for all types of waste (EWC-Stat) by economic activity (NACE Rev 2) and by type of treatment from the National Statistics Office (INE). The exercise of downscaling this data through the number of employees by the economic activity sector was made. However, the results revealed a picture that raises many doubts as to its reliability and were excluded from the UCA.

Another reason to exclude this data from the study was the impossibility to consider the local data provided by the local companies that collect and treat household and similar waste in Porto, due to the risk of double counting.

To obtain a more realistic picture of what type of waste is produced in the city and its destination, more reliable data should be obtained from the Environmental Portuguese Agency (APA) where companies register their information. However, most of the time this kind of information is confidential and non-disclosable.

Material Stock

For the analysis of the building stock, data from the Municipality of Porto was used. The following information on the buildings (residential and some non-residential) was obtained: geometries and description of the building.

To get the data needed to employ the MSA method, and as already noted before, a lot of assumptions needed to be made which resulted in a deviation from the real picture of the material stock of Porto. However, it is possible to understand the potential of the tool and where to apply efforts to improve this study to get crucial information to tackle circularity in the city.

The main assumptions made are as follows:

- Gross floor area - It was assumed as the area of the polygon of each building multiplied by the estimated number of floors;
- Height - was estimated by subtracting the ‘cota’ (elevation of the bottom of the building above sea level) from the elevation of the building;
- Number of floors - estimated assuming a ceiling height of 3 meters. It was calculated by dividing the height by 3;
- Year of construction - The existent information was aggregated by statistical subsection and by age cohorts. To estimate the age cohort of each building it was assumed the most predominant date in the subsection where the building is located.

In addition, in the absence of material intensities for Porto or Portugal buildings reality, to calculate the material stock it was chosen to apply available material intensities from European Southern Countries for its similarity in the heating degree days (Nemry & Uihlein, 2008). The material intensities used were the same used by Miatoo, *et al.* (2019) to calculate the total material stock of Padua (Italy), since they report material intensities for 13 materials commonly used in construction (mortar/plaster, lightweight concrete, concrete, steel, bricks, timber, glass, synthetic insulation materials, mineral insulation materials, other insulation materials, bituminous waterproofing materials, flooring materials and other materials n.e.) and for four different building typologies (Detached houses, Apartment buildings, High-rise buildings and Non-residential buildings).

Finally, the material intensities have been linked to the building dataset matching the typologies defined (see building typologies part) and estimated year of construction.

The data used is of low quality and many assumptions were made and as such the results should be analysed with great care and that should be taken into consideration that they are not a reliable picture of Porto's Material Stock, however, a first exercise was made to understand how to apply these methods and what kind of information we can take to improve city's circularity.

A lot of work must have to be done to improve the building data gathered, and a research opportunity as well is highlighted to get material intensities to Portuguese buildings.

9. Analysis of Data and Indicators: Assessing Circularity

This last section of the UCA report analyses the status quo in terms of material circularity in Porto. It takes into account the findings visualised in the (Sankey) diagrams and the conclusions from the indicators. The overall results of the Urban Circularity Assessment are discussed and interpreted here, before providing recommendations to accelerate the transition towards a more circular Porto.

9.1. Insights on Status Quo of Porto

The Urban Circularity Assessment for the City of Porto was conducted for 2009 and 2019 and was analysed a set of indicators of scale and circularity. And the main conclusion we can quickly draw is that the city still has a long way to go to achieve a circular economy, despite all the initiatives taking place.

Of 910,015 tonnes of processed materials (PM), 856,161 tonnes were primary resources and let to 708,544 tonnes of IntOuts. Where 5.9% of all PMs and 7.6% of all IntOuts were secondary materials. A potential of 74.4% and 74.0% for input and output ecological cycling rate potential, respectively, was found, however with a decreasing when compared to 2009.

Around 72.17% of the materials processed locally are used for energetic uses while only 27.83% is for material uses, where 52% of them are for construction and renovation of buildings. Energetic use is responsible for the majority of emissions, almost the same weight compared with export flows, comprising challenges such as climate change.

The quantity of waste generated that follows a circular economy practice (reuse, recycling, etc) is also still small, representing only 5.9% of the total processed materials. This ISCr value is low but not so far as the estimated value founded for EU28 in 2014 by Mayer, et al. (2018) (ISCr of 9.6%), and its higher than the estimated ISCr of 3.2% for Portugal in 2018 (own estimation following Mayer *et al*., 2018 method and eurostat sources). The lower values are surprinsing take in consideration that Porto, as well UE28, has strict waste regulations, elaborate waste collection and recovery systems, with a recovery rate that reached 37.4% in 2019 (CMP, s.d.). The results reveals that is important to further improve the recycling and downcycling of EoL waste, however to achieve circular economy goes far beyond increasing this values (Mayer, *et al*., 2018).

Despite Porto's ambition to become a circular city by 2030 and the launch of [Porto Climate Pact] by the beginning of the year 2022 to mobilize collective action to decarbonize the city, it is clear from the UCA analysis that Porto still is a linear and carbon-rich city processing yearly approximately 777 kt, adding 132 kt of additional stock and reinjecting only 54 kt in their economy. The UCA makes clear the efforts that still need to exist towards a circular economy.

In addition, the material stock assessment (MSA) illustrates the weight of Porto, which building stock amounts to 28,000 kt (or around 130 t per capita). The building stock study provides insightful information about how to reduce the extraction of virgin materials and increase the reuse and recycling of construction materials. MSA allows us to know where the materials are and when they are expected to become available to future demands. Finally, the MSA not only allows you to define a circular strategy in the construction sector but also define where to locate reuse hubs, develop materials marketplace and estimate jobs creation (in material handling, logistics, etc.).

The results of UCA just provide a first insight about the materiality of Porto's economy and it highlighted the need to improve and deepen existing data on these topics, mainly related to buildings, in order to get a more feasible and reliable picture of Porto's circularity. These future improvements will allow UCA to become a solid tool for Porto to support decision-making and define policies and concrete strategies.

Numerous data sources were analysed and processed to carry out the UCA analysis, being possible, in the case of Porto, to obtain data at the city-level scale for material flows which increases the accuracy and reliability of the results. The same does not apply to the building material stock where it was necessary to make numerous assumptions to get some results and that compromised the quality of the results. Still, it provides a basis for understanding, using an accounting method that has been validated and used in a national and European context.

Further recommendations about how to use the results of this study and how to improve it can be found in the next section.

Despite the results of the UCA, it is important to note that Porto has defined in 2017 their circular economy strategy and a 2030 Roadmap as being at the forefront of the transition to a circular future. Porto have already ongoing several projects in the city focused on the efficient use of resources and circular economy that are not fully reflected in this analysis, since it is not always possible to quantify them, but that should be highlighted for the record:

- **Circular construction**
  - Material bank, since 1987 - receives and stores the demolition materials characteristic of the city's architectural heritage - tiles, balconies, etc. - which can be reused free of charge in the building rehabilitation or new construction by the Porto citizens owners. There is currently an ambition to expand the scope and space for other flows of demolition materials by promoting its circularity.
- **Circular Public Procurement**
  - The municipality has introduced some sustainable criteria to increase sustainable practices and sustainable procurement and reduce Porto's negative

impact. In 2021, an internal cross-departmental task force was created to carry out the construction of a Sustainable Public Procurement Policy, including circular principles. A public tender will be launched shortly to hire an external consultancy to manage, facilitate and support the construction of this policy and its implementation.

- **Circular Food System**
  - Urban vegetable gardens, since 1997 - to uphold regenerative local food production and facilitate healthy local food.
  - Dose Certa, since 2008 – The "Dose Certa" Project is being developed in restaurants and canteens. By accounting and characterizing (edible and nonedible food) the food waste produced it's possible to point out which type of food is wasted and correct the quantities that are served to the client thus reducing the food waste. Combining two paths - analysing food and waste produced and training chefs and workers for a more conscious planning of meals - it has been possible to reduce effectively the amount of food waste.
  - Embrulha, since 2016 – To reduce food waste in restaurants, a new biodegradable foodie bag was developed by LIPOR allowing citizens to take their leftovers home. We call it 'Embrulha.' The distribution of this reusable, free-of-charge package for leftover food among restaurants is an option for reducing food waste.
  - Zero Desperdício, since 2021– Zero Waste' Movement is a distribution network of food surpluses. A broad network of stakeholders from the food value chain (donors, redistributors and beneficiaries) commit to the challenge of food waste.
  - Organic market, since 2004 - short supply chain that promotes a close relationship between organic food producers and consumers.
  - Solidarity restaurants, since 2016 - provide more than 500 meals per day and several food products used in these restaurants are donated by organisations from the catering, restaurant sectors and distribution companies, contributing to the reduction of food waste.
  - Good Food Hubs, since 2021 - integrated in EEA Grants co-financed project 'Asprela + Sustentável' that aims to connect organic producers and consumers (using a digital platform/app to sales and face-to-face markets and events).
- **Servitization**
  - Municipal electric fleet, since 2017 - 70% of the municipal fleet are electric and renting.
- **Shared Infrastructures**
  - Multifunctional spaces that are reused for several uses.
- **Repair and Reuse**

- Reboot, since 2021 - integrated in EEA Grants co-financed project 'Asprela + Sustentável' that consists in a computer sharing and recycling programme through a computers repair training program and computers repair events. The repaired/recovered equipment will be donated to people that need it and/or social institutions to promote digital access.
- CREW/LIPOR and Repair Cafés - reconnect the community to the repair of electrical and electronic equipment, involving and empowering it with the necessary tools.
- REPLAY – contributes to divert toys from going to landfills and incineration, inviting citizens to donate their toys that would otherwise go to waste.
- School book bank, since 2013 – School Book Exchange Program
- Markets for sale of used materials – many markets available in the city to sell used materials.

- **Elimination (Single-Use Plastics)**
  - Adhesion to the Portuguese Pact for the Plastics, since 2020.
  - Preliminary Municipal Action to reduce the plastics in the municipality, since 2019.
- **Optimised Urban Waste Management**
  - Biowaste collection in commercial sector, since 2007 - door-to-door selective collection of biowaste (catering services, restaurants, coffee shops, canteens, hotels);
  - Biowaste collection in residential sector, since 2018 - selective collection of biowaste in this sector through door-to-door collection and since 2021 through street bins with access control. Both with the goal to promote the quality of the food waste collected.
  - Biowaste local treatment, since 2008 – Local treatment of biowaste thought composting, in private houses and urban vegetable gardens and since 2011 implemented community composting.
  - Zero Food Waste in Porto's University Canteens – Initial project in 2018 for Engineering Faculty where it is applied a mathematical model to predict meals and allowing improve meals management.
  - Selective collection – selective collection of various waste streams which are sent to sorting facilities promoting new raw materials. The selective collection is made door-to-door in HORECA and residential sectors, Ecocentres and Ecopoints.
- **Cooperation, Research and Innovation**

- Collaborative network on circular economy, since 2016 - a stakeholders' network to share experience, challenges and opportunities and to promote synergies to replicate circular economy actions.
- FoodLoop, in 2021/2022 – a circular entrepreneurship contest, promoted under CityLoops project, to stimulate innovation, new business models and entrepreneurship on circular economy applied to food system.
- Support on research, technology and innovation projects/initiatives – Aiming to accelerate the transition to circular economy and achieve circular goals, and, at the same time, support national research and innovation, Porto Municipality is supporting universities, faculties and research, innovation and entrepreneurship centres in applications for research grants and European funding programmes. The following projects are examples of some consortia that the Municipality supports or endorses:
  - Planning of routes in food transport of social solidarity projects – master's thesis (finished)
  - Governance of food systems towards circular economy in the digital age – PhD project funded by FCT (ongoing)
  - LIFEfoodCycle – application to LIFE funding for a Circular Economy MarketPlace (CEMP) for food waste prevention (ongoing)
  - GrowLIFE to a sustainable local consumption project – application to LIFE-2021-SAP-CLIMA-GOV call (starting in 2023)

- **Local resilience**
  - Municipal nursery – local production of native trees with exportation to the Porto Metropolitan Area.
  - Project 'We have a tree for you' – The municipality gives freely native trees for private gardens.
- **Education for sustainability**
  - Education for sustainability Municipal Plan, available every scholar year, since 90's - contributes to environmental literacy, acquisition of new skills and know-how, and learning with and in Nature. This plan includes a program – R'Circular – orientated to students of the professional education to apply circular economy projects promoting active participation, collaboration, and critical mass among young people on their daily choices.
  - Geração + Project, since 2014 – an integrated environmental education and training program promoted by LIPOR also applied in Porto that involves 68 social and educational institutions, working daily with almost 24,000 citizens at Porto.
- **Industrial Simbiosis**

- Developed the study of industrial metabolism and circular economy in the Porto Metropolitan Area (AMP) (2018).
- Portal SymbiOPOrto: The circular economy with and for the companies (2018) - A platform to promote the efficient use of the resources between AMP companies, contributing to the identification of potential partnerships and to establish industrial symbiosis network (deactivated).

9.2. Recommendations for Making Porto More Circular

As mentioned in the previous part, Porto has already well defined its circular economy strategy and its 2030 Roadmap to a Circular City where it has defined the pathway that Porto wants and needs to follow to tackle the circular economy. Nevertheless, the UCA study identified and highlights some opportunities which can be considered to make Porto even more circular:

- **Develop a monitoring system for the city's circularity**: Porto has a lot of projects ongoing that promote circular economy, however, for the time being, it is hard to understand its impact on the circularity of the city, since most of them are not measured and are not integrated into statistical data. To improve UCA study and get a most reliable picture of Porto's circularity, it is essential to quantify and compile data from these projects in order to integrate them in a future update of this study.
- For **material stock**, it is essential to improve the building cadaster with the information needed to carry out MSA, to get more feasible and accurate data, mainly height, gross floor area and year of construction of each building. This improvement is of high importance to map Porto's urban mine and to promote the reuse of construction materials. This information is also important to update material banks that exists in the city since 1987 where only heritage materials are available.
- **New research opportunities**: It is also an opportunity to promote scientific research related to material intensities of the building typologies characteristic of the city of Porto. Once again, to get more accurate data for material stock analysis and a clear picture of available materials that can be reused.
- **Develop a bioeconomy**: although Porto does not have a high weight of agricultural production, the city is a great source of biomass, mainly food waste, which should be intensely exploited to promote the development of new business models to create new materials and energy. Additionally, Porto has green spaces as its second usage of the land, covering 18% of the municipality, that can be capitalized to close the loop of the biomass material.
- **Develop a municipal policy of circular public procurement**: reinforce the introduction of circular criteria in new public procurement processes, promoting circularity in the acquisition of goods and services by the Municipality and the Municipal Companies.

- **Industrial symbiosis**: even with a low expression in the city, industries are a source of high consumption of materials and energy and should be on the radar for tackling a circular economy. Promote synergies among themselves and with other utilities in the city, such as reuse of heat, by-products, etc., to minimise the import of materials and energy consumption.

References

APA. (july de 2020). *Relatório Anual Resíduos Urbanos 2019.* Obtido de https://apambiente.pt/sites/default/files/_Residuos/Producao_Gest%C3%A3o_Residuos/Dados%20RU/RARU%202019.pdf

Bellstedt, C., Carreño, G. E., Athanassiadis, A., & Chaudhry, S. (2022). *CityLoops WP4 D4.4 Urban Circularity Assessment Method.* Obtido de CityLoops datahub : https://cityloops.metabolismofcities.org/library/1010979/

CMP. (2018). *Pessoas e Atividades. Dinâmicas Económicas: Relatório de Caracterização e Diagnóstico. Revisão do Plano Direto Municipal do Porto.* Obtido de https://pdm.cm-porto.pt/documents/58/53_PDMP_ECD_Din_Eco.pdf

CMP. (9 de july de 2021). *World mayors sign the Porto Declaration on Tourism and the Future of Cities*. Obtido de Porto.: https://www.porto.pt/en/news/world-mayors-sign-the-porto-declaration-on-tourism-and-the-future-of-cities

CMP. (2022). *Planta de Ordenamento do PDM*. Obtido de SNIG: https://snig.dgterritorio.gov.pt/rndg/srv/por/catalog.search#/metadata/357abce3-2e21-4580-a29c-8cebbafe71f7

CMP. (2022a). *PULSAR - Estratégia de Desenvolvimento Económico do Porto.* Obtido de https://www.cm-porto.pt/files/uploads/cms/Pulsar_Estrategia_Desenvolvimento_Economico_Porto_Relatorio_Sumario_2022Sv1QqfFXj3.pdf

CMP. (s.d.). *Porto*. Obtido de Resíduos e Limpeza: https://ambiente.cm-porto.pt/sustentabilidade-ambiental/residuos-limpeza

Eurostat. (december de 2010). Guidance on classificationof waste according to EWC-Stat categories. Supplement to the Manual for the Implementation of the Regulation (EC) No 2150/2022 on Waste Statistics.

IMT. (2022). *Parque de veículos rodoviários motorizados presumivelmente em circulação, segundo o tipo*. Obtido de https://www.imt-ip.pt/sites/IMTT/Portugues/IMTT/relatoriosectoriais/Informacao-Estatistica/Documents/2022/INE_Parque_circ_Tipo_ve%C3%ADculo.pdf

INE. (2013). *Proportion of resident population that comes in the territorial unit (commuting) (%) by Place of residence (at the date of Census 2011); Decennial*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0007089&contexto=bd&selTab=tab2&xlang=en

INE. (2016). *Guests (No.) in hotel establishments by Geographic localization (NUTS - 2002) and Type (hotel establishment); Annual*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0005158&contexto=bd&selTab=tab2

INE. (2021). *Material flow accounts.* Obtido de https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_destaques&DESTAQUESdest_boui=473630762&DESTAQUESmodo=2&xlang=en

INE. (2022). *Enterprises (No.) by geographic localization (NUTS - 2013), Economic activity (Division - CAE Rev3)*. Obtido de https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0008511&contexto=bd&selTab=tab2&xlang=en

INE. (2022a). *Enterprises (No.) by geographical localization (NUTS - 2013) and dimension; Annual*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0009819&contexto=bd&selTab=tab2&xlang=en

INE. (2022b). *Gross value added (€) of Enterprises by Geographic localization (NUTS - 2013) and Economic activity (Division - CAE Rev. 3); Annual*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0008514&contexto=bd&selTab=tab2&xlang=en

INE. (2022c). *Guests (No.) in tourist accommodation establishments by Geographic localization (NUTS - 2013) and Type (tourist accommodation establishment); Annual*. Obtido de https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0009876&contexto=bd&selTab=tab2

INE. (2022d). *Guests by inhabitants (No.) in tourist accommodation establishments by Geographic localization (NUTS - 2013); Annual (1)*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0011141&contexto=bd&selTab=tab2

INE. (2022e). *Lodgind capacity in tourist accommodation establishments by 1000 inhabitants (No.) by Geographic localization (NUTS - 2013); Annual*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0008784&contexto=bd&selTab=tab2&xlang=en

INE. (2022f). *Nights (No.) in tourist accommodation establishments by Geographic localization and Place of residence (Country - short list); Annual*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&contecto=pi&indOcorrCod=0009183&selTab=tab0

INE. (2022g). *Persons employed (No) in Enterprises by Geographical localization (NUTS - 2013) and Economic activitiy (Division - CAE Rev.3); Annual*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0008512&contexto=bd&selTab=tab2&xlang=en

INE. (2022h). *Proportion of non-resident guests (%) by Geographic localization (NUTS - 2013); Annual*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0008571&contexto=bd&selTab=tab2

INE. (2022i). *Proportion of resident population that comes in the territorial unit (commuting) (%) by Place of residence (at the Census 2021 moment); Decennial*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0011654&selTab=tab0

INE. (2022j). *Sales of new vehicles per 1000 inhabitants (No.) by Place of residence (NUTS - 2013) and Type of vehicle; Annual*. Obtido de Portal INE: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0008464&contexto=bd&selTab=tab2&xlang=en

Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P., & Blengini, G. A. (2018). Measuring Progress towards a Circular Economy: A Monitoring Framwork for Economy-wide Material Loop Closing in the EU28\. *Journal of Industrial Ecology, Volume 23, Number 1*, 62-76.

Miatoo, A., Schandl, H., Forlin, L., Ronzani, F., Borin, P., Giordano, A., & Tanikawa, H. (2019). A spatial analysis of material stock accumulation and demolition waste potential of buildings: A case study of Padua. *Resources, Conservation and Recycling*, 245-256.

Nemry, F., & Uihlein, A. (2008). *Environmental Improvement Potentials of Residential Buildings (IMPRO-Building).* Obtido de https://publications.jrc.ec.europa.eu/repository/bitstream/JRC46667/reqno_jrc46667_jrc46667%5B1%5D%5B1%5D.pdf.pdf

PORDATA. (2022). *Non financial enterprises density*. Obtido de Pordata: https://www.pordata.pt/en/db/municipalities/search+environment/table/5832171

PORDATA. (2022a). *Population density, according to the Census*. Obtido de Pordata: https://www.pordata.pt/municipios/densidade+populacional+segundo+os+censos-591
Santos, P. F., Castro, P., & Santos, C. (2021). *Sector-wide Circularity Assessment for the Biomass Sector - Porto.* Obtido de CityLoops data hub by Metabolism of Cities: https://cityloops.metabolismofcities.org/dashboards/porto/publications/1009888/

- Portugal
- Norte
- Área Metropolitana do Porto
- Population of Porto (1981-2021)
- Porto land use map

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 – Fibre
	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 roudwood)
	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	**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 aliminium
	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 unis 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

[source: CityLoops – D4.4 – Urban Circularity Assessment Method]

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_92 – 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

[source: CityLoops – D4.4 – Urban Circularity Assessment Method]

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 821033.