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The circularity level of municipal waste management systems in Portugal: a comparative case study between the metropolitan areas of Porto and Lisbon

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THE CIRCULARITY LEVEL OF MUNICIPAL WASTE MANAGEMENT SYSTEMS
IN PORTUGAL: A COMPARATIVE CASE STUDY BETWEEN THE METROPOLI-
TAN AREAS OF PORTO AND LISBON

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Abstract

The circular economy is gaining momentum as a solution for returning resources to the economy and reducing pressure on the planet. Large and growing amounts of municipal waste, combined with increasing urbanization, raise the question of how to manage it for sustainable development. However, no general method is yet known to determine the degree of circularity in municipal waste management systems. This work examined how municipal waste management can be improved and how it supports sustainable development goals. An assessment of the stages of development of the waste management system towards circular economy was also made. In addition, a set of circularity indicators based on waste streams was developed. A comparative case study was conducted between the two waste systems of the largest urban regions in Portugal. The main results show that such waste management companies have initiated circular economy measures and that they have also experienced positive developments in terms of waste streams, with increases in collection, separation and diversion rates. However, more work is needed to better align with the science behind the circular economy. The underlying problem is that they operate as a linear system, whereas they need to operate as a circular system. The lack of information was one of the major limitations of this study. It is recommended that further research be conducted on municipal waste systems to consolidate information relevant to the circular economy.

Keywords: circular economy; municipal waste management; circular economy indicators; circular waste management system; sustainable development.

Table of Contents

1. Introduction.....	1
1.1. Present Problem.....	1
1.2. Sphere and Objectives.....	2
1.3. Document Structure.....	3
2. Literature Review	4
2.1. Circular Economy.....	4
2.1.1. Defining the Concept	4
2.1.2. Legislative Structure	6
2.1.3. Scale of Application.....	7
2.2. Sustainable Development Goals.....	9
2.3. Municipal Waste Management	10
2.3.1. Legal Framework	11
2.3.2. Waste to Energy.....	13
2.4. Waste Management and Circular Economy.....	15
2.5. Circular Economy Indicators	16
2.5.1. Definition of Indicators	16
2.5.2. Importance of Indicators.....	16
2.5.3. Assessing Circularity in Municipal Waste Management.....	17
3. Methodology	20
3.1. Research Structure	20
3.2. Research Methods.....	21
3.2.1. Overview of MWSM	21
3.2.2. Circular Practices	22
3.2.3. Circularity Indicators.....	23
4. Case study	25
4.1. Results Analysis	25
4.1.1. The Portuguese Municipal Waste Management Systems.....	25
4.1.1.1. Lipor	26
4.1.1.2. Valorsul.....	26
4.1.2. Alignment with National Targets	26
4.1.3. Municipal Waste Management System Models	27
4.1.4. Sustainable Development Goals	29
4.1.5. Circular Practices	32
4.1.6. Circularity Indicators.....	37
4.2. Results Discussion	40
4.2.1. Circular Development.....	40
4.2.2. Circularity Level.....	43
4.2.2.1. Total Generated Waste and Municipal Waste Generation	43
4.2.2.2. Collected Waste and Preparation for Recycling Rates.....	43
4.2.2.3. Incineration and Landfill Rates of Waste.....	45
5. Conclusion	46

5.1. Main Conclusions	46
5.2. Main Contributions	47
5.3. Limitations and Future Research	48
6. References	49

List of Figures

Figure 1: The 10R framework for the CE.....	6
Figure 2: The waste hierarchy.	14
Figure 3. Model of waste management by Lipor.....	28
Figure 4. Model of waste management by Valorsul.....	28

List of Tables

Table 1: Lipor's compliance with the PERSU 2020 goals.....	27
Table 2: Valorsul's compliance with the PERSU 2020 goals.....	27
Table 3: Mapping the contributions of Lipor and Valorsul to SDG 6 entitled "Ensure available and sustainable management of water and sanitation for all".....	30
Table 4: Mapping the contributions of Lipor and Valorsul to SDG 7 entitled "Ensure access to affordable, reliable, sustainable and modern energy for all".....	30
Table 5: Mapping the contributions of Lipor and Valorsul to SDG 8 entitled "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all".....	31
Table 6: Mapping the contributions of Lipor and Valorsul to SDG 11 entitled "Make cities and human settlements inclusive, safe, resilient and sustainable".....	31
Table 7: Mapping the contributions of Lipor and Valorsul to SDG 12 entitled "Ensure sustainable consumption and production patterns".....	32
Table 8: Overview of the results of the assessment of the two MWMSs regarding Governance, Sector and Market.....	33
Table 9: Overview of the results of the assessment of Lipor's MWMS regarding Collection and Transport, Waste Disposal, Energy Recovery, Waste Recycling, Prevention and Reuse.....	34
Table 10: Overview of the results of the assessment of Valorsul's MWMS regarding Collection and Transport, Waste Disposal, Energy Recovery, Waste Recycling, Prevention and Reuse.....	36
Table 11: Overview of the results of the assessment of the differences between MWMSs.	37
Table 12: Lipor's circularity indicators.	38
Table 13: Valorsul's circularity indicators.....	39

1. Introduction

1.1. Present Problem

According to the World Bank, about 2.24 billion tons of municipal solid waste were generated in 2020. In the coming years, total global waste generation is expected to reach 3.88 billion tons by 2050, more than double the population growth projected for the same period (Kaza et al., 2021). More population means more demand and more consumption, leading to an acceleration in production output (Grace, 2020). This rapid increase in production and consumption leads urban societies to generate greater amounts of waste. (Vij, 2012). Therefore, the increase in urban population, which has changed from 34% in 1960 to 56% in 2020, has a significant impact on the growth of waste generation (World Bank, 2021). According to Chhay et al. (2018), the most influential socioeconomic driver of waste generation is the growing urban population. Currently, many countries are industrializing and improving their living standards, which significantly reduces the number of people living in extreme poverty (Ravallion, 2016). In addition, higher income countries generally produce more waste per capita (Kaza et al., 2021). All else being equal, the amount of waste produced is usually proportional to population, although it increases more rapidly with higher household income. (Schneider et al., 2017). These factors, along with a throwaway culture and built-in obsolescence, lead to higher waste generation.

Circular economy (CE) is an emerging topic of interest to both academia and the corporate world - the latter because of its promise to significantly improve business value and competitiveness (Urbinati et al. 2017). Problems such as overconsumption and resource scarcity require creative solutions, i.e., new business development. This includes transitioning from a linear economy, where raw materials are used to make a product and discarded after use, to one CE, where material loops are closed (Ellen MacArthur Foundation, 2013; Murray et al., 2017). The transition to CE focuses on reducing, reusing, recycling, and recovering materials throughout the supply chain while creating environmental quality, economic development, and social equity for current and future generations (Kirchherr et al., 2018).

From a more specific CE perspective, we need to consider the transformation of waste into resources that are fed to new production processes (Aceleanu et al., 2019). Given the increasing amount of municipal waste (MW) generated in Europe in recent years due to excessive

consumption, it has become necessary to study strategies for sustainable waste management (Mesjasz-Lech, 2014). Municipal waste management (MWM) plays an important role in a circular society, as this sector is responsible for collecting waste from businesses and households in order to subsequently valorize these resources. This requires long-term planning and the development of non-toxic materials that produce less waste while maintaining the market value of items through closed loops (Ellen MacArthur Foundation, 2017).

Although the generation of MW in Portugal has remained at a constant level, large amounts of waste are still disposed of in landfills and incinerators (APA, 2019a). Given the environmental impact of these activities, the European Parliament (Lee et al., 2017) wants to move away from this. Therefore, it is necessary to evaluate the level of involvement in activities related to MW, especially in the two companies responsible for waste management in the country's metropolitan areas. This particular focus is underexposed in the literature.

1.2. Sphere and Objectives

This work was carried out as part of a curricular internship at a municipal waste management company - Lipor - in Baguim do Monte, Portugal. The internship lasted from October 2021 to March 2022 in the Sustainability Unit, which in turn is part of the Sustainability, Communication and Marketing Department. Lipor is a waste management company that has been operating in the Greater Porto area for forty years and promotes CE. They are also committed to waste management from a resource perspective, adding value throughout the production cycle, i.e., using waste as a resource (Lipor, 2020a). Valorsul has a similar CE philosophy and has been responsible for MWM in the Lisbon metropolitan area for twenty-seven years (Valorsul, 2022). Although these are well-established organizations, it is not entirely clear how they are working toward CE and what structural changes they have made to that end.

The main task of the internship was to compare the current municipal waste management systems (MWMS(s)) in Portugal with a CE standard, with the aim of studying the sector's commitment to waste management restructuring in order to move to a fully CE. This was done through a comparative case study of the MWMS of Lipor and Valorsul. Therefore, the main objective of this work is to answer the following research question: *What is the circularity level of the two largest*

MWMSs in Portugal? The following sub-questions were answered to support this research question:

- 1 - To what extent do the activities of Lipor and Valorsul contribute to improved municipal waste management and thus to the SDGs?
- 2 - How do Lipor and Valorsul behave towards CE, and what circular practices have been implemented?
- 3 - What is the level of circularity of the MWMSs of Lipor and Valorsul, and how has it evolved over time?

1.3. Document Structure

This work is divided into five main chapters. In chapter 1, the problem background and the environment and objectives are presented. In chapter 2, the inner workings of CE and of MWM, the relationship between the two, and the indicators of CE are explained in more detail. Chapter 3 presents the methodology and the methods divided into three research sections. Chapter 4 analyzes the case study, including separate analysis and discussion of the results. Chapter 5 addresses the research question and draws conclusions.

2. Literature Review

In the interest of studying the current Portuguese MWM scenario in the eyes of CE, an analysis of the CE concept, its legal context and scales of application is presented. Next, the connection between Sustainable Development Goals (SDGs) with CE and MWM is provided. Furthermore, MWM is explored along with its legal context. Afterward, waste management's relationship with the CE is explored. Lastly, CE indicators, their relevance and their assessment of MWM are described.

2.1. Circular Economy

2.1.1. Defining the Concept

In 1966, Boulding introduced the metaphor of Spaceship Earth. The goal of this metaphor was to promote the transition from a "cowboy economy" that did not care about biophysical boundaries to a "spaceman economy" based on intelligent resource management. In this way, Boulding (1966) viewed the world as a closed and circular system with a finite assimilative capacity. Therefore, economic pressure had to be proportional to the carrying capacity of the Earth. This attempt to explain issues of sustainability was a useful basis for Pearce and Turner's research on CE (Segerson, 1991).

The first theoretical model attempting to define CE was originally created from an economic perspective (Segerson, 1991). After studying the linear system and exploring the impact of natural resources on the overall economy, Pearce and Turner illustrated the transition to CE. In this way, CE was used to define an economic system in which waste generated in the stages of extraction, production, and consumption is transformed into inputs.

CE comes from various fields of study, such as regenerative design (Ayres & Udo, 1994), natural capitalism (Hawken et al., 1999), industrial ecology (Esty & Porter, 1998), cradle to cradle (McDonough & Braungart, 2002), industrial symbiosis (Zhu et al., 2007), the performance economy (Stahel, 2010), and general systems theory (Von Bertalanffy, 1950; Ghisellini et al., 2016). The common underlying idea of these theories is the pursuit of a closed material cycle throughout the economic system that minimizes environmental damage and vulnerability without hindering economic growth.

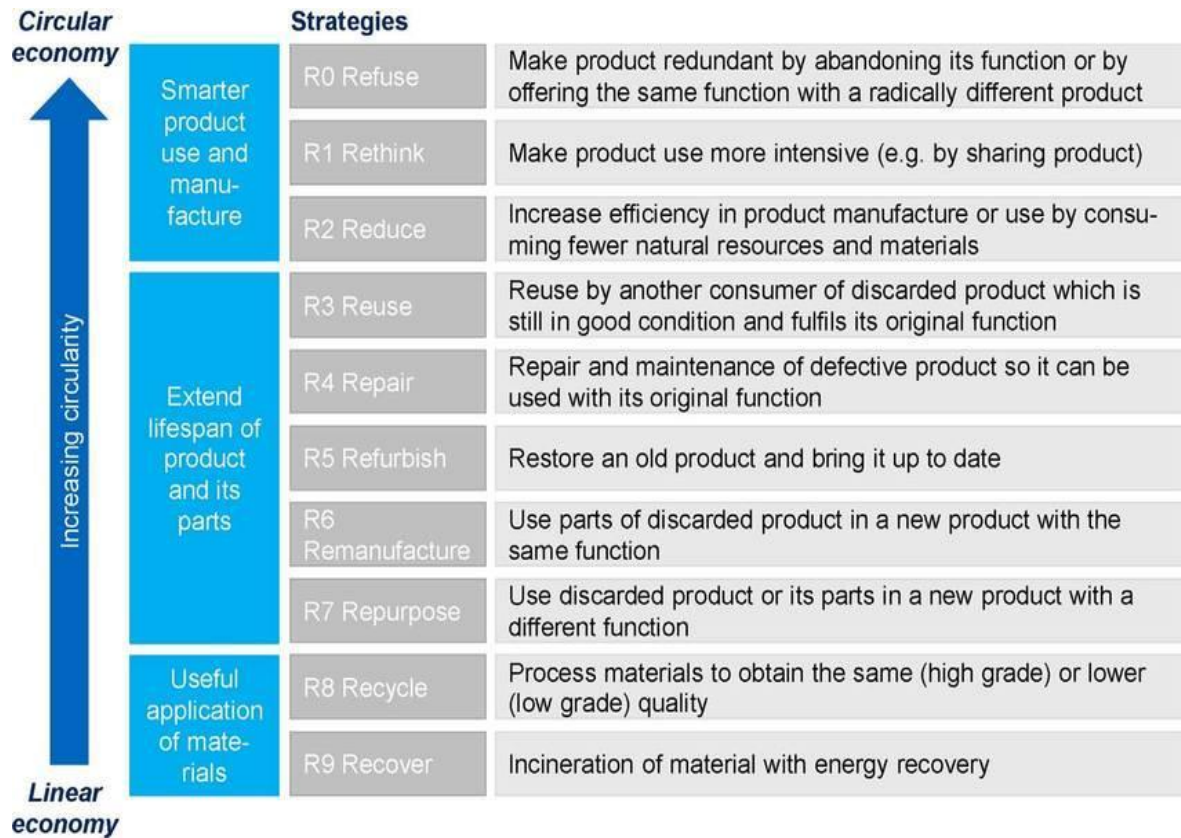
CE has been defined as "an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximize ecosystem functioning and human well-being" (Murray et al., 2017). CE has also been defined as a regenerative system that minimizes resource usage by limiting material and energy cycles, which may be realized through sustainable design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling (Geissdoerfer et al., 2017).

This work adheres to the definition of CE as structured by the Ellen MacArthur Foundation (2013), which describes it as an industrial economy that is restorative or regenerative by intent and design. A CE replaces the term "end-of-life" with "restoration," promotes penetration of renewable energy sources and reduction of pollutants that limit reuse and minimizes waste generation through innovative design. There are two material flows: biological nutrients and technical nutrients. The nutrients of the biological flow are designed so that they can safely re-enter the biosphere, while the nutrients of the technical flow are designed to circulate in high quality without reaching the biosphere (Ellen MacArthur Foundation, 2013). The key principles of CE are: avoid waste, build resilience through diversity, rely on energy from renewable sources, think in terms of "systems", and waste is food (Ellen MacArthur Foundation, 2013).

The CE concept aims to reduce the dependence of the economic system on the exploitation of resources and to reduce the environmental impacts associated with waste production. By eliminating and limiting energy and material loops, it is possible to achieve a sustainable flow of materials between the environment and the economy (Stahel, 2013).

Implementing the 3Rs principles-reduce, reuse, and recycle-can help make CE a reality (Wu et al., 2014). Ghisellini et al. (2016) define reduction as the concept of increasing efficiency with a focus on limiting inputs in the form of energy, raw materials, and waste. Reuse means reusing waste components in a manner consistent with their original design. Recycling is the process of reusing waste materials in new manufacturing processes. However, energy is the only exception, as it cannot be recycled. Moreover, it should be complemented by three additional elements - recovery, remanufacturing, and redesign (Jawahir & Bradley, 2016). And to achieve improved effectiveness while maintaining a product's primary function, the 10R framework (Potting et al., 2017) should be considered, which includes "refuse", "rethink", "repair", and "refurbish", as shown in figure 1.

Figure 1: The 10R framework for the CE.



Source: Potting et al., 2017.

2.1.2. Legislative Structure

Notwithstanding its European roots, CE has become a major player in European legislation only in the last decade. Concerned about the rising cost of raw materials, the European Commission announced a resource efficiency initiative that was initially implemented through the Roadmap for a Resource-Efficient Europe (European Commission, 2011a). This was followed by the presentation of a series of policy initiatives known as Closing the loop - an EU action plan for the Circular Economy (European Commission, 2015). This plan established a policy framework that expands and combines current policy and legal instruments, with measures that cover the entire life cycle: from production and consumption, through waste management and the market for secondary raw materials, to a revision of waste regulations.

In 2017, the Portuguese government approved the Action Plan for the Circular Economy (PAEC in Portuguese). This is a strategic model for growth and investment based on the efficiency and valorization of resources and the minimization of environmental impacts. It is a document that has been created in light of Portugal's international commitments, such as the Paris Agreement, the Sustainable Development Goals and the European Union itself. The plan recognizes the CE as an integral part to leave behind an environmentally harmful linear economy (Resolution of the Council of Ministers no. 190-A/2017).

The main objectives of the PAEC are: to improve the methods of classification of by-products, to reduce the primary consumption of single-use plastics from fossil sources, to recover and recycle value-added materials from waste streams. All of this is based on the economic principles of the circular economy, which aim to: 1) Develop products, services and business models that eliminate the production of waste and pollution, such as toxic materials. 2) To keep products and materials in use as long as possible, preferably at their highest economic value and utility. 3) To ensure the regeneration of the material resources used and the underlying natural systems.

In 2020, the European Commission presented a new Circular Economy Action Plan (CEAP), which proposes several new initiatives aimed at modernizing and transforming the European economy while protecting the environment (European Commission, 2020). The proposal is one of the key elements of the European Green Deal (European Commission, 2019), which sets out an ambitious roadmap for a carbon-neutral economy. The CEAP includes the following main building blocks: making sustainable products the norm in the EU, empowering consumers, focusing on sectors that consume the most resources and have high potential for circularity; and ensuring less waste. The new measures also include a transition monitoring framework that applies at both the individual Member State level and the EU-wide level (European Commission, 2018).

2.1.3. Scale of Application

CE is implemented at three fundamental scales: macro, meso, and micro. The macro level refers to the level of the city, province, region, or nation, implemented, for example, through policy changes. The meso level includes eco-industrial parks and industrial networks and symbioses between companies. The micro level usually focuses on a single product, service, or organization

(Ghisellini et al., 2016; Kirchherr et al., 2017), including citizens as consumers (Vanhamäki et al., 2019).

However, there are some discrepancies in the definitions of macro, meso, and micro. Recently, China has aggressively developed industrial parks (Geng et al., 2012), typically characterized by a mix of manufacturing, scientific research, residential, and commercial/service areas (Geng & Doberstein, 2010). In this regard, Chinese industrial parks are associated with cities, implying a larger size (Moraga et al., 2019). Meso is also defined as the creation of eco-industrial parks (Geng et al., 2012). The macro scale is often limited to the national level, with the global level being a possible addition (EASAC, 2016). Some argue that the macro level goes beyond countries and encompasses the entire world (Kirchherr et al., 2017). For the Chinese, regions are deemed macro scale, while Smol et al. (2017), in analyzing eco-innovation in the context of CE, propose regions as a link between macro and micro scale, suggesting a meso scale. To combat these different terms, Moraga et al. (2019) suggest following the micro, meso, and macro terms with the domain of analysis for clarity (e.g., consumer, product, service, company, technology, city, park, region, nation, continent, or globe).

The definitions of the European Commission (2015) differ slightly from those in the literature. First, macro-level interventions are about targets, guidelines, additional indicators, and measuring impact on national and international commitments. At the meso level, the focus is on financial institutions, associations, regional authorities, municipalities, universities, and research and development organizations. At the micro level, the focus is on companies, technology centers, competitive clusters, non-governmental organizations, and consumers.

These three levels of action are considered in the PAEC. First, the macro level uses the same rationale as the CEAP - product, consumption, waste/secondary raw materials, with knowledge being the central element for developing solutions. These actions take into account (i) actions already underway by the ministries involved that need to be strengthened (e.g., food waste, by-products/waste, research and innovation) and (ii) new actions on key topics such as reuse and regeneration and consumer incentives. Thus, at the macro level, actions of structural scope are implemented that have transversal and systemic impacts and promote the appropriation of the principles of CE by society. The meso level then focuses on the sectoral level, where each sector should establish its own transition agenda and the process can benefit from instruments such as "circular agreements". This level therefore represents actions or initiatives defined and taken by

actors in the value chain of the sectors concerned to increase productivity and the efficient use of the country's resources in order to achieve economic, social and environmental benefits (Pego, 2020). Third, the micro level focuses on acceleration strategies for the CE, which best fit the socioeconomic profile of specific regions and areas. Thus, at the micro level, there are actions or initiatives defined and taken by a range of regional and/or local government entities, including economic and social actors, that incorporate the local economic profile and value it in addressing social challenges (Pego, 2020). At this level, the CE converges with the valorization of the territory, and strategies are selected in which the regions work (e.g. industrial symbioses), and guidelines are also developed for actions within the management of urban and peri-urban metabolism in the companies located there. The levels of action are interrelated and mutually reinforcing. This creates feedback mechanisms that evolve the context in an iterative way, allowing the consolidation of knowledge, strategies, projects and results, and strengthening the actors involved (Resolution of the Council of Ministers no. 190-A/2017).

2.2. Sustainable Development Goals

The United Nations is an intergovernmental organization that promotes a global development framework around the world. This framework follows a set of long-term guidelines that establish goals and targets to be followed by many nations. Strategies are developed to strive for more sustainable development for all countries. In 2015, the 17 SDGs were released, replacing the previously established Millennium Development Goals (MDG) (United Nations General Assembly, 2017). The 2030 Agenda for Sustainable Development was adopted to ensure a better and more sustainable future for all. It seeks to address the major issues we face. In doing so, it recognizes that eradicating poverty involves actions that promote economic growth while addressing a variety of social needs such as health, education, and gender equality (Miola & Schiltz, 2019). Some have noted that the SDGs differ from the MDGs in that they emphasize the interconnected environmental, social, and economic elements of development by promoting sustainability (Schleicher, 2018).

CE techniques can help integrate the human health, environmental, and development goals and targets of the SDGs. For example, approaches that view waste as a valuable resource rather than negative externalities of production can help minimize environmental footprints and improve

economic efficiency (Liu et al., 2018). According to Schroeder et al. (2019), CE practices and related business models can help achieve some of the SDGs. The continuous increase in waste production raises serious concerns worldwide about how to manage waste in a sustainable way. This highlights the need to evaluate WM practices to minimize the negative impacts associated with MW and achieve the United Nations SDGs (Pujara et al., 2019).

In fact, several goals and targets are connected to the foundations of CE. This link is very strong, for example, in Goals 8 and 12, labeled "Decent work and economic growth" and "Responsible consumption and production" respectively (Priyadarshini et al., 2020). While the first goal emphasizes the need to decouple economic development from environmental degradation, the second goal includes targets related to resource management efficiency, food loss reduction, and waste reduction through recycling and reuse—all of which are important prerequisites for CE (Priyadarshini et al., 2020). In addition, there is strong evidence of a link between CE and SDGs 2, 3, 5, 6, 7, 8, 9, 11, 12, and 16 (Rodriguez-Anton et al., 2019; Priyadarshini et al., 2020). Moreover, waste management has been found to be linked to the SDGs, both directly for Goals 2, 3, 8, 9, 11, 12, 13, 14, 15, 17 and indirectly for Goals 1, 4, 5, and 7 (Sharma et al., 2021). There are clearly SDG relationships that affect both waste management and CE.

2.3. Municipal Waste Management

In recent decades, European policy has established a legal framework, along with several environmental action plans, directives, and studies, aimed at reducing the negative environmental and health impacts of waste and promoting resource efficiency in Europe (European Commission, Directorate-General for Environment, 2010). The Waste Framework Directive (2008/98/EC), for example, sets out basic concepts and principles for waste management in the EU, such as the five-step "waste hierarchy." The waste hierarchy prioritizes waste management, with waste prevention as the best choice, followed by reuse and recycling, thus closing the product life cycle loop. Energy recovery from waste is a lower priority, with landfilling being the least acceptable alternative. EU waste policy aims to protect the environment and human health and support the EU's transition to a CE. It sets three main goals and objectives: improving waste management, promoting innovation in recycling, and limiting landfilling (European Commission, 2022). The Waste Framework Directive (2008/98/EC) established how Member States should manage

waste collection and treatment, although municipalities and regions are responsible for defining and regulating the implementation of waste and material policies, as they are usually responsible for waste collection and treatment.

However, it is common practice for municipalities to outsource responsibility for the collection and treatment of household waste to intermunicipal WM organizations. These partners collect and treat waste from surrounding municipalities, i.e., they oversee the collection of one or more categories of waste in specific geographic regions (Taelman et al., 2018). These regions are typically characterized by heterogeneous urbanization patterns, ranging from sparsely populated rural areas to densely populated urban areas, with different collection tactics. It is worth noting that some of the waste generated and collected in the region cannot always be processed there, e.g., for logistical reasons or due to societal pressures, and as such, it will be transported elsewhere for treatment (Taelman et al., 2018).

Metropolitan areas are defined as a city plus its surrounding areas that roughly correspond to the extent of the city's labor market ("commuter zone") (OECD, 2021). Both companies analyzed in this report operate in metropolitan areas. However, they do not treat the total waste generated in their respective metropolitan areas, even though they are responsible for a significant portion of those areas. In this work, these specific geographic regions are referred to as areas of operation.

2.3.1. Legal Framework

MWM is important in the context of general waste management because it has characteristics that distinguish it from other wastes, such as its origin, composition and management strategies. (Decree-Law No. 73/2011 of June 17th). The Portuguese Environmental Agency (APA in Portuguese) has prepared, revised and implemented a national waste policy called the Strategic Plan for Municipal Waste (PERSU in Portuguese) (Order no. 186/2007 of February 12th). According to PERSU, MW is waste from households as well as other waste that resembles its nature or composition (Order no. 187-A/2014 of September 17th). MW comes from a very large and dispersed number of producers (mainly private consumers), which presents a management challenge. In terms of physical composition, MW is composed of different types of materials and end-of-life products such as biowaste, paper/cardboard, carton packaging for liquid food,

plastics, textiles, glass, metals, composites, ceramics, and also more complex end-of-life products such as waste from electrical and electronic equipment (WEEE), used batteries and accumulators (Order no. 187-A/2014 of September 17th). Waste management includes the collection, transport, recovery and disposal of waste and respective supervision of these operations, the post-closing management of landfills, and the actions as traders or brokers (Decree-Law No. 73/2011 of June 17th).

APA oversees the management of stakeholders involved in the implementation of measures that allow the country to align with European policies, directives and targets that contribute to increasing prevention, recycling and other forms of MW recovery, thus reducing the consumption of natural resources with limited availability. Given the complexity of this task, there have been several successive MWM plans: PERSU I (1997-2007), PERSU II (2007-2016), and PERSU 2020 (2014-2020). PERSU I laid the foundation for waste policy, abolishing open-air dumps, enabling the establishment of sanitary landfills and a national waste management network, and taking the first steps to promote separate collection and recycling (Abreu et al., 2021). PERSU II focused on moving up the waste hierarchy, separating waste at the source, reducing landfilling, and increasing multimaterial recycling (Order no. 186/2007 of February 12th). Finally, PERSU 2020 aimed to eliminate the direct disposal of MW in landfills, significantly reduce the proportion of BMW going to landfills, and increase the proportion of recyclables in total waste to achieve the goals for preparation for reuse and recycling (Order no. 187-A/2014 of September 17th). In addition, the Program for the Prevention of Municipal Waste (PPRU in Portuguese) was launched in 2010 to increase citizen involvement and focus more on prevention, as a correlation between the change in GDP and the production of MW was previously identified (Instituto Nacional de Estatística, 2016). It also aimed to decouple economic growth from waste production (Dispatch no. 3227/2010).

An adjustment entitled PERSU 2020+ was approved (Order no. 241-B/2019 of July 31st) because a European Commission report warned of the risk of Portugal failing to meet preparation for reuse and recycling targets, and because the new challenges of the CE represent a paradigm shift for the sector by 2035, namely:

- Mandatory separation and recycling at source or selective collection for biowaste by December 31, 2023.

- Under the revised Waste Framework Directive (2008/98/EC), targets for preparation for reuse and recycling, measured against total municipal waste, have been set at 55% in 2025, 60% in 2030 and 65% in 2035.
- The Packaging Waste Directive includes targets for increasing recycling of packaging waste measured at the recycler: 65% by weight by December 31, 2025, and 70% in 2030 (30% for wood, 55% for plastic, 75% for glass, and 85% for paper), and a ban on landfilling recyclable waste starting in 2030.
- In line with the Landfill Directive, the landfill reduction target is a maximum of 10% of total municipal waste generated by 2035.

2.3.2. Waste to Energy

This issue is somewhat controversial, with a significant number of private entities calling this practice "sustainable" and "circular." In a waste-to-energy (WtE) facility, waste that cannot be used for composting and recycling processes goes through a controlled incineration process, generating electricity. Incineration with energy recovery has been removed from the EU taxonomy as sustainable because it could jeopardize one of the most important environmental goals, namely the transition to a CE, waste prevention and recycling (Makavou, 2021). The EU taxonomy is an essential part of the European Commission's legislative proposals on sustainable finance and serves as a basis for the creation of new financial regulatory frameworks (Regulation (EU) 2020/852). The fact that the report excludes WtE is therefore a crucial step towards a real CE, as it helps to focus on supporting real circular economy solutions.

According to the European Commission (2015), preserving the value of products, materials and resources in the economy for as long as possible and minimizing the generation of waste are essential aspects in a CE. The European Union recommends that Member States phase out public support for energy recovery from mixed waste and only provide funding if there is no risk of overcapacity and the objectives of the waste hierarchy are fully met (European Commission, 2015). High incineration rates are incompatible with more ambitious recycling targets. There are other processes that involve energy recovery, such as anaerobic digestion of organic waste with the production of fertilizer, which is officially classified as "recycling." However,

waste incineration with or without energy recovery has been classified as "other recovery" and "disposal", so it does not contribute to meeting recycling targets (European Commission, 2017). Energy recovery occupies a preferential place in the waste hierarchy over landfilling (Directive 2008/98/EC). Incineration with energy recovery should be the lowest priority in a CE because the materials are no longer available for reuse in products. (Potting et al., 2017). Incineration removes the opportunity for materials to circulate by destroying them. High amounts of incineration can prevent us from reaching a CE (Pires & Martinho, 2019). Figure 2 shows the stages of the waste hierarchy, where prevention is the most recommended.

Figure 2: The waste hierarchy.



Source: Directive 2008/98/EC.

Therefore, incineration (with or without energy recovery) and landfilling are not considered CE because once the materials are taken there, they cannot be returned to the economy as material for other products and any possibility of material preservation is destroyed. Recovery through incineration reduces waste to the ash produced, recycling reduces landfilling to processing waste only, reuse prevents the entire product from ending up in the landfill except for repair waste, and prevention of waste generation logically avoids landfilling altogether (Van Ewijk & Stegemann, 2016).

2.4. Waste Management and Circular Economy

A waste management system (WMS) has been described as a "system-relevant infrastructure system that has the function of collecting, treating (including sorting) and disposing all types of generated waste. Activities that promote waste prevention and reuse or concern trading and broking of waste or secondary raw materials are also part of the system as well as components regarding all governance (e.g. public authorities, laws, regulations), technical (e.g. treatment technologies), and organizational (e.g. infrastructure, collecting services) aspects and other resources (e.g. qualified labor, financial resources, natural resources) required for this function" (Campitelli et al., 2022).

However, traditional approaches to waste management do not properly reflect the CE (Zhang et al., 2019). Some studies have found that current waste management practices may hinder the transition to a CE. Current waste management practices have been criticized for promoting CE by increasing waste recycling, rather than taking a more systems-oriented approach (Ghisellini et al., 2016; Singh & Ordoñez, 2016). In addition, some limitations to material cycles have also been discovered. The goal of aiming for complete cycles entails a significant loss of residues at different stages, leading to inefficiencies in recycling. In addition, the potential of recycling to reduce demand for new materials is currently low. (Geyer et al., 2016). Another major barrier to improving the circular economy through recycling is the large amount of materials used for energy generation (Haas et al., 2015).

The literature on MWM shows that a successful MWMS must address both the technical aspects (collection, disposal, recycling) and the governance aspects (Bjerkli, 2013). It also shows that the focus in developed countries is on the technical aspects. (Filho et al., 2016). A circular waste management system (CWMS) is characterized by six crucial features (in order of importance): the application of sustainable design in the production phase, the adoption of laws that structure and coordinate such design, robust sorting and collection techniques for household waste, thorough treatment channels for different waste streams, a considerate, careful and knowledgeable population, and finally, the conservation of resources and the reduction of total waste generation (Aramburu, 2021).

2.5. Circular Economy Indicators

To make progress toward CE, it is critical to assess the performance of national, regional, and local programs. Therefore, it is necessary to develop a set of credible indicators.

2.5.1. Definition of Indicators

There are many definitions of indicators, including “variable”, “grade”, and “measurement”, and others (Meadows, 1998). Indicators are usually numerical pointers that convey important information about a physical, social, or economic system. They go beyond mere numbers to illustrate patterns or cause-and-effect relationships (Veleva et al., 2001). Countries and businesses use indicators to turn the enormous complexity of our evolving environment into a manageable amount of valuable data (Singh et al., 2012). Here, an indicator is defined as a measure that characterizes an ecosystem or one of its critical components (Kurtz et al., 2000). According to Veleva et al. (2001), the three main goals of indicators are: (i) to raise awareness of objectives; (ii) to provide decision makers with a tool to measure progress toward established targets; (iii) to support decision making.

2.5.2. Importance of Indicators

According to EASAC (2015), companies may lack the knowledge, confidence, and competence to implement CE solutions. This is due to (a) lack of indicators and targets, (b) lack of investment and long payback periods, (c) lack of awareness of alternative circular options and economic benefits, and (d) lack of workforce skills and CE initiatives at all levels of education. Winans et al. (2017) identify information sharing as a barrier to implementing CE practices. CE projects do not survive if there is no evaluation system or industry support. The European Environmental Agency (EEA) (2016), in an analysis of indicators that may be relevant to measuring circular performance, found that existing knowledge is somewhat dispersed. According to the EEA, better organized information is needed to guide decision-making processes around CE. Haas et al. (2015) also believe that determining the current level of circular economy is critical to establishing a baseline against which to measure change. To promote CE, it is vital to use evaluation and assessment techniques such as indicators to monitor and quantify development (Walker et al., 2018).

The number of measurement tools available for analyzing the performance of products, services, and systems from the perspective of CE increase along the number of CE-related publications (Blomsma et al., 2019). Product-related indicators have been a focus of previous research: Saidani et al. (2019) analyzed 55 sets of circularity indicators and provided a selection tool; Parchomenko et al. (2019) structured 63 CE metrics into three groups - resource-efficiency, material stocks and flows, and product-centric – and Kravchenko et al. (2019) consolidated 270 indicators to analyze the sustainability of CE activities.

The European Commission's monitoring framework for the CE makes it possible to track the progress of the CEAP through a set of indicators, which at the moment are based on previously collected data. The framework consists of 10 macro indicators, some of which are divided into sub-indicators and grouped into four subject categories: production and consumption, waste management, secondary raw materials, competitiveness, and innovation (Eurostat, 2018a).

2.5.3. Assessing Circularity in Municipal Waste Management

Determining circularity in MWMSs is challenging given their complexity. Hoek (2019) analyzed the impact of CE policies on waste flows by calculating relevant indicators for the municipality of Utrecht in the Netherlands, e.g., total waste, residual waste and incineration, waste separation and degree of contamination, recycling rates & secondary material produced, and carbon dioxide emissions. The following indicators can be used to analyze MWMSs in the context of CE:

Total Generated Waste represents the total volume of waste managed, as MWMSs also manage some small amounts of non-municipal waste (Bastos et al., 2019). A truly CE will produce zero waste (Franco-García et al., 2019). Therefore, the total amount of waste produced illustrates the remote nature of the concept. However, some authors argue that additional socioeconomic variables should be taken into account, e.g., urbanization, GDP per capita, tourism, working age, importance of the economy, migration, and education level (Magazzino et al., 2021; Antczak, 2020). Nonetheless, a decrease in total waste generation may represent the degree of effectiveness of circular practices, e.g., increased awareness among consumers and producers prior to products being MWMSs' responsibility and may indicate improved circularity.

Municipal Waste Generation refers exclusively to MW streams managed by MWMSs (Bastos et al., 2019). The fluctuations of this indicator reflect the strength of waste prevention measures

and the evolution of individual consumption patterns. The reduction in MW generation shows the success of waste prevention strategies and the change in consumption habits of residents. Collected Waste represents the total waste collected by municipalities or in their stead, including waste from other municipalities that do not have sufficient treatment capacity for their own waste (Bastos et al., 2019). It can be calculated both as a total amount and per capita. An increase in waste collected may indicate higher circularity (Lee et al., 2017), but the per capita value may better parallel similar MWMSs (United Nations Statistic Division, 2011). It should be coupled with a composition indicator that captures the percentage of total materials collected (Vardopoulos et al., 2020).

Collected Waste Composition provides data on the relevance of each stream in the overall picture (Bastos et al., 2019). Waste composition is directly related to fuel consumption costs (Yadav & Samadder, 2017) and provides information on individuals' consumption patterns. A detailed MW composition enables the identification of potential waste prevention strategies targeting different waste streams. A fairly important stream here is separated waste, which represents the amount of waste collected separately as a share of total municipal waste. Individual households separate different types of waste, which are then collected separately by municipalities. A superior circular waste system is characterized by increased waste separation (Lee et al., 2017). Waste separation and collection have been shown to make other waste infrastructure cheaper to operate (Chifari et al., 2017). However, higher separation rates could be associated with higher contamination due to lower separation efficiency (Haupt et al., 2017).

The Incineration Rate of Waste indicates the amount of waste sent to WtE facilities with simultaneous energy recovery (Pomberger et al., 2017). Currently, a large portion of MW is incinerated (mostly residual waste), a rather unattractive waste treatment option. The goal of CE is to move away from incineration (Lee et al., 2017). Therefore, the incinerated quantities can serve as a reference for the circular ineffectiveness of waste processes before they are sent to the incineration process.

Landfill Rate of Waste refers to the amount of waste disposed of in landfills (Bastos et al., 2019). As with incineration, there is no material recovery of waste that is sent to landfill. Since incineration is preferred over landfilling, it is interesting to compare their evolution over time and see in what proportion one replaces the other (Pires & Martinho, 2019).

Recycling Rates reflect how waste is used as a resource (European Commission, 2015). However, Portuguese MWMSs focus mainly on preparing waste for recycling and then selling it to the recycling industry. Although government environmental agencies combine both preparation for reuse and preparation for recycling into a single indicator to meet environmental targets, it is important to differentiate and separate them because reuse is a higher priority than recycling in a CE (Potting et al., 2017). In this work, preparation for reuse is defined as recovery operations consisting of checking, cleaning or repairing, by which products or components of products that are waste in nature are prepared for further use without any other pre-processing (Pires & Martinho, 2019). In addition, preparation for recycling is defined as "recovery operations consisting of checking, cleaning or repairing, by which products or components of products that are waste in nature are prepared for" recycling (Decree-Law No. 73/2011 of June 17th). Reuse and recycling increase resource efficiency and help reduce environmental impact, so preparation for recycling rates is crucial for an evaluation of CE (Castellani et al., 2015).

The only materials that are recycled come from biowaste, highlighting the importance of composting/anaerobic digestion in contributing to MW recycling (de Sadeleer et al., 2020). Biowaste is used to produce compost that can be applied to agricultural land, helping to improve soil quality. Clearly, Europe-wide demand for compost exceeds availability (Unger & Razza, 2018). In a CE, these resources can be fully recycled and returned to the economy to close the materials loop. In households, they are often mixed with other waste and thrown away, increasing the contamination rate (Eurostat, 2018b).

3. Methodology

In this chapter, the research methodology is presented.

3.1. Research Structure

The purpose of this work was to determine the extent to which the two largest waste management institutions in Portugal operate within the framework of CE. It is important to keep in mind that the CE must be a major structural change, rather than a small change in the current paradigm, to have a significant impact (Kirchherr et al., 2017). The following research question was posed in light of the previously stated study objectives and knowledge gap:

What is the circularity level of the two largest MWMSs in Portugal?

In the interest of answering the aforementioned central research question, the following sub-questions were developed:

1st sub-RQ: To what extent do the activities of Lipor and Valorsul contribute to improved municipal waste management and thus to the SDGs?

2nd sub-RQ: How do Lipor and Valorsul behave towards CE, and what circular practices have been implemented?

3rd sub RQ: What is the level of circularity of the MWMSs of Lipor and Valorsul, and how has it evolved over time?

The methodology underlying this work is qualitative in nature, providing flexible ways to identify, collect, analyze, and interpret data and information. Incorporating qualitative methods into a waste stream analysis adds valuable information (Newenhouse & Schmit, 2000). A qualitative approach is appropriate for this study because it allows identification of key strategies for implementing practices that promote improved MWM in the context of CE (Díaz-López et al., 2021). Since this work is exploratory in nature, it requires a qualitative approach to answer the research question (Zagragia & Rydningen, 2016).

A comparative case study in the MWM sector in Portugal was conducted using secondary data to research the relevant practices of the organizations responsible for waste management in the metropolitan areas of Porto and Lisbon in relation to the implementation of CE in MW governance (Lee-Geiller & Kütting, 2021). The data obtained were used to structure the qualitative

and cross-national comparative analysis. Data generation for this research relied primarily on document analysis and secondarily on newspaper articles, press releases, and company websites. Through the comparative case study technique, a deeper understanding was developed by comparing elements (Bryman & Bell, 2015). This way, the comparative case design allowed the research and discovery of both similarities and differences between Portuguese MWMS in terms of their commitment to the CE (Prodanov, C. C. (2013). Moreover, the author is familiar with both urban regions under study, which is valuable for comparative research.

The research began as part of a curricular internship at Lipor to gain an understanding of waste system operations and internal attitudes toward CE. To answer each sub-research question, the research was divided into three parts. Part 1 describes the circular interventions in the systems, the impact they had on each waste system, and their subsequent contribution to the SDGs. Later, in part 2, their practices are summarized in relation to CE and compared using the waste management system development stage concept (WMS-DSC) proposed by Campitelli et al. (2022). Finally, in part 3, the MWMSs of Lipor and Valorsul are evaluated using circularity indicators for the years 2017, 2018 and 2019.

Although data were available for 2020, they were not included. In 2020, the COVID-19 pandemic disrupted global waste generation. It was reported that the production of medical supplies (Silva et al., 2020) and the delayed collection services for infected citizens (Nghiem et al., 2020) led to an increase in plastic waste. In addition, waste generation in the city of Lisbon decreased sharply during the lockdown period in Portugal, which lasted from March to May 2020 (Sarmiento et al., 2022). Suffice it to say that the pandemic brought unexpected turbulence to waste generation, so using 2020 waste volumes did not allow for logical conclusions.

3.2. Research Methods

3.2.1. Overview of MWMS

The first part of the research process provided an overview of each MWMS, including examination of national MWM goals achieved, analysis of working infrastructures and waste flow models, and the contribution to the SDGs. By mapping the current waste streams of the MWMSs, it was possible to get an initial visualization of improvements towards a CWMS and

to see how such processes could lead to an eventually fulfilled CE. It was also possible to see which streams were negatively impacting CE. To examine the positioning of MWMSs in relation to the SDGs and whether they support them through their core activities, the outline of Campitelli et al. (2022) was used, which assigns SDGs 3, 4, 6, 7, 8, 9, 10, 11, and 12 to different components of MWMSs along with the corresponding indicators.

3.2.2. Circular Practices

The second part of the research process was to provide an overview of the developments of a circular MWMS in both companies based on Campitelli et al.'s WMS-DSC (2022). WMS-DSC is an assessment tool that primarily targets MWMS and helps determine the maturity of the waste system in relation to CE. This technique was also used to identify the operations at Lipor and Valorsul that can be considered circular. For this purpose, only the activities identified by Campitelli et al. (2022) as part of a fully realized CE were classified as circular practices. The assessment components used were governance, sector and market, collection and transport, waste disposal, energy recovery, waste recycling, and finally prevention and reuse. The assessment was made taking into account the legal possibilities of the companies - it would not make sense to assess them in terms of actions that they are not legally allowed to perform. The WMS-DSC characterizes within the CE the waste systems according to 5 stages:

- First, stage 1 aims to eliminate all types of waste. There are no processes at the source and waste is rampantly dumped or publicly incinerated. The legal structure is weak - there are no regulatory mechanisms, responsibilities are not defined, and systems are unclear, resulting in poorly functioning waste collection. There is a lack of relevant data. The informal sector contributes to waste collection and sorting of recyclables. There is neither occupational health and safety nor climate and environmental protection.
- Stage 2 targets protecting human health through controlled waste disposal. Legislation clarifies responsibilities and establishes control bodies, while data collection is implemented. Waste strategies improve process awareness and safety. Waste collection is expanded but is still not widespread (especially in rural areas). Funding is more reliable. Basic recycling facilities are being created as the recycling market develops. Employment

opportunities exist, but there are not enough personnel. Health safety in industry, urban sanitation, and conditions in the informal sector have improved.

- Stage 3 focuses on reducing landfill volume and emissions. Better sorting is achieved through source separation, better recycling rates, and more frequent use of recycling facilities. Collection is also more efficient. Other waste treatment options are encouraged through regulation (landfills, energy recovery, anaerobic digestion, refuse-derived fuels (RDF)). Marketing of recycled products increases. Emission control regulations emerge. The informal sector is fully legalized. Extended producer responsibility for their waste is introduced. More and better processing facilities bring even more jobs to the sector and lead to improved occupational health and safety. Creation of environmental awareness campaigns.
- Stage 4 refers to the increased use of waste as a resource. More advanced recycling leads to a higher output of secondary raw materials, thus closing the material cycle. Waste is treated with the most advanced technologies. WtE plants serve as a substitute for material recycling for fuel recovery. Reducing landfill rates combined with increased attention to waste prevention. The waste industry is evolving, becoming more competitive, and WM is being adopted by different types of formal organizations that have a higher demand for skilled talent.
- Finally, stage 5 outlines future aspirations based on proper fulfillment of a CE that focuses on waste prevention and effective resource management. Exceptionally high recycling rates and quality of recyclates attest to the recirculation of materials, which can be verified through accessible, monitored and reported data due to excellent digitalization. Circular business models are becoming mainstream and fully realizing the CE.

3.2.3. Circularity Indicators

The third part of the research process was to evaluate the relevant MWMS using circularity indicators to gain an understanding of the evolution of waste flows' mass over time. This was done using secondary data from APA for 2017, 2018, and 2019. Based on section 2.5.3., the following indicators were created for the case study analysis:

Total Generated Waste (ton) - total volume of waste generated/received; includes MW and a small portion of non-municipal waste.

Managed Municipal Waste (kg per capita) - calculated by dividing MW by the population of a given area; MW includes mixed waste, separated waste, and waste from other MW producers.

Collected Waste (%) – the amount waste collected as a percentage of total generated waste; includes mixed waste as well as separately collected fractions for recovery (through door-to-door collection and/or bring points).

Collected Waste Composition (%) - calculated as the share of the known amount of specific waste streams in the total amount of MW.

Waste Separation (%) - proportion of waste collected separately.

Incineration Rate of Waste (%) - share of the amount of incinerated waste in total generated waste.

Landfill Rate of Waste (%) - share of the amount of landfilled waste in total generated waste.

Preparation for recycling (%) - the amount of pretreated waste sold to the recycling industry as a share of total generated waste.

Recycling of biowaste (kg per capita) – the amount of waste sold and/or used as compost; determined by the ratio of composted MW to total population; biowaste consists of organic and green waste.

4. Case study

In this chapter, the research results are presented and discussed. First, an overview of the MWMSs to be compared is provided, including a brief introduction, their alignment with national waste targets, and an outline of their waste streams. Then, this analysis is complemented by an examination of these companies' contributions to the SDGs. This is followed by a review of their circular practices using WMS-DMC (Campitelli et al., 2022). Finally, the calculation of relevant circularity indicators related to waste volumes is presented. Moreover, these results are discussed considering synergies and overtones between them to help readers better understand the meaning of the data and their implications for MWM in the context of CE.

4.1. Results Analysis

4.1.1. The Portuguese Municipal Waste Management Systems

According to APA (2019a), there are 23 MWMSs in mainland Portugal, 12 multimunicipal and 11 intermunicipal systems. The different MWMSs have different characteristics, which is why they are classified into groups considering variables such as population density, average household disposable income, and total production of MW (APA, 2019a). Of the 255 entities responsible for municipal waste collection, only 27 are also directly responsible for the separate collection of recyclables, covering 28 municipalities, most of them in the Lisbon and Porto metropolitan areas, associated with the Valorsul, Tratolixo and Lipor MWMSs. In this cluster, only Tratolixo does not have a WtE plant, which obviously affects the waste flows and the way the company manages its waste. This means that Tratolixo's system is not considered in this study. It should be noted that a very small part of the collected waste is transferred to Valorsul's WtE plant when there is available capacity due to the geographical proximity of the two companies. This means that Lipor and Valorsul stand out on a national level due to their comparable operational characteristics such as area, volume and recovery processes. In addition, these two companies have the only two organic recycling plants in the country that exclusively accept biowaste from separate collection.

4.1.1.1. Lipor

Lipor - Intermunicipal Waste Management Service of Greater Porto falls under the category of organizations known as intermunicipal associations. It is responsible for the management, recovery and processing of waste from 8 municipalities - Espinho, Gondomar, Maia, Matosinhos, Porto, Póvoa de Varzim, Valongo and Vila do Conde - in the greater Porto area. Lipor currently serves about 1 million inhabitants, representing about 10% of the country's population in a total area of 646 square kilometers, or about 0.7% of Portugal's total land area (Lipor, 2021a; PORDATA, 2021). Lipor coordinates initiatives to raise public awareness about waste. A recent initiative promotes awareness of the importance of recycling waste and sorting it correctly in collection bins (Lipor, 2020b).

4.1.1.2. Valorsul

Valorsul - Recovery and Treatment of Solid Waste in the Lisbon and Western Regions, SA is a public limited company whose exclusive corporate purpose, under a public service concession, is to manage the multimunicipal system of sorting, selective collection, recovery and treatment of MW (Valorsul, 2021a). Only 5 of the municipalities in which the company operates are shareholders and the majority shareholder is Environmental Global Facilities (EGF). EGF owns a total of 11 MWMSs in Portugal, while it is itself integrated with Mota-Engil Group and URBASER. Valorsul is responsible for the waste management of 19 municipalities - Alcobaça, Alenquer, Amadora, Arruda dos Vinhos, Azambuja, Bombarral, Cadaval, Caldas da Rainha, Lisboa, Loures, Lourinhã, Nazaré, Óbidos, Odivelas, Peniche, Rio Maior, Sobral de Monte Agraço, Torres Vedras, and Vila Franca de Xira - in the greater Lisbon area (Valorsul, 2021a). It currently serves about 1.6 million inhabitants, or about 16% of the population. Its area of operation is about 3,231 square kilometers, or about 3.5% of the country's total land area (Valorsul, 2021a; PORDATA, 2021).

4.1.2. Alignment with National Targets

In an attempt to hold each MWMS accountable and ensure a proportional distribution of effort to achieve the national goals, PERSU 2020 has established three targets that must be met individually: BMW landfilling (%), preparation for reuse and recycling (%), and selective collection (kg per capita per year). The first two contribute directly to the achievement of the national

targets, while the third target is indirectly relevant for Portugal to achieve the targets for preparation for reuse and recycling, as well as the packaging waste recycling targets recommended in the Packaging Directive (APA, 2019a). The results and targets can be seen in tables 1 and 2 below:

Table 1: Lipor's compliance with the PERSU 2020 goals.

LIPOR	2017		2018		2019	
	Result	Target	Result	Target	Result	Target
Preparation for reuse and recycling (%)	33	30	36	32	34	34
Landfilling of BMW (%)	2	10	2	10	2	10
Selective collection (kg per capita)	44	45	48	49	54	53

Source: APA, 2018, 2019b, 2020.

Table 2: Valorsul's compliance with the PERSU 2020 goals.

Valorsul	2017		2018		2019	
	Result	Target	Result	Target	Result	Target
Preparation for reuse and recycling (%)	28	21	36	22	40	33
Landfilling of BMW (%)	20	23	23	23	14	16
Selective collection (kg per capita)	45	44	50	49	54	52

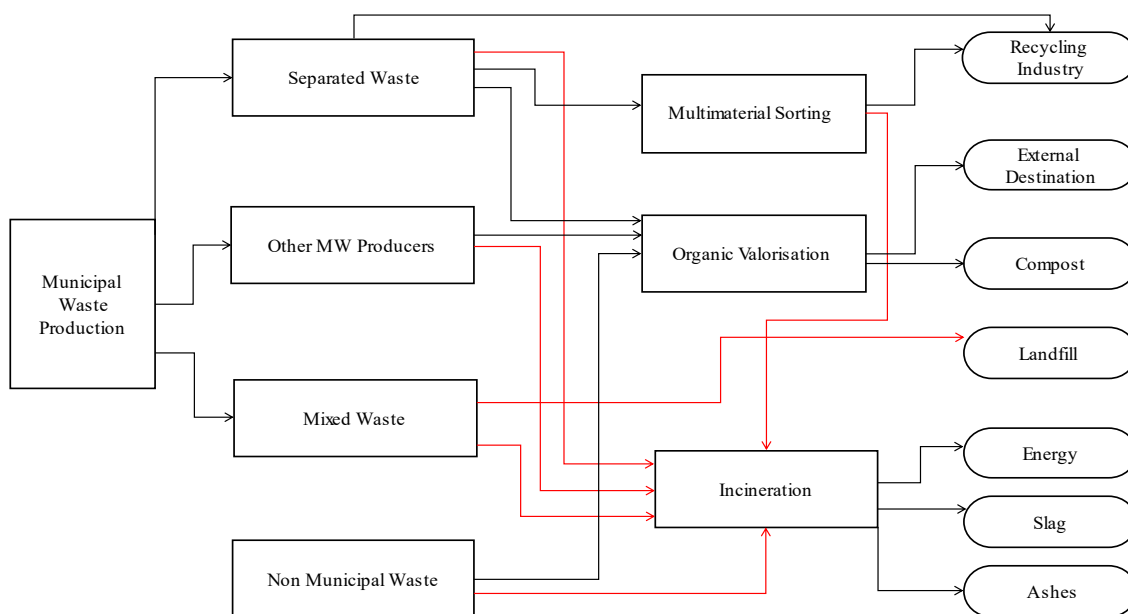
Source: APA, 2018, 2019b, 2020.

Both MWMS met their respective PERSU 2020 targets, with the exception of Lipor's selective collection results, which missed the target by 1 kg per capita in both 2017 and 2018.

4.1.3. Municipal Waste Management System Models

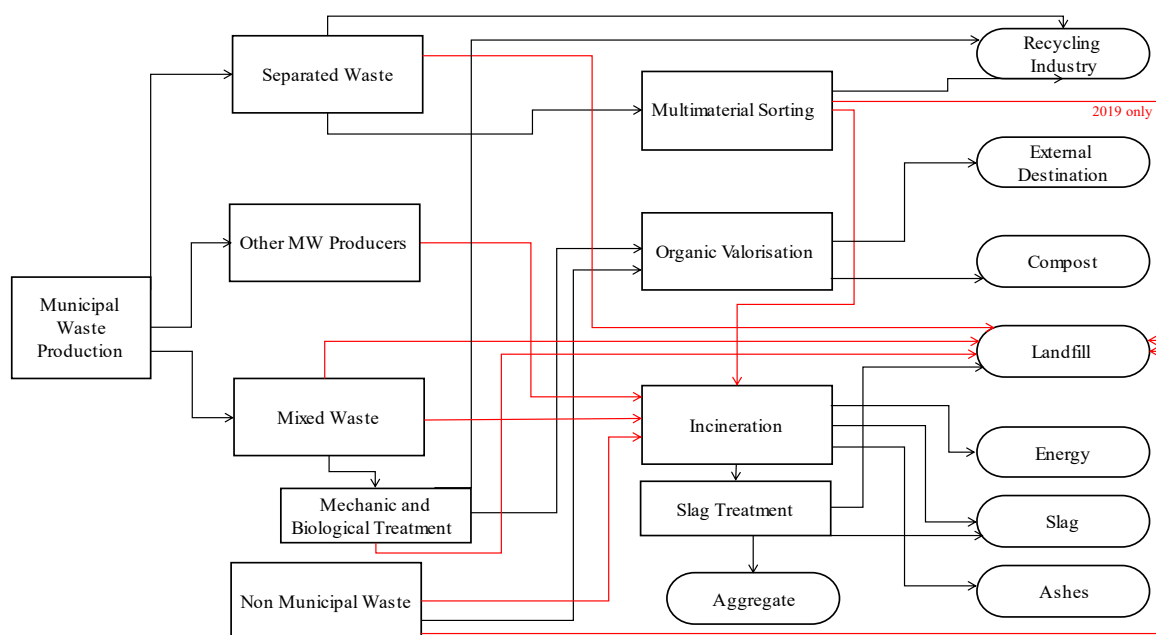
The MWMS models are based on secondary data presented in the annual report by APA. Each system is shown in figures 3 and 4 below. The red lines represent waste flows that do not contribute in any way to CE, i.e., streams in which materials are destroyed by incineration or land-filling. It should be noted that losses due to impurities, as well as small reject fractions that have to go through another waste process, have not been considered due to their tiny share. Nevertheless, they are taken into account in the further calculations of the indicators.

Figure 3. Model of waste management by Lipor.



Source: Based on data from APA, 2018, 2019b, 2020.

Figure 4. Model of waste management by Valorsul.



Source: Based on data from APA, 2018, 2019b, 2020.

Waste separation at source is done by separate collection. The fractions collected are paper/cardboard, plastic/metal, glass, bulky waste, used cooking oil, WEEE, batteries, green waste, organic waste and mixed waste. Sorting of multimaterial waste consists of the process of separating MW into different types, which takes place after the waste is collected. The collection process is variable and depends on the preferences of the municipalities: private bins are delivered by the municipality to every house in low-rise residential areas, while street containers are intended for residential areas with high buildings. Some municipal bins are even accessible only through a personal key given to residents.

Non-municipal waste includes various types of waste - agricultural waste, construction and demolition waste, hospital waste, industrial waste, sewage sludge, and others - that can be received and treated by MWMS (APA, 2022). Generally, waste is sent to landfills only when incinerators are operating at full capacity or during maintenance.

As can be seen in figures 3 and 4, there are two major differences in the waste processes of the two companies. First, Valorsul has a slag treatment process that produces an artificial aggregate that is used for sub-base layers of roads. Together with slag, it can also serve as a cover for MW cells of landfills (Valorsul, 2021b). Second, Valorsul sends some mixed waste to another company for a mechanical and biological treatment. In these facilities, organic waste is separated from other types of waste types, and afterward, it undergoes a controlled decomposition process using microorganisms, producing an organic fertilizer. During this process, energy is obtained from biogas. One fraction is prepared for recycling, another is composted, and the remainder is landfilled (Valorlis, n.d.).

4.1.4. Sustainable Development Goals

To examine how MWMS position themselves in relation to the SDGs and whether they actually support the SDGs through their core activities, the starting point was the mapping done by Campitelli et al. (2022). SDGs 3, 4, 6, 7, 8, 9, 10, 11, and 12 were assigned to several subcomponents related to governance, sector and market, collection and transport, waste disposal, energy recovery, waste recycling, and prevention and reuse (Campitelli et al., 2022). However, MWMS do not have control over the governance and sector and market components. Thus, the related

SDGs were excluded. The remaining SDGs were 6, 7, 8, 11, and 12, and their respective targets and associated indicators were examined. To this end, the indicators were cross-referenced with the SDG Tracker, a tool developed by researchers at the University of Oxford and the Global Change Data Lab. This resource monitors and assesses global and national progress against each of the SDGs and allows analysis to determine if a particular SDG target indicator needs improvement in Portugal, the country relevant to both MWMSs (Our World in Data, 2017). It is possible to visualize the SDGs affected by the MWM companies and deduce whether they really implement structured processes to support the achievement of the SDGs. The mapping of MWMS support to the SDGs can be seen in tables 3, 4, 5, 6, and 7:

Table 3: Mapping the contributions of Lipor and Valorsul to SDG 6 entitled “Ensure available and sustainable management of water and sanitation for all”.

Target	Indicators	Current Indicator Value	Actions assigned to SDG		Contribution to Indicator
			LIPOR	Valorsul	
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of domestic and industrial wastewater flows safely treated	73% - needs improvement.	A - Small quantities of hazardous waste from households are collected separately, since April 2021.	A - Controlled waste disposal in sanitary landfills or incineration plants. B - Leachate water treatment.	Despite LIPOR having a more desirable approach, no evidence of contribution has been found.
	6.3.2 Proportion of bodies of water with good ambient water quality	No data.	B - Controlled waste disposal in sanitary landfills or incineration plants. C - Leachate water treatment.		No evidence of contribution has been found.

Source: Based on data from Our World in Data, 2017; Campitelli et al., 2022.

Table 4: Mapping the contributions of Lipor and Valorsul to SDG 7 entitled “Ensure access to affordable, reliable, sustainable and modern energy for all”.

Target	Indicators	Current Indicator Value	Actions assigned to SDG		Contribution to Indicator
			LIPOR	Valorsul	
7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.1 Proportion of population with access to electricity	100% - does not need improvement.	Reliable selling of recovered energy from incineration plants.	Reliable selling of recovered energy from incineration plants.	Both companies supply yearly energy to about 150.000 residents through waste incineration with energy recovery.
	7.1.2 Proportion of population with primary reliance on clean fuels and technology	100% - does not need improvement.	Energy provided is not from renewable sources.	Energy provided is not from renewable sources.	

Source: Based on data from Our World in Data, 2017; Campitelli et al., 2022.

Table 5: Mapping the contributions of Lipor and Valorsul to SDG 8 entitled “Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all”.

Target	Indicators	Current Indicator Value	Actions assigned to SDG		Contribution to Indicator
			LIPOR	Valorsul	
8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead	8.4.1 Material footprint, material footprint per capita, and material footprint per GDP	No data.			
	8.4.2 i) Domestic material consumption ii) domestic material consumption per capita iii) domestic material consumption per GDP	i) no data. ii) 11 tonnes per capita (2019) - needs improvement. iii) 0.5kg/\$US - needs improvement.	A - Diversion rate. B - Initiatives to educate population on waste prevention.	A - Diversion rate. B - Initiatives to educate population on waste prevention.	A - Both reported increase in diversion rate. B - Campaigns are presumed to have an effect, but no evidence was found.

Source: Based on data from Our World in Data, 2017; Campitelli et al., 2022.

Table 6: Mapping the contributions of Lipor and Valorsul to SDG 11 entitled “Make cities and human settlements inclusive, safe, resilient and sustainable”.

Target	Indicators	Current Indicator Value	Actions assigned to SDG		Contribution to Indicator
			LIPOR	Valorsul	
11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.1 Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities	Europe and Northern America: 89.6% (2017) - needs improvement.			A - Both reported increase in collected municipal waste.
	11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	8.16 micrograms per cubic meter (2017) - needs improvement.	A - High and improving collection rates. B - Controlled waste disposal in sanitary landfills or incineration plants.	A - High and improving collection rates. B - Controlled waste disposal in sanitary landfills or incineration plants.	No evidence of contribution has been found.

Source: Based on data from Our World in Data, 2017; Campitelli et al., 2022.

Table 7: Mapping the contributions of Lipor and Valorsul to SDG 12 entitled “Ensure sustainable consumption and production patterns”.

Target	Indicators	Current Indicator Value	Actions assigned to SDG		Contribution to Indicator
			LIPOR	Valorsul	
12.2 By 2030, achieve the sustainable management and efficient use of natural resources	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP	No data.			
	12.2.2 i) Domestic material consumption ii) domestic material consumption per capita iii) domestic material consumption per GDP	i) no data. ii) 11 tonnes per capita (2019) - needs improvement iii) 0.5kg/\$US - needs improvement.	A - Diversion rate. B - Initiatives to educate population on waste prevention.	A - Diversion rate. B - Initiatives to educate population on waste prevention.	A - Both reported increase in diversion rate. B - Campaigns are presumed to have an effect, but no evidence was found.
12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses	12.3.1 (a) Food loss index and (b) food waste index	(a) Global food loss index - total of 112.65 kg per capita, including retail, out of home and household levels (2019) - needs improvement.	Initiatives to educate population on food waste.	Initiatives to educate population on food waste.	Campaigns are presumed to have an effect, but no evidence has been found.
12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	12.4.1 Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement	Basel convention - 100%; Rotterdam Convention - 96.55%; Montreal Protocol - 100%; Stockholm Convention - 25% - needs improvement.	Small quantities of hazardous waste from households are collected separately through designated public mobile waste containers, free of charge (since April 2021).	Collection initiative lasting a week (November 2018).	Both reported a positive contribution, but LIPOR's is permanent whilst Valorsul's was temporary.
	12.4.2 (a) Hazardous waste generated per capita; and (b) proportion of hazardous waste treated, by type of treatment	(a) Hazardous waste generated per capita - no data. (b) proportion of hazardous waste treated, by type of treatment - no data.			
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	12.5.1 National recycling rate, tons of material recycled	Municipal waste recycled - no data. Electronic waste recycling rate - no data.	A - Preparation for recycling. B - Initiatives to educate population on waste prevention	A - Preparation for recycling. B - Initiatives to educate population on waste prevention	Both reported increase of waste generation per capita. LIPOR reported decrease of preparation for recycling rates whereas Valorsul reported a decrease. LIPOR contributes negatively while Valorsul has a mixed effect.

Source: Based on data from Our World in Data, 2017; Campitelli et al., 2022.

According to tables 3, 4, 5, 6, and 7, no data were found to confirm MWMS support for SDG target indicators 6.3.1, 6.3.2, 11.6.2, and 12.3.1. Target indicators 7.1.1 and 7.1.2, related to affordable, reliable and modern access to energy services, do not need further improvement in Portugal, as 100% of the population already has access to electricity. The remaining contributions will be exposed further along in section 4.2.

4.1.5. Circular Practices

Using Campitelli et al.'s WMS-DSC (2022), tables 8, 9, 10, and 11 present an overview and comparison of the evolution of the two MWMSs toward CE. The Governance and Sector and Market components are shared by both as they are part of the same country. This analysis also identifies which practices in each MWMS are circular, i.e., which practices fit into stage 5 of the CE. In analyzing the results in tables 8, 9, 10, and 11, the same key was used, where dark blue

means the subcomponent was fully met, light blue means the subcomponent was partially met, and white means the subcomponent was not met or no data were available.

Table 8: Overview of the results of the assessment of the two MWMSs regarding Governance, Sector and Market.

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Governance	G.1 Duties and targets					
	G.2 Laws, Regulations and Agreements					
	G.3 Nomenclature					
	G.4 National level WM					
	G.5 Regional level WM					
	G.6 Municipal level WM					
	G.7 Stakeholder cooperation					
	G.8 Control mechanisms					
	G.9 Authorization and public participation					
	G.10 Quality standards and threshold values					
	G.11 Data collection, reporting and evaluation					
	G.12 Education					
	G.13 Research					
	G.14 Awareness building					
	G.15 Occupational health and safety					
	G.16 Environmental protection					
Sector and Market	SM.1 Sector development					
	SM.2 Jobs					
	SM.3 Informal sector					
	SM.4 WM system structure and organization					
	SM.5 Financial funding					
	SM.6 Enterprises					
	SM.7 Recycling market					

Source: Adapted from Campitelli et al. 's WMS-DSC (2022).

Table 8 illustrates that for the metropolitan areas of Porto and Lisbon, as well as the higher political levels, G was between stages 2 and 4, with the subcomponents in stages 1 and 4 often partially met. G.4 was the most developed compared to the lower levels of government. G.5 was the least developed because there are no regional authorities or bodies responsible for waste management in Portugal. G.6 is essential for MWMSs - however, it was partially between stages

2 and 4. G was more advanced than SM, which was in stages 2 through 4. SM.3 was mainly at stage 4 because there is no informal waste sector in Portugal. SM.4 at stage 2 shows that waste management is not very well structured. There was not a single subcomponent at stage 5.

Table 9: Overview of the results of the assessment of Lipor's MWMS regarding Collection and Transport, Waste Disposal, Energy Recovery, Waste Recycling, Prevention and Reuse.

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Collection and transport	CT.1 Waste collection					
	CT.2 Service provider					
	CT.3 Collection rates					
	CT.4 Separate collection					
	CT.5 Collection of recyclables					
	CT.6 Waste transport					
	CT.7 Transfer stations					
	CT.8 Collection of hazardous wastes					
Waste disposal	WD.1 Waste disposal					
	WD.2 Operational measures					
	WD.3 Leachate water management					
	WD.4 Landfill gas management					
	WD.5 Other means of disposal					
Energy recovery	ER.1 Thermal disposal and energy recovery					
	ER.2 Incineration plants					
	ER.3 Energy and raw material recovery					
Waste recycling	WR.1 Waste recycling					
	WR.2 Composting					
	WR.3 Fermentation					
	WR.4 Sorting and recycling plants					
	WR.5 Refuse derived fuel					
	WR.6 Recycling of construction and demolition waste					
	WR.7 Recycling rates					
	WR.8 Diversion rate and Circular material use rate					
Prevention and reuse	PR.1 Prevention					
	PR.2 Circular business and usage models					
	PR.3 Product design					
	PR.4 Process optimization and operational disposal strategies					
	PR.5 Waste generation					
	PR.6 Zero-waste index					

Source: Adapted from Campitelli et al. 's WMS-DSC (2022).

CT was between stages 1 and 5, but most of the fully met subcomponents were in stages 2 to 3. CT.4 was only partially met at stage 3. CT.5 was in stage 1 because no data were available for the collection of recyclables. WD was between stages 2 and 3, with WD.1 also partially met in stages 4 and 5. ER was in stages 2 through 3, including ER.1, which was partially met in stage 4. Most of the subcomponents of WR are at stage 1, but only WR.2 reached stage 3 and only WR.2 was at stage 2. WR was then defined as being between stages 1 to 3. PR.2 fully reached stage 3 and even partially reached stage 4, thanks to international companies promoting circular business models, so PR is in stage 2 to stage 3. Table 9 above shows the lag of WR compared to the other components. There was no subcomponent that was fully met at stage 4, only partially met. CT.2 was the only subcomponent at stage 5.

Table 10: Overview of the results of the assessment of Valorsul's MWMS regarding Collection and Transport, Waste Disposal, Energy Recovery, Waste Recycling, Prevention and Reuse.

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Collection and transport	CT.1 Waste collection					
	CT.2 Service provider					
	CT.3 Collection rates					
	CT.4 Separate collection					
	CT.5 Collection of recyclables					
	CT.6 Waste transport					
	CT.7 Transfer stations					
	CT.8 Collection of hazardous wastes					
Waste disposal	WD.1 Waste disposal					
	WD.2 Operational measures					
	WD.3 Leachate water management					
	WD.4 Landfill gas management					
	WD.5 Other means of disposal					
Energy recovery	ER.1 Thermal disposal and energy recovery					
	ER.2 Incineration plants					
	ER.3 Energy and raw material recovery					
Waste recycling	WR.1 Waste recycling					
	WR.2 Composting					
	WR.3 Fermentation					
	WR.4 Sorting and recycling plants					
	WR.5 Refuse derived fuel					
	WR.6 Recycling of construction and demolition waste					
	WR.7 Recycling rates					
	WR.8 Diversion rate and Circular material use rate					
Prevention and reuse	PR.1 Prevention					
	PR.2 Circular business and usage models					
	PR.3 Product design					
	PR.4 Process optimization and operational disposal strategies					
	PR.5 Waste generation					
	PR.6 Zero-waste index					

Source: Adapted from Campitelli et al. 's WMS-DSC (2022).

Table 10 was very similar to Table 5, illustrating the similarities between both MWMS. Thence, table 11 depicted below clarified the discrepancies between them.

Table 11: Overview of the results of the assessment of the differences between MWMSs.

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Collection and Transport	CT.8 Collection of hazardous wastes	LIPOR	LIPOR	LIPOR		
		Valorsul				
Waste Disposal	WD.3 Leachate water management		LIPOR			
			Valorsul			
Energy Recovery	ER.3 Energy and raw material recovery		LIPOR			
			Valorsul	Valorsul		
Waste Recycling	WR.1 Waste recycling	LIPOR				
		Valorsul		Valorsul		
	WR.3 Fermentation		LIPOR			
			Valorsul			
	WR.8 Diversion rate and Circular material use rate		LIPOR			
			Valorsul			

Source: Adapted from Campitelli et al. 's WMS-DSC (2022).

Lipor's CT.8 was in stage 2 and partially met in stages 1 and 3, making it more advanced than Valorsul's CT.8, which was fully at stage 1. WD.3 was in stage 2 and stage 3 for both companies. In addition, both MWMSs fully met the ER.3 criteria for stages 2 and 3, and Valorsul also partially achieved stage 4. As for WR.1, Valorsul was partially in stages 1 and 3, while Lipor was only partially in stage 1. For WR.3, Valorsul has an advantage because it was between stages 2 and 3 while Lipor was in stage 2. WR.8 gave Lipor an advantage because it was partially in stages 2 and 3 compared to Valorsul's placement in stage 2.

4.1.6. Circularity Indicators

The appropriate indicators are presented here to evaluate the circularity of the two MSWMs in relation to the waste streams. The indicators were calculated based on the waste stream volumes from APA for 2017, 2018, and 2019. Section 2.5.3. explained the objective and relevance of each indicator, while section 3.2.3. presented the way they were calculated. The results can be seen in tables 12 and 13:

Table 12: Lipor's circularity indicators.

	2017	2018	2019
Total Generated Waste (ton)	512 988	533 084	544 913
Municipal Waste Generation (kg per capita)	528	546	556
Collected Waste (%)	97,1%	97,1%	97,3%
Collected Waste (kg per capita)	520	538	549
Collected Waste Composition (%)			
Mixed Waste	80%	78%	77%
Separated Waste	20%	22%	23%
Composed of: Paper/cardboard	15%	15%	16%
Plastic/metal	11%	12%	12%
Glass	19%	17%	17%
Wood	9%	10%	11%
WEEE	1%	1%	1%
Batteries	0,006%	0,004%	0,005%
Bulky waste	5%	5%	5%
Used cooking oil	0,1%	0,1%	0,1%
Green waste	22%	22%	19%
Organic waste	18%	17%	18%
Others	0%	0%	0,001%
Incineration Rate of Waste (%)	78%	76%	72%
Landfill Rate of Waste (%)	2%	2%	5%
Preparation for Recycling Rate of Waste (%)	10%	11%	8%
Recycling of Biowaste (kg per capita)	12	13	12

Source: Based on data from APA, 2018, 2019b, 2020; PORDATA, 2018, 2019, 2020.

Table 12 reveals some important findings. More than 500 thousand tons of waste were collected, but the share of separately collected waste was only about 20%. The per capita generation of municipal waste increased, which is an undesirable development for the CE. Landfill rates were low, in contrast to incineration rates, which are quite high. Preparation for recycling rates decreased, indicating diminished circularity.

Table 13: Valorsul's circularity indicators.

	2017	2018	2019
Total Generated Waste (ton)	923 279	923 042	939 137
Municipal Waste Generation (kg per capita)	577	575	581
Collected Waste (%)	95,4%	95,6%	95,8%
Collected Waste (kg per capita)	552	551	558
Collected Waste Composition (%)			
Mixed Waste	87%	85%	84%
Separated Waste	13%	15%	16%
Composed of: Paper/cardboard	26%	27%	28%
Plastic/metal	17%	17%	18%
Glass	21%	20%	20%
Wood	2%	2%	2%
WEEE	0,1%	0,1%	0,2%
Batteries	0,01%	0%	0,01%
Bulky waste	5%	6%	5%
Used cooking oil	0%	0%	0%
Green waste	3%	3%	3%
Organic waste	26%	24%	23%
Others	0,2%	0,4%	0,4%
Incineration Rate of Waste (%)	67%	61%	67%
Landfill Rate of Waste (%)	21%	25%	17%
Preparation for Recycling Rate of Waste (%)	8%	8%	9%
Recycling of Biowaste (kg per capita)	0,5	0,4	0,6

Source: Based on data from APA, 2018, 2019b, 2020; PORDATA, 2018, 2019, 2020.

As shown in table 13, the proportion of separated waste in Valorsul was even lower than in Lipor, although the city has more 400 thousand tons of waste to treat. However, the increase in per capita municipal waste generation was relatively lower than that of Lipor. The same is true for the increase in waste collected per capita, which was also lower than that of Lipor. Preparation for recycling increased slightly, but recycling of biowaste was extremely low. Landfill rates are higher and are in direct contrast to incineration rates, which are lower compared to Lipor.

4.2. Results Discussion

The results show that in 2017, 2018, and 2019 there are differences in the amount and progression of MW flows in the metropolitan areas of Porto and Lisbon, and in the organizations' commitment to taking CE appropriate action. Here, the main results are discussed to help readers better grasp the importance of the data and its implications for MWM in the context of CE.

4.2.1. Circular Development

As can be seen in the MWMS models shown in figures 3 and 4, only 4 out of 9 Lipor processes that occur immediately after receiving waste can potentially contribute to CE, compared to 6 out of 12 for Valorsul. This means that about half of the waste in both MWMSs destroy any type of material, since there is no material recovery for waste that ends up in landfills and incinerators. Thus, there is no chance for these materials to re-enter the economy and eventually fulfill a CE (Pires & Martinho, 2019). In addition, no changes were made to the relevant infrastructures and waste treatment options in either MWMS during the years in question, so no implementations related to CE were found here.

CE addresses the entire supply chain (Singh & Ordoñez, 2016). Obviously, these MWMSs uniquely address developments that cover 2 CE principles, namely R8 - recycling and R9 - recovery (Lee et al., 2017). As far as recycling is concerned, they mainly prepare waste for recycling because the only recycling that is carried out is the recycling of biowaste by Valorsul, and in extremely small quantities. Other strategies such as R3 - reuse, R4 - repair, R5 - refurbishment, R6 - remanufacturing, and R7 - repurpose could be addressed directly by creating facilities that perform these functions, such as community-specific repair stores, thrift shops or sharing centers. By attempting to extend the longevity of a product and/or its components, these programs promote waste reduction (Lee et al., 2017). Instead, they are limited to awareness campaigns and educational initiatives. A good example of this is Lipor's newly developed Center for Recovery and Reuse, which focuses on educational activities and repair workshops (Lipor, 2020c).

The companies responsible for the MWMSs studied claim that their strategy is linked to the SDGs. Lipor claims a link to SDGs 2, 4, 6, 7, 8, 9, 11, 12, 13, 15, and 17, while Valorsul's parent company, Mota-Engil, is committed to SDGs 1, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17 (Lipor, 2020d; Mota-Engil Group, 2022). The analysis showed that Lipor and Valorsul impact

SDGs 6, 7, 8, 11, and 12 at best. Their impacts on these goals range from not at all to mixed to positive, often lacking supporting data. Lipor had a more desirable approach to supporting the SDGs.

Moreover, both MWMSs are equivalent in terms of circular practices, as the only notable circular practice is the exclusive collection of waste by the formal sector. This is not a peculiarity of either MWMS, but in fact typical of all waste systems in Portugal (Merta, 2016). Nevertheless, there are 6 important areas where both MWMSs differ significantly in terms of their stage of development towards the CE.

The first concerns collection and transportation, more specifically the collection of hazardous waste. Although industrial hazardous waste is not collected by either MWMS, as it is collected and treated by other private entities, in April 2021 Lipor started collecting small amounts of household hazardous waste by setting up a mobile drop-off point (Lipor, 2021b). Obviously, no data are available yet; moreover, this would fall outside the scope of the years studied. Valorsul did a week-long collection campaign in 2018 (Valorsul, 2018). Regarding the CE maturity level, Valorsul is fully in stage 1, while Lipor is partially between stages 1 and 3, showing that progress is being made. This is consistent with Lipor's more desirable approach to supporting SDG 12, target 4.

The second point concerns leachate water management. While both MWMSs have leachate drainage and treatment systems in their respective landfills, only Lipor treats leachate well enough to discharge it to receiving waters. Valorsul has to discharge the leachate to a dedicated waste treatment facility (Costa, 2015). This is the reason why Valorsul is partially between stages 2 and 3, while Lipor is partially in stage 2 and fully in stage 3. However, there is no indication of future work related to leachate water management.

Both hazardous waste collection and leachate water management correlate with Lipor's more favorable contribution to SDG 6, which relates to clean water and sanitation, more specifically indicator 6.3.1. Hazardous waste collection is a new project, so there is no relevant data yet, but it could reduce the release of hazardous substances into water bodies and sanitation infrastructure.

The third deviation is related to energy and raw material recovery. Here, Valorsul is more developed CE wise and goes partially to stage 4, while both are completely between stages 2 and 3. Although both MWMSs use slag to cover sanitary landfills, Valorsul's facilities treat the slag and

use it for road construction. Valorsul also recovers metals from the incineration process, which are then sold for recycling - 100% of ferrous metals and 70% of non-ferrous metals. (Valorsul, 2021b). Lipor is still working on a project to develop the recovery of metals from waste incineration (Industria e Ambiente, 2021). Both MWMSs sell energy back to the grid, which links them to SDG 7, but the target indicators do not need to be improved further in Portugal, so there is no contribution to this target.

The fourth distinction is related to waste recycling. Valorsul treats some of its waste through a mechanical and biological process. This treatment option allows further separation of materials and allows more waste to be composted and prepared for recycling. However, it is not currently a very efficient process, as it does not contribute much to the rates of preparation for recycling - at its best, it supplemented the rates of preparation for recycling by 0.1 percentage points. However, it was responsible for about half of the recycling of biowaste, although Valorsul recycles only small quantities overall. Nevertheless, mechanical and biological treatment of waste is considered by Campitelli et al. (2022) as a critical step to become CE. Lipor does not have such a treatment process. Consequently, Valorsul is partially between stages 1 and 3, while Lipor is partially in stage 1. There is a lack of data about the ensured input for treatment for preparation for recycling plants.

The fifth dissimilarity relates to fermentation. Valorsul has an anaerobic digestion plant and thus has an advantage over Lipor, which is still planning to build an anaerobic digestion plant (Lipor, 2022). This means that Valorsul is fully in stage 3, while Lipor is in stage 2. Valorsul's plant extracts energy from biogas and uses the digestate as fertilizer for the next composting cycle. There is also the possibility of expanding the capacity of the plant once the collection volumes of biowaste justify it (Valorsul. n.d.).

The sixth feature that distinguishes the approaches of both MWMSs is the diversion rate. Both MWMSs reported increases in diversion rate contributing positively to SDG 8 and SDG 12, target 2. The diversion rate is the waste that is neither incinerated nor landfilled (Zaman & Lehmann, 2013). Lipor's waste diversion rate has improved over the years and was 20% in 2017, 21% in 2018, and 22% in 2019. Valorsul has improved even more, with 10% in 2017, 13% in 2018, and 14% in 2019, placing it in development stages 1 and 2, while Lipor is between stages 2 and 3. These positionings are partial because the other criterion in the same subcomponent is circular material use rate. There are no data available to calculate the circular material use rate

for Lipor and Valorsul. Therefore, the national values were used, which for Portugal are around 2%, placing it in stage 2 (Eurostat, 2018a).

4.2.2. Circularity Level

The circularity indicators in section 4.1.6. can be used to show and compare how the MWMSs of Lipor and Valorsul performed in relation to waste flow volumes in 2017, 2018, and 2019. These indicators can represent goals and strategies in a CE, so they are discussed in greater detail here.

4.2.2.1. Total Generated Waste and Municipal Waste Generation

Both Lipor and Valorsul experienced an increase in total waste generation between 2017 and 2019. This result is in direct contradiction with the goals of CE, which aim to reduce waste generation, indicating decreased circularity (Franco-García et al., 2019). Municipal waste generation, which is based on population size, has also increased. Lipor's value increased from 528 kg per capita in 2017 to 556 kg per capita in 2019, in contrast to Valorsul's value, which was 577 kg per capita in 2017, decreased to 575 kg per capita in 2018, and increased again to 581 kg per capita in 2019. This had a negative impact on SDG 12, target 5, which also means that the waste prevention and reduction education campaigns conducted proved ineffective in changing the consumption habits of residents sufficiently to reduce waste generation. This is contrary to a desired CWMS (Aramburu, 2021).

4.2.2.2. Collected Waste and Preparation for Recycling Rates

Both systems saw modest improvements in the amount of waste collected, despite already high levels. Looking at kilograms per capita, collected waste at Lipor increased from 520 kg per capita in 2017 to 549 kg per capita in 2019, a total increase of 29 kg/capita in just 2 years, while collected waste at Valorsul fluctuated slightly, increasing from 552 kg per capita in 2017 to 551 kg per capita in 2018 and to 558 kg per capita in 2019. This shows a positive impact of both MWMSs on SDG 11, target 6, indicator 1. A healthy and improving collection system also supports a CWMS (Aramburu, 2021).

Regarding the composition of the collected waste, we can also see the better positioning of Lipor, since the ratio of separated waste to mixed waste is better. The Portuguese guidelines

include targets for separated waste to support CE (APA, 2019a). At Lipor, the proportion of separated waste increased from 20% in 2017 to 23% in 2019, while at Valorsul the proportion of separated waste was 13% in 2017 and increased to 16% in 2019. Incidentally, the collection of mixed waste was reduced in the same scale. Thus, both systems increased their percentage of separated waste by 3 percentage points between 2017 and 2019, which helped achieve the 2020 selective collection targets (APA, 2021). These increases in waste separation may be due to the expansion of door-to-door collection that Lipor and Valorsul have recently been promoting with the help of affiliated municipalities. In fact, Lipor even launched a special campaign for this in 2019, which could lead to higher separation rates in the future (Lipor, 2019). Nonetheless, increased waste separation could point to greater circularity in both regions (Lee et al., 2017).

Improving the longevity of products and materials is a benefit of higher quantities of separated waste. In both regions, separate collection increased slightly in the paper/cardboard, plastic/metal, glass, and wood fractions. However, green waste collection was more significant in Lipor, as its share of collected waste was significantly higher and increased during the period in question. Lipor's composting facility has a processing capacity of 60,000 tons per year - for both green and organic waste (Lipor, 2020e) - while Valorsul's composting facility can process only 1,300 tons of green waste per year (Valorsul, 2021c). This allows the northern region to be more committed to green waste collection. This is reflected in Lipor's biowaste recycling values, which are about 12 kg per capita, far from Valorsul's biowaste recycling values, which are about 0.5 kg per capita. However, Valorsul has an anaerobic digestion plant only for organic waste with a treatment capacity of 40,000 tons per year (Valorsul, n.d.). And indeed, according to the EU definition, anaerobic digestion is the only treatment option for organic waste that leads to material recycling (European Commission, 2011b). Despite the lower recycled volumes of biowaste, Valorsul is in a more favorable position with an anaerobic digestion process, while Lipor is still planning the construction of a facility for this treatment option (Campitelli et al., 2022).

Higher waste separation rates are related to higher preparation for recycling rates. Valorsul's preparation for recycling rate increased from 8% in 2017 to 9% in 2019, which has a positive impact on SDG 12, target 5. Lipor's preparation for recycling rate increased from 10% in 2017 to 11% in 2018 and then decreased to 8% in 2019, negatively impacting SDG 12, target 5. This could be due to Lipor's less efficient sorting facilities and/or less careful sorting behavior by the population. These values contrast with the 3 percentage point increase in separated waste

reported by both MWMSs, which could be explained by an increase in material contamination, although higher at Lipor. This could jeopardize a successful CE (Haupt et al., 2017). In this work, the rates of preparation for recycling are calculated as the amount of waste in recycled form sold to the recycling industry relative to total waste generation. This differs from the calculation formula of APA, but both do not take contamination into account.

Nevertheless, both MWMSs achieved their respective goals of preparation for reuse and recycling during the period studied (APA, 2019a). Lipor's rate of preparation for reuse and recycling increased from 26% in 2012 to 36% in 2020, while Valorsul's rate increased from 20% in 2012 to 38% in 2020 (APA, 2013, 2021). Assuming a similar linear trend and the current rate of growth, the preparation for reuse and recycling rates of Lipor and Valorsul will be 42% and 49%, respectively, in 2025. Thus, both MWMSs are expected to miss the 55% target for preparation for reuse and recycling in 2025 (Order no. 241-B/2019 of July 31st). Valorsul is more advanced with its mechanical and biological treatment in terms of waste recycling in a CE (Campitelli et al., 2022). However, the preparation for recycling is not very advanced, being used only for less than 10% of the total mixed waste.

4.2.2.3. Incineration and Landfill Rates of Waste

At Lipor, the waste incineration rate decreased from 78% to 72% between 2017 and 2019, while the landfill rate increased from 2% to 5% during the same period. At Valorsul, the waste incineration rate decreased from 67% in 2017 to 61% in 2018 but increased again to 67% in 2019. This also contrasts with landfilling, which was 21% in 2017, increased to 25% in 2018, and dropped to 17% in 2019. Since incineration is always preferable to landfilling (Pires & Martinho, 2019), this is a negative and positive trend for Lipor and Valorsul, respectively, in terms of waste disposal in a CE. Nevertheless, both systems have improved their diversion rate, which is an optimistic horizon for a CE. This could be explained by the higher separation rates, since most of the waste incinerated or landfilled is from mixed waste.

5. Conclusion

5.1. Main Conclusions

The concept of circular economy focuses on closing material and energy loops and the way resources are managed under the current economic paradigm that, according to scientific writings, is leading humanity to an uninhabitable existence. This study argued that the circular economy relies on waste management systems to effectively treat municipal waste to increase resource efficiency. Growing waste volumes pose a threat to the environment and the population that will persist if we do not properly evaluate current practices and rapidly improve them (Lee et al., 2017). Creating a national roadmap for the circular economy brings the concept into public policy (Resolution of the Council of Ministers no.190-A/2017). As part of a curricular internship and with the intention of analyzing the distinct commitment to the circular economy, this study examined two municipal waste management companies that are the most representative of this sector in Portugal: Lipor and Valorsul.

The main research question was: *What is the circularity level of the two largest MWMS in Portugal?* To support it, the following sub-research questions were answered:

- 1 - To what extent do the activities of Lipor and Valorsul contribute to improved municipal waste management and thus to the SDGs?
- 2 - How do Lipor and Valorsul behave towards CE, and what circular practices have been implemented?
- 3 - What is the level of circularity of the MWMSs of Lipor and Valorsul, and how has it evolved over time?

The results obtained from the chosen research methods show that both municipal waste management companies have not improved their systems, resulting in a mixed contribution to the sustainable development goals. Given these are the leading municipal waste management systems in Portugal, the results do not bode well for the presumed circularity of systems in rural and isolated areas. They were also at similar stages of development on the path to a circular economy, and only one circular practice was discovered - waste collection being done exclusively by the formal sector. Moreover, there were different developments in the two systems in terms of the level of circularity. On the negative side, waste generation has increased in both systems, even

when population size is taken into account. On the positive side, collection, separation and diversion rates have increased in both systems. Regarding preparation for recycling, the rate decreased at Lipor, while it increased at Valorsul. Both companies are expected to miss the national separate collection target in 2025. In addition, mixed waste still accounts for over 77% of waste collection. This is a worrying figure as preparation for recycling rates are dependent on high waste separation rates, assuming that contamination does not naturally increase.

5.2. Main Contributions

Considering that the circular economy plays an important role in environmental efforts nowadays, the results of this study will benefit both academia and business.

The contribution to academia comes from the new knowledge gained in evaluating municipal waste management in the context of the circular economy. This work was the first application of the benchmarking tool in cities of the Global North (Campitelli et al., 2022), complemented by a set of circularity indicators. This combination of methods represents a significant theoretical advance in determining circularity in municipal waste systems compared to previous research (Hoek, 2019). It can be used and/or perfected to assess other waste management systems in large European urban regions to compare different circular economy developments across Member States.

The benefit of this study to professionals and organizations is that it can be used to better understand and properly evaluate the circularity of municipal waste management, which is critical in these times of transition to a circular economy. It is important that organizations properly assess their waste systems, but also understand the pitfalls of improper assessment and the associated circularity level that results from improper methods. Therefore, waste management companies that apply the methods used in this study will achieve more scientifically sound results in their circularity assessments, provide society with better information about the circular economy, and avoid potential greenwashing claims. The greater demand for circular business models provides an incentive for organizations to transform, justifying the need for more effective circularity assessments. As a result, administrators will be informed about what should be emphasized in a circular economy to improve companies' circular performance and work toward a circular waste management system. To achieve this, these companies should establish formal and

continuous cooperation structures where science directly supports the decision-making process of the waste management sector's decision making process.

5.3. Limitations and Future Research

There were several limitations to this study. First, the analysis of waste streams focused on mass, composition, and type of treatment, ignoring quality. The emphasis on quantity needs to be reconciled with the assessment of the contamination levels of the collected waste. Second, the lack of information. Limited access to internal data led to the use of mainly secondary data from the Portuguese Environmental Agency, although this data was also very confusing. Company-specific data were also not readily available, so parts of the study relied on company websites to obtain information. Possible research into circular information is recommended. Third, the lack of indicators of citizen attitudes could be addressed in future work. This research was more concerned with evaluating the complex waste management systems that only function when the behavior of the population cannot be changed. In addition, research on the other systems could provide a national panorama of the evolution of the circular economy in this sector. Future research and partnerships could promote the detour of waste to resources, as well as technological investment opportunities that would enable cutting-edge processes.

Even though waste management companies from the largest urban regions in Portugal have initiated actions towards circularity and have committed to contribute to the Sustainable Development Goals, it has been possible to identify that much remains to be done, especially in terms of circular economy principles. This is because it requires a very wide range of sectoral strategies and integrated movements throughout the value chain, which is still very linear. Trying to implement circular policies through a linear waste management system does not advance the effective shift to a circular economy. If we really want to make the economy circular, we need a united front of businesses, governments and citizens. If any of these stakeholders does not commit to the circular economy, it will not be achievable, the *status quo* will be maintained, and sustainable development will be compromised.

6. References

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