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Iniciativas de compostagem urbana descentralizada: Um estudo de caso na cidade de Aveiro

Decentralized urban composting initiatives: A case study in the city of Aveiro

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biologia Aplicada, realizada sob a orientação científica do Doutor José Manuel Gaspar Martins, Professor do Departamento de Ciências Sociais, Políticas e do Território (DCSPT) da Universidade de Aveiro e sob coorientação do ex membro integrado do Centro de Estudos do Ambiente e do Mar (CESAM) PhD. Ricardo Luís Teles de Carvalho

o júri

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palavras-chave compostagem comunitária, compostagem doméstica, economia circular, questionário, gestão de resíduos, metabolismo urbano

resumo

Portugal é um país que está em transição para implementar objetivos de gestão de resíduos sólidos de acordo com as metas da União Europeia, nomeadamente a diretiva-quadro de resíduos. No contexto europeu, esta circunstância acelerou a adoção de regras de gestão de resíduos na região, incluindo incentivos para a compostagem de biorresíduos com vista à produção de biofertilizantes. Nesse contexto, os municípios têm sido incumbidos de desenvolver políticas locais e fornecer financiamento para novas iniciativas que possam apresentar soluções para os riscos ambientais e socioeconómicos associados à deposição de biorresíduos em aterros municipais.

Para isso, este trabalho teve como objetivo identificar os sistemas de compostagem mais eficientes, caracterizar as iniciativas de compostagem descentralizadas (DCI) no contexto urbano afim de identificar estratégias para potencializar a compostagem no contexto urbano e apontar estratégias eficazes para acelerar e ampliar as práticas de compostagem urbana pelos cidadãos através do estudo de caso do projeto Ciclocompost e do questionário. Foi realizado um inquérito sobre a percepção de mais de 100 cidadãos residentes na cidade de Aveiro (Portugal) relativos à gestão dos seus bioresíduos. O estudo demonstra que as limitações dos entrevistados para a compostagem são significativas e estão associadas principalmente à falta de espaço e conhecimento sobre o assunto, enquanto as motivações estão associadas aos benefícios ambientais.

keywords community composting, home composting, circular economy, questionnaire, waste management, urban metabolism

abstract Portugal is a country that is in transition to implement solid waste management objectives in accordance with the goals of the European Union, namely the waste framework directive. In the European context, this circumstance accelerated the adoption of waste management rules in the region, including incentives for the composting of bio-waste with a view to the production of biofertilizers. In this context, the municipality have been tasked with developing local policies and providing funding for new initiatives that may provide solutions to the environmental and socio-economic risks associated with the disposal of bio-waste in municipal landfills.

For this, this work aimed to identify the most efficient composting systems, characterize the decentralized composting initiatives (DCI) in the urban context in order to identify strategies to enhance composting in the urban context and set effective strategies to accelerate and expand urban composting practices through the study of case cities of the Ciclocompost project and the controlled. A survey was carried out on the perception of more than 100 citizens residing in the city of Aveiro (Portugal) regarding the management of their biowaste. The study demonstrates that the interviewees' limitations for composting are significant and are mainly associated with the lack of space and knowledge on the subject while motivations are associated with environmental benefits.

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List of Abbreviations

APA - Portuguese Environmental Agency
COP - Conference Of the Parties
CO_2 – Carbon Dioxide
CH_4 – Methane
C/N ratio – the ratio of the mass of carbon-to-nitrogen
DCI - decentralized composting initiatives
EU - European Union
H_2O - Water
GHG – Greenhouse Gas
GWP – Global Warming Potential
LCA - Life Cycle Assessment
MRRU - Urban Waste Registration Map
MSW - Municipal Solid Waste
NH_4 - Ammonium
OFMSW - Organic Fraction of Municipal Solid Waste
RGGR - General Waste Management Regime
SGRU - Urban Waste Management Systems
UWM – Urban Waste Management
VOCs - Volatile Organic Compounds

1. Introduction

In recent years, the prospect of transitioning from linear systems, on which practically all economic subsystems are built, to more circular and decentralized systems, which are focused on reducing waste and pollution while providing new chances for growth and development, has gained importance. Its proof may be seen in the debate space that it took up on the agenda of the last COP27 (Conference Of the Parties) in Egypt, in contrast to prior editions. This Convention is where the highest decision-making happens. All Parties to the Convention are represented at the COP27, where they review the implementation of the Convention and any other legal instruments adopted by the COP27 and make decisions required to endorse the effective implementation of the Convention, along with institutional and administrative agreements (United Nations).

Solid waste management has always been an environmental and sanitary health risk along human evolution, but it was during the industrial revolution that waste production took on greater proportions, so that nowadays it is possible to observe the consequences of poor management of solid waste. According to Seadon (2006) in the first housing centers, waste was deposited on the streets or close to houses; another practice was burning it. There was no common existence of waste management systems or a specific place for their deposition. However, there are records of some ancient civilizations that used a simpler management model, as in Greek cities and in Mahenjo-Daro, in an Indus village. Many diseases were caused by the lack of sanitation and waste management, as it has been perceived over the years.

The first meetings that gave rise to the Treaty of Paris had a more economic concern, giving rise to the precautionary and polluter pays principles. However, with the appearance of the first treaties, there was a more reactive vision than the prevention of possibly harmful events. Nevertheless, between the years of 1977 and 1986, efforts were directed towards developing the concept of pollution prevention. Biowaste is strongly related to urban food systems, sanitary hygiene, and other industrial operations, such as the manufacturing of pulp and textiles, in the flow of materials with which we interact in our everyday lives. Even a thorough study of the flow of this sort of material through its value chain reveals its inefficiencies. This is demonstrated by the large volume of material that is rapidly judged to be of little value and handled as waste. Cities around the world are well positioned to catalyze a shift to a circular economy for food due to their economic importance, vast material flows, and diversified and concentrated human potential. Municipalities get unparalleled flexibility to customize their infrastructure and determine their development course as they obtain increasing legislative independence and become global political powerhouses. As a result, they are credible change agents and already take the lead on issues such as climate change and air pollution. Food production and distribution are on their agenda, and it is conceivable that they will become the next urban frontier (Seadon, 2006).

1.1. Waste management worldwide

The most obvious and bothersome remains of human society are municipal solid wastes (MSW). The overall quantity of MSW created annually was predicted to be around 1.5 Gt (Themelis, 2007), with this figure expected to rise to around 2.2 Gt by 2025 (Hoornweg and Bhada-Tata, 2012). Approximately 300 Mt is recycled, 200 Mt is handled with energy recovery, another 200 Mt is dumped in sanitary landfills, and the remaining 800 Mt is disposed of in non-sanitary landfills or dumps. As a result of mixing with other materials and exposure to reactive environmental conditions, much of the recoverable stuff in MSW gets scattered (IPCC, 2014).

The generation in world cities of solid waste was in 2002 approximately 1.3 billion metric tons per year and this number is just going to increase. In global perspective, proportionally, biowaste has the largest generation which is 46% (Hoornweg and Bhada-Tata 2012 apud Lim, 2015). The generation of waste by urban residents was expected to almost double from 3.5 million tons/day in 2002 to 6.1 million tons/day in 2025, and a total of $375 billion will be spent for its management in 2025 (World Bank; 2012 apud Khandelwal, 2018). Inadequate management of MSW through open burning, open dumping, and unhealthy landfill contributes to many environmental problems such as global warming, ozone depletion, human health risks, environmental damage, ecosystem depletion of abiotic resources, etc. (Laurent et al. 2014 apud Khandelwal, 2018).

The following Figure shows the proportion of waste worldwide.

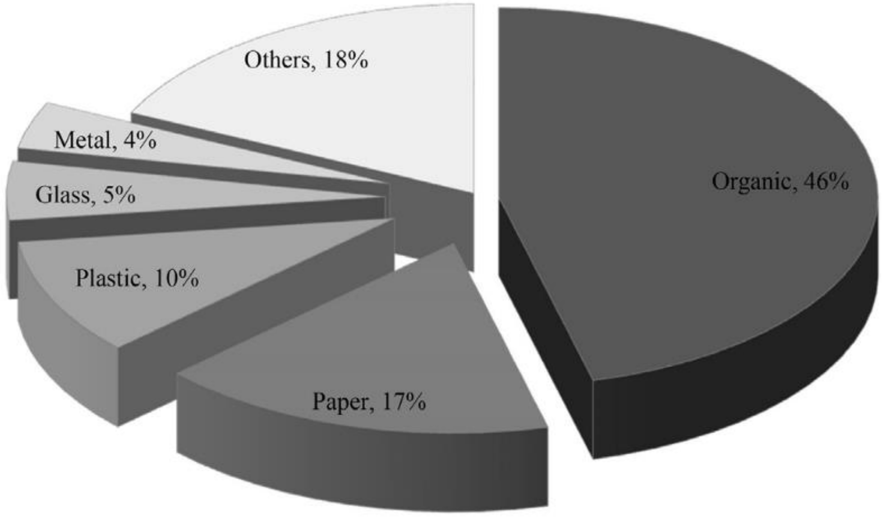

Figure 1. Generation of each type of waste. Fonte: (Hoornweg and Bhada-Tata 2012 apud Lim, 2015).

Current solid waste management methods are landfill, incineration, recycling, reuse, source reduction (Wu et al., 2014 apud Lim, 2015). Landfill and incineration are characterized as waste disposal methods, which are the least preferred options in the waste management hierarchy. In many parts of the world, landfills dominate the dominant method of waste disposal, as it is the cheapest in terms of capital costs (Laner et al., 2012 apud Lim, 2015).
In developed countries, landfills are equipped with a combination of waste containment systems, such as leak detection and management systems for leachate and biogas collection. In contrast, developing countries often lack adequate landfills (Hoornweg and Bhada-Tata, 2012 apud Lim, 2015).

Thus, the restriction of land and the usefulness of waste as a resource are solid reasons to withdraw from landfilling and switch towards a more sustainable waste management strategy (Marshall and Farahbaksh, 2013 apud Lim 2015). For instance, because of the EU Landfill Directive European countries are eliminating the landfill which requires its member states to reduce landfilling of biodegradable waste to less than 35% of the quantity produced in 1995. Countries such as Belgium, Austria, Denmark, Germany, Luxembourg, Netherlands and Sweden have accomplished and exceeded the targets of the EU Landfill Directive (EEA, 2009 apud Lim, 2015).

1.2. Waste management in Europe

In Europe, food waste accounts for the greatest portion of municipal solid waste (MSW) (with a share of 30-50 percent; Treadwell, et al., 2018 apud Tonini, 2020). Food waste management that is inappropriate or suboptimal has negative environmental, health, and social consequences (Manfredi and Christensen, 2009; Manfredi et al., 2010), as well as missed potential for boosting environmental and socio-economic returns (Manfredi et al., 2010 and, amongst others, Eriksson et al., 2016; Schanes et al., 2018; Albizzati et al., 2019), a fact that can be particularly problematic in urban contexts. On this background, the European Commission prioritizes prevention measures in order to achieve Sustainable Development Goal 12 (halving food waste per capita by 2030 and reducing food losses in the production and supply sectors; United Nations, 2015), but it also encourages separate collection of generated food waste and resource recovery (European Parliament and the Council, 2018; European Commission, 2015). In recent years, the EU (European Union) has moved away from landfilling as a form of MSW management, resulting in increased recycling and incineration of MSW (Eurostat, 2019 apud Tonini, 2020). However, the policy aims of 60-65 percent MSW processed and sent for reuse or recycling for the years 2030-2035 is only likely to be realized if food waste incineration is avoided and food waste is upscaled, for instance by composting biowaste. While a broad management hierarchy is recommended (European Parliament and Council, 2018), the management scheme chosen to achieve environmental, economic, and social sustainability at the local level might be situation-dependent. And an important goal for achieving biowaste management policies should be based on life cycle thinking (European Parliament and the Council, 2008).

1.3. Waste management in Portugal

Waste management in Portugal is enshrined in the National Waste Management Plan and, specifically, urban waste management is postulated in the Strategic Plan for Urban Solid Waste (PERSU). Urban waste is defined as “waste from homes as well as waste that, by their nature or composition, are similar to waste from homes” according to the Decree-Law No. 73/2011. The urban residue has a characteristic that differs from other waste flows, that is the fact that the urban waste shows a higher number of producers as well as diffuse locations. The eradication of open dumps in a short period of time was one of the greatest milestones of PERSU I. But more than occasional services, PERSU provided a base and structure for the waste management system, developing selective collection systems with the introduction of eco-points and eco-centers throughout the country and also constructing infrastructure. These infrastructures, which constituted the instruments that allowed the management of waste, were inserted in Multi Municipal and Intermunicipal Systems, the first companies constituted by the junction of different municipalities with the *Empresa Geral de Fomento* (EGF) and the second only by the aggregation of several municipalities. The economy of scale achieved with these systems was channeled to new investments in the sector, which led to an increase in efficiency in the management of urban waste in the country. In 2013, the 7th EAP was approved at the headquarters of the European Union - defined for the same time horizon as PERSU 2020, where priority is given to those postulated in the national strategic plan such as considering waste as a source of resource and reducing its production - per capita and in absolute terms, reducing landfill, optimize recycling efficiency and develop markets for secondary raw materials, and producing limits to the production and use of non-recyclable materials (Silva, 2016).

The new Strategic Plan for Urban Waste (PERSU 2020), approved by Ordinance No. 187-A / 2014, of 17 September, defends a new policy based on the economic use of managed and generated waste, using, in particular, the urban waste sector as a means of stimulating local economies and national while integrating citizens, making it an integral part of the global management system. Urban waste management is included in the scope of the plan, excluding those originated by large producers, that is, those responsible for a production of more than 1,100 liters per day and specific flows such as electrical and electronic equipment, used batteries and accumulators or packaging. In PERSU2020, the focus is on acting upstream in the waste management chain and downstream with the enhancement of existing infrastructures through process optimization in order to guarantee the fulfillment of the established goals - applying the waste management hierarchy, environmental, social and financial sustainability and the protection of human health by avoiding or reducing the environmental impacts that arise from inefficient management (Silva, 2016).

Although the goals to be achieved are at the national level, there was a distribution of the efforts required to all management systems with adaptation of specific goals to them, and the fulfillment of these goals allows the achievement of the national goal - except for the goal of reducing production waste, where, according to PERSU2020, the goal to be achieved at national level is established. For the allocation of specific targets, each management system had to provide information on its operations, such as waste flows and even possible improvements to be made for the period from 2012 to 2020, with this information it’s possible to forecast for waste production (Silva, 2016). Urban areas through a hypothetical Business As Usual (BAU) scenario, which generally considers that the trends in the present will remain in the future (Silva, 2016).

Currently, a concept that is arising is “Circular Economy’’. It comes to disrupt the view of the linear economy of “take-make-dispose”. The Ellen MacArthur Foundation (2019) says that a circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment. In contrast to the ‘take-make-waste’ linear model, a circular economy is regenerative by design and aims to gradually decouple growth from the consumption of finite resources. After defining what an economy actually is, this learning path explores the nuances of the concept of a circular economy, including the difference between biological and technical materials, the different opportunities that exist to keep materials and products in use, and the history of the idea. Finally, the benefits of shifting from a linear to a circular economy are highlighted.

1.4. Motivation and relevance of the thesis

Urban biowaste management is highly relevant due to the increased production of food and other types of biowaste in cities, as well as due to the lack of adequate infrastructure for its treatment. In the European context, this situation led to an acceleration in the implementation of EU waste management policies, including incentives for promoting the composting of biowaste towards the production of biofertilizers. In this context, it has been the duty of municipality to establish local strategies and the support to new projects that can address the environmental and social problems caused by biowaste disposal in landfills.

On this background, decentralized composting initiatives (DCI) in urban environments can be alternative and complementary to centralized waste management systems, in order to sensitize citizens and enhance urban ecology by contributing to tackling environmental risks in cities caused by poor management of biowaste. From the environmental point of view, it is today consensual that biowaste composting are less polluting than conventional disposal. A study conducted in Malaysia showed that an increase in the proportions biowaste composting is more feasible than landfilling in municipal waste management over the next 10-15 years (Yang et al. 2015 apud Lim, 2015). In fact, usually landfills need proper maintenance and continuous care after closure, especially in developing countries (Lim, 2015). Instead of disposing of biowaste in landfills, biological composting is a resource efficient way to treat biowaste and produce biofertilizers, making nutrients available for soil application, contributing to soil amendment. The DCI is an important matter for the new biowaste management strategies. According to APA the Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste has many objectives for waste and includes recovery of biowaste on site.

The motivation of this thesis is to identify the motivations and limitations that the citizens of Aveiro face in managing their biowaste via composting, to open possibilities of improvement of biowaste management using a complementary method to the centralized one. This study analyzed in detail the perspectives of the citizens of Aveiro, including participants of the Ciclocompost Project, a DCI initiative developed in Aveiro to contribute to community composting.

1.5. Objectives and structure of the thesis

The aim of this study is i) to identify the most resource efficient and low-emission decentralized composting systems used worldwide, and ii) characterize of DCI in the urban context in order to identify strategies for enhancing composting in the urban context. Thus, this work aims to contribute to map/identify the less polluting composting technologies and people's perceptions and behaviors regarding biowaste management in cities and homes. This research hopes to provide strategic outcomes to stakeholders in the field of waste management to scale-up urban composting practices by citizens. To address the main objective of this work, a case study is applied to the urban context of Aveiro, a coastal growing city with a dynamic economy and population growth located in central Portugal.

After mapping the most sustainable decentralized composting systems from both a resource efficiency and environmental point of view, the main objective of this work is to understand the aspects that may unlock the scale up of composting practices. Considering the emergence of EU policies for scaling up composting practices and that the effective implementation of such policies is limited by citizens participation, as well as the fact that a limited number of studies have been conducted in this domain, this work focuses on mapping the socio-economic aspects associated with the barriers and opportunities for biowaste composting in the urban environment. Thus, this work focused on mapping the perception of citizens of Aveiro have about the importance of biowaste management and possible strategies that contribute to local sustainability through qualitative (face-to-face questionnaire) and semi-quantitative (online questionnaire) interviews with the application of a questionnaire to allow a better understanding about, for instance, i) "what is the perception of citizens about biowaste treatment?" and ii) "why people choose to compost or not compost their biowaste?". In the case of those who are used to compost, this study aims to understand i) "what motivates citizens to compost?" and in the case of those who do not compost, ii) understand the barriers behind them. The results of both online and field surveys (i.e. questionnaires) are used to map and better understand biowaste composting in the city of Aveiro. The Ciclocompost project, a DCI funded by the Participatory Budget for Direct Action funded by the Municipality of Aveiro is the case study analyzed in this thesis.

The surveys are the main methodology and are developed in the semi-quantitative analysis of socio-environmental perception of citizens about biowaste composting in biological waste treatment systems. The analysis was conducted by applying a questionnaire (Google Forms) and the application of a face-to-face questionnaire in the city of Aveiro. The application SPSS was also used to draw some statistical inferences regarding the data.

2. Literature review

2.1. Greenhouse Gas (GHG) emissions from waste management

Worldwide, each stage operation of waste management results in GHG. To reduce GHG emissions in this sector, several countries have developed waste management technologies to replace the direct disposal in landfills without further treatment. Improvements worldwide made include the energy generation through landfill gas recovery, landfill bioreactors, aerobic compost bins, anaerobic digesters, incineration with energy recovery, waste-derived fuel, and co-combustion in cement kilns.

Landfills and open dumps are the dominant methods of waste disposal worldwide. Even though these disposal methods frequently have reduced first costs, they may contribute to serious local air and water pollution and release high GWP landfill gas. Landfill gas is generated from the anaerobically decomposed organic material. It is made up of around 50%-60% methane, 40%-45% CO_2, and traces of non-methane volatile organics and halogenated organics. In 1995, landfill methane emissions in the United States were 64 Mt Ceq, slightly higher than methane emissions from livestock and manure in the agricultural sector (IPCC, 2014). According to data from field studies done across the world, landfill methane output can range from 0.003 to 3000 g/m_2/day (Bogner et al., 1995). Not all landfill methane is released into the atmosphere; some is trapped in the waste and some is converted to CO_2.

Another common waste treatment option which is alternative to the disposal of waste in landfills is incineration. Incineration is today used in several parts of the world, e.g. Europe, Japan and the United States. However, aspects such as the high capital cost of incinerators have all discouraged trash burning as a viable alternative in underdeveloped nations. An additional improvement to incineration units is related to the installation of waste-to-energy (WTE) plants to generate heat and power, avoiding emissions from the combustion of fossil fuels which are the most used fuels to produce energy in many parts of the world. This is because heat and power generated from the combustion of paper, yard waste, and biowaste generate less net GHG emissions rather than the combustion of fossil fuels.

In Europe, considering that landfill disposal and incineration are still the most common waste treatment options used, the waste sector contributes the fourth-largest share of GHG emissions in the region, accounting for 2.9% of all GHG emissions in the region (European Economic Area, 2013). Although, according to APA, GHG emissions associated with waste management decreased in 2019, in Portugal, mainly due to the increased use of biogas as an energy source in waste and wastewater treatment systems, as well as a focus on Mechanical and Biological Treatments, which aims to reduce urban waste (MSW) by increasing the amount of recyclable biowaste recovered (APA, 2019).

In Portugal, the urban waste management (UWM) industry accounts for around 7% of all GHG emissions in the country, with landfill methane emissions accounting for 6.8 percent of this total. Thus, the decarbonization strategy for the UWM industry should include a significant reduction in waste deposition in landfills (Feliz Mil-Homens, 2022). Every year, over 3 million tons of municipal waste is disposed in landfills, accounting nearly 60% of the total waste being treated, which is more than the double the European average. According to the current waste management strategy, this proportion should be lowered to a maximum of 10% by 2035 (Feliz Mil-Homens, 2022).

In Figure 2 it is possible to see the primary sources of GHG by sector in Portugal, including the emissions from waste management which represents 7,2%.

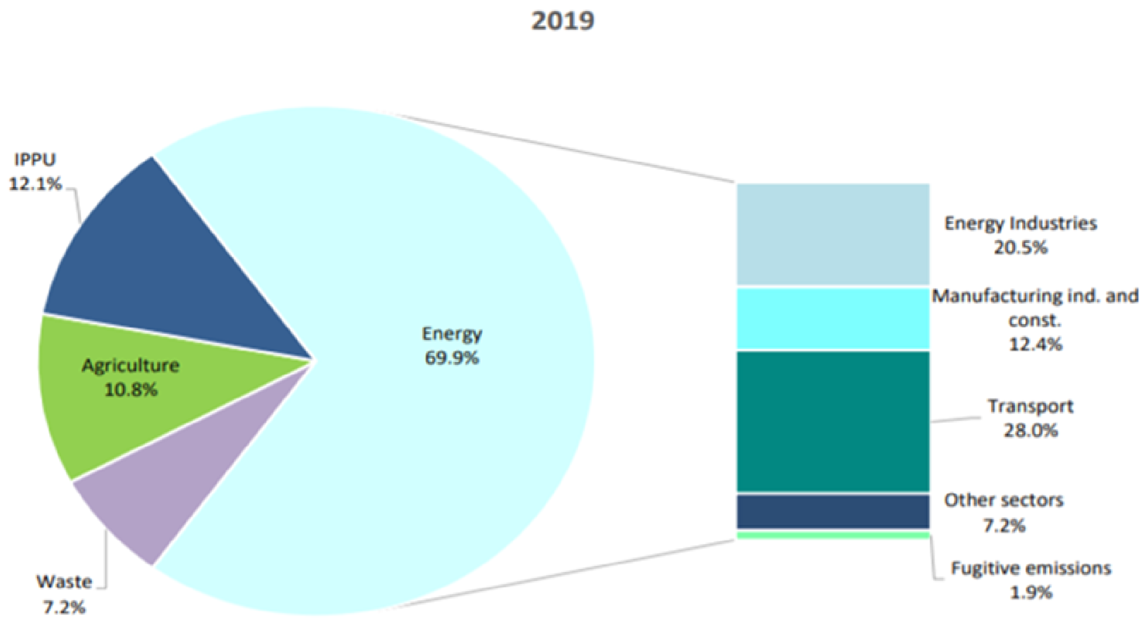

Figure 2. GHG Emission by sector in Portugal. Source: APA (2019)

In Portugal, in 2019, waste management accounted for over 7% of the emissions from all the sectors, almost the same percentage as in 1990. However, until 2005, the sector had a significant growth in emissions (more than 40%) and has been on a declining trend since then. This trend is mostly due to increased waste generation in the country (which is linked to increased family incomes and the country's urbanization throughout the 1990s). In recent years, the implementation of biogas recovery systems in waste and wastewater treatment systems, as well as the promotion of mechanical and biological treatment, have all helped to reduce emissions in recent years, with the goal of diverting urban trash from landfills and increasing recycling.
Within the biological waste management options, composting biowaste is being now considered in the European circular economy strategy. Worldwide, several types of composting systems and technologies have been tested to transform biowaste in biofertilizer.

2.2. Legislation for waste management

2.2.1 UE legislation for waste management

The development and adoption of the European Green Deal was driven by the threats and systemic risks, scientifically proven, associated with climate change, the loss of biodiversity and the increase in pollution.
The EU pact lays out the framework for the EU's growth policy over the next five years, with the goal of creating a carbon-neutral economy by 2050, one that is more resource efficient, emits less pollution, is regenerative of biodiversity and environmental services, and promotes greater inclusion and intergenerational equity. As a result, environmental goals and climate action are at the center of European development plans, which are translated into policy tools capable of changing the socioeconomic backdrop.

Two policy instruments should be highlighted among the specified priorities: the "European Climate Law" and the "Transition to a Circular Economy." The first will formalize the goal of climate neutrality European Green Deal for 2050 in legislation: by June 2021, the Commission plans to review and reassess all policy instruments related to climate change adaptation and mitigation, with the goal of translating the true cost of carbon in the economy in a clear, fair, and effective manner, namely by internalizing this environmental externality in product prices.

On the other hand, the new European "Action Plan for the Circular Economy" renews and expands the previous Plan's ambitions for a more sustainable production and consumption system. Such perspective is required to meet the carbon neutrality and biodiversity targets, because resource extraction and processing is responsible for more than half of global emissions, as well as more than 90% of biodiversity loss and hydrological stress.

The transition from a "waste management" to a "materials management" sector will require transformations and critical innovations, driven not only by recycling targets, but also by targets for the reduction of waste from specific streams, which, when combined, require greater material flow segregation, namely biowaste, and the effective and proactive substitution of raw materials in production and manufacturing.

Initiatives like "From Farm to Plate'', which aims to limit food losses and encourage short production and consumption loops, as well as encouraging the regeneration and recycling of nutrients and soil organic matter, both of which can be provided through biowaste treatment applications such as composting (From Farm to Plate).

The Circular Economy bundle refers to a collection of regulatory elements that, taken together, transfer the multiple goals of waste avoidance, material recovery, and ultimate treatment into the field. The first set of these items were published in 2018, with new instructions published in three key Directives: the Waste Directive, the Packaging Directive, and the Landfill Directive, all of which will be transferred into national legislation by July 2020 (Directive 2008/98/CE).

The European Parliament and the Council enacted Directive (EU) 2018/851 on May 30, 2018, revising Directive 2008/98/EC on waste, which is presently being transferred into national law (General Regime of Waste Management - RGGR). This revision included, for example, the requirement to establish networks for the selective collection of biowaste or to proceed with the separation and recycling of biowaste at the source, as well as minimum requirements for all extended producer responsibility regimes, requiring that producers of products assume responsibility for managing the waste phase of their products and pay a financial contribution to do so. It also establishes a landfill reduction objective, with member states aiming to guarantee that, starting in 2030, landfills are unable to absorb any suitable waste.

The European waste management strategy establishes new targets for recycling which have been set for 2025 (55%), 2030 (60%), and 2035 (65%), being the target for landfilling 10% associated with only inert materials or materials that can no longer be recycled (EU Waste Framework Directive, 2008).

The implementation of the European waste management strategy, including biowaste valorization, strongly aligns with the achievement of the 2030 Sustainable Development Goals in a variety of ways (SDGs). For instance, action on biowaste management through the implementation of composting systems has a direct beneficial influence on at least 4 of the 17 SDGs:

- SDG2: End hunger by 2030: Guarantee sustainable food production systems and implement resilient agricultural practices that increase productivity and production through the production of biofertilizers via composting, supporting the regeneration of ecosystems, strengthening the capacity to adapt to climate change, extreme weather, droughts, floods, and other disasters, gradually improving land and soil quality.
- SDG 12: Protection and usage of natural resources in a sustainable manner: Reducing the use of synthetic fertilizers through food waste recycling via composting.
- SDG 13: Climate action: Incorporate climate-related policies, strategies, and planning into national policies, strategies, and planning through the valorization of biowaste to produce biofertilizers of disposing them in landfills.
- SDG 15: Protect soil life: By 2030, battle desertification, rehabilitate damaged land and soil, particularly land affected by desertification, droughts, and floods, and work toward a world free of land degradation through the application of high quality biofertilizers.

2.2.2 Portuguese Legislation for waste management

The Decree-Law No. 152/2002, which translated the European Council Directive 1999/31/EC on landfills, already mandated the development of a national strategy to minimize biodegradable urban waste, setting quantitative objectives for 2006, 2009, and 2016.

To comply with the requirement, the "National Strategy for the Reduction of Biodegradable Urban Waste to Landfills" (ENRUBA) was issued in 2003, which included plans for selective collection of biodegradable waste. The Strategic Plan for Urban Waste (PERSU) updated ENRUBA in 2006, moving towards the undifferentiated collection of common waste utilizing mechanical and biological treatment facilities (MBT).

According to PERSU 2030, following the European waste management strategy in the field of biowaste collection aligned with the need for a stronger national response for biowaste valorization, the Strategic Guidelines for biowaste were developed in 2020 to ensure that "biowaste is separated and recycled at source, or is collected selectively and not mixed with other types of waste" by the end of 2023 (PERSU 2030).

The General Waste Management Regime (RGGR), established by Decree-Law number 152-D/2017 introduce significant changes to the landscape of public policy instruments in this area, including increases in fees associated with waste disposal in landfills (Waste Management Fee - TGR), prohibitions on landfilling recyclable materials, including biowaste, and bonuses associated with biowaste diversion from the undifferentiated stream (PERSU 2030).

In accordance with PERSU 2030, all fractions with recycling potential were considered for 2025 and 2030, as defined in Ordinance No. 851/2009, of 7 August, which includes biowaste.
In the case of biowaste management, new guidelines were provided by the national strategy in two ways through the information included in the Urban Waste Registration Map (MRRU) report (APA, 2022). A significant commitment to the collection and treatment of biowaste is highly demanded including the involvement of citizens in the process of sorting their biowaste at home.

2.2.3. Municipal biowaste management in Portugal

In Portugal, urban waste management is ensured by 23 management systems, as it is possible to see in Figure 3. Urban waste systems, of which 12 are multi-municipal and the 11 inter-municipal. In inter-municipal systems, municipalities always have the majority of the capital, according to the municipal companies law. On the other hand, the multi-functional systems were initially operated by public companies controlled by EGF, which owned the majority of the capital, and the rest belonged to the municipalities that made up the system. However, with the privatization of EGF -

now Environmental Global Facilities - through its acquisition by the Mota-Engil group, there was a change in the legal nature of multi-functional systems, which became majority-owned by private capital, in accordance with Decree Law No. 96/2014, of June 25 (Christiane, 2016).

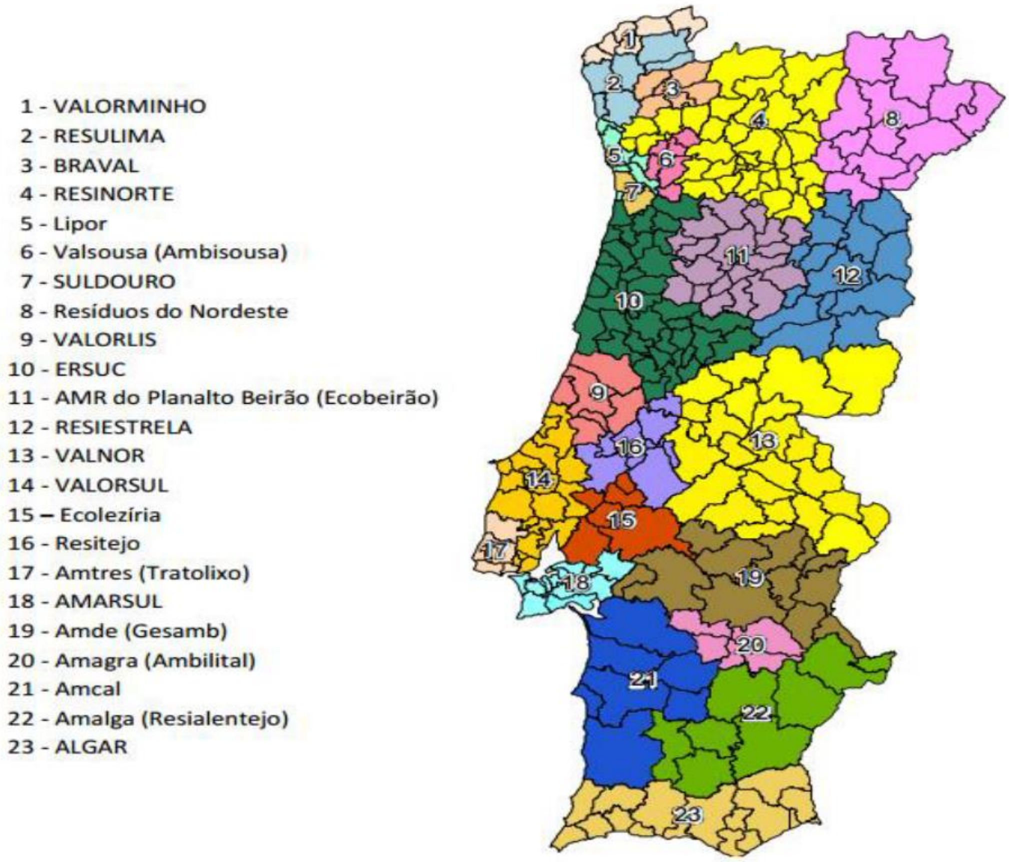

Figure 3. Portugal's waste management system map. Source: Christiane, 2016.

These systems differ in terms of the number of municipalities that make up its structure, the area, population, and dispersion covered, and the socioeconomic situations of the populations they serve. This distinction, which can be seen in the flow and production of urban waste in the Portugal, supports the choices made in terms of selective collection, treatment, and valorization, as well as the equipment and infrastructures put in place. Regarding the 255 management entities responsible for undifferentiated/municipal collection in the Portugal only 27 are also directly responsible for the multi-material selective collection activity in which 28 municipalities are covered, mostly in the areas of Greater Lisbon and Greater Porto, associated with SGRU Valorsul, Tratolixo and LIPOR (APA, 2019).

On the other hand, the SGRU's restructuring has been regarded as one of the sector's major hurdles in terms of achieving economies of scale. It should be noted that in 2009, the Association of Municipalities of Vale do Ave, the Association of Municipalities of Vale do Douro Norte, REBAT, RESAT and RESIDOURO merged to form RESINORTE, and in 2010, VALORSUL and RESIOESTE merged to form VALNOR, which now manages the MSW of the six municipalities of the Association of Municipalities of Raia-Pinhal (having integrated in 2005 the five municipalities of AMARTEJO) (APA, 2019).

The state or municipal ownership of the systems, as well as the legal type of the relevant management organization, are distinguishing factors for the SGRU. Multi-municipal systems are government contracts issued to corporations who own a majority position in *Empresa Geral do Fomento* (EGF), a subsidiary of *Águas de Portugal*. The lone exception is the *Braval* system, which was purchased by the municipalities of Braga, Póvoa de Lanhoso, Vieira do Minho, Amares, Terras de Bouro, and Vila Verde in 2000 (which were reversed in 2021). Municipal management is transferred to associations of municipalities, inter-municipal enterprises (with full capital or total public capital), or private concessions in municipal ownership systems (APA, 2019).

In terms of infrastructure, the coastal area has a higher concentration, which reflects the higher population density. The location of the MSW management systems and treatment infrastructures in mainland Portugal is depicted in the diagram below (December 2017) (APA, 2019).

Municipalities are responsible for the selective collection of biowaste, albeit this is still a relatively limited collection in mainland Portugal at the moment. Other flows, such as bulky waste, hazardous waste, textiles, wood, and used cooking oil, are also collected selectively by some municipalities (PERSU 2030).

Figure 4. Quantity of biowaste that is disposed of in landfill through the years. Source: APA, 2021

In terms of MSW direct destinations, increases in landfilling (+23.2 % compared to 2019) and trash forwarding for material recovery (+7.8 % compared to 2019) may be seen. The shipping of waste for mechanical treatment, mechanical and biological treatment, and organic recovery declined somewhat to roughly 18.7%, as did the cargo of waste for energy recovery (APA, 2021).

Although there was a slight increase in the fraction collected selectively for material recovery, compared to the total of waste, the data points to an unfavorable evolution towards compliance with the waste hierarchy, as there is an increase in direct disposal in landfills. On the other hand, although there was a slight increase in the fraction collected selectively for material recovery, compared to the total of waste, it may not yet reflect the investments made towards the increase in selective disposal, a result of population behavior (APA, 2021).

According to PERSU 2030 is possible to see a slight difference between the types of waste treatment. The following was the route for direct destinations of MSW manufactured in Portugal according:

- Multi Material Valuation – 12%;
- Mechanical Treatment – 9%;
- Mechanical and Biological Treatment – 24%;
- Organic Enhancement – 2%;
- Energy Recovery – 21%;
- Landfill – 33%.

As it is possible to see in Table 1, the destination by operation type throughout the years, which increased in landfill, showing also the increase of waste production.

Table 1. Destination of waste by operation type through the years. Source: PORDATA, 2022

DESTINATION BY OPERATION TYPE					
Year	**Total**	**Landfill**	**Energy recovery**	**Organic recovery**	**Recycling**
2002	4,595,146	3,290,129	943,927	134,714	212,665
2003	4,692,784	3,177,606	1,002,012	286,231	226,936
2004	4,665,193	3,044,037	993,463	308,125	319,568
2005	4,745,184	2,969,265	1,056,755	313,385	405,779
2006	4,898,076	3,142,766	978,077	301,885	475,349
2007	4,967,273	3,170,430	947,902	321,038	527,902
2008	5,471,844	3,530,220	992,953	382,025	566,647
2009	5,496,267	3,341,707	1,082,831	423,515	648,214
2010	5,457,137	3,380,815	1,058,376	398,593	619,354
2011	5,177,780	3,048,127	1,088,265	446,595	594,792
2012	4,765,923	2,592,797	929,808	693,833	549,485
2013	4,597,940	2,320,195	1,090,623	593,001	594,121
2014	4,710,464	2,307,172	973,645	664,974	764,673
2015	4,527,221	2,166,853	941,312	745,494	673,562
2016	4,606,744	2,144,400	949,692	813,608	699,044
2017	4,782,961	2,335,276	989,436	854,114	604,135
2018	4,983,766	2,518,233	946,132	880,935	638,465
2019	5,027,378	2,505,484	996,124	883,189	642,581
2020	5,070,835	2,710,614	962,401	724,592	673,228

In 2017, the total amount of urban waste produced in Portugal was over 4 million tons, or to 1.32 kg per person per day. Undifferentiated collection accounted for 83.5 % of all urban waste collected,. The percentage of reuse and recycling preparation was 38%. According to the APA's 2017 status of the environment report, biodegradable urban waste (Biowaste) was deposited in landfill at a rate of 43%. (APA, 2018b). There are 32 % for landfill, 28 % for mechanical and biological treatment, 21 % for energy recovery, 10 percent for recovery material, 7 % for mechanical treatment, and 2 % for organic recovery when it comes to direct forwarding of urban waste to the main management operations. When looking at the eventual destinations of the waste, however, it becomes clear that the distribution in percentage terms differs significantly: According to the APA's annual municipal waste 2017 report, 57 % of municipal waste is disposed of in landfills, 21 % is recovered energy, 12 % is recycled, and 10 % is composted/digested. (APA, 2018).

It can be seen that from 2002 to 2019 there was a very large increase in the amount of waste produced, as well as an increase in the recovery of biowaste. But proportionally speaking, the recovery of biowaste is still very low when compared to what is generated.

The selective collection of biowaste, as well as the contribution through its treatment at source, have a considerable weight in achieving the imposed objectives in a scenario of fulfilling goals (PERSU 2030).

2.2.4 Municipal waste treatment in the city of Aveiro

Aveiro municipality has a population of 80 880 (INE, 2021) and is located in the *Centro* Region of Portugal. The responsibility of collection of unsorted MSW is Aveiro City and the waste collected is transported to the Integrated Center for Treatment and Recovery of MSW of Aveiro (Rodrigues et al., 2015).

ERSUC is responsible for the municipality waste management and comprises the MBT unit for the treatment of unsorted MSW; a refuse landfill; an automated screening station for the treatment of recyclable waste from separate collection; a unit for the preparation of refuse derived fuel (RDF) for the fraction with calorific value recovered at the MBT; a unit for energy recovery from the MBT's biogas; and a refuse landfill. The organic component now separated at the MBT is processed with anaerobic digestion before being composted or landfilled to form an organic amendment ("FERTISUC"). The company ERSUC, S.A. has an exclusive concession until 2030 to valorize and dispose of unsorted MSW from the multi-municipal system "*Litoral Centro*" (to which the municipality of Aveiro belongs), which consists of 36 municipalities and has a population of almost one million people. ERSUC, S.A. is also in charge of collecting packaging waste separately (paper and cardboard, plastic and metal). ERSUC, S.A. is a joint venture between municipalities (42.5 percent of the capital) and a state corporation (EGF—Empresa Geral do Fomento; 51.5 percent), which is on the verge of privatization, with two private entities holding the remaining 6.0 percent (ERSUC 2014 apud Rodrigues et al, 2015).

In the Municipality of Aveiro road containers biowaste is still placed together with unsorted waste in trash containers. After collection by the municipality, the waste is delivered at MBT unit (run by ERSUC, S.A.) and anaerobic digestion (with biogas production) takes place (Rodrigues, 2015).

2.3. Biological conversion and composting technology

Biological decomposition of biowaste (composting) can be aerobic and anaerobic (Minale and worku 2014 apud Lim, 2016) with the first one more common. The organic matter in the waste is consumed by aerobic thermophilic and mesophilic microorganisms as substrates and converted into products such as CO_2, H_2O, NH_4 or stabilized organic matter (Qian et al., 2014 apud Lim, 2016). The resulting compost is a stable, humus-rich, complex mixture that can improve the physical properties of the soil (Watteau and Villemin, 2011 apud Lim, 2016). Factors that influence the composting process are temperature, initial C/N ratio, aeration, porosity, moisture content and pH (Shafawati and Siddiquee, 2013 apud Lim, 2016). During the composting process, these parameters are regulated and controlled to provide an optimal environment for the microorganisms that break down the biowaste (Lopez- Gonzalez et al., 2015 apud Lim, 2016).

Composting is a complex ecological biological process characterized by a continual shift in the species of microorganisms engaged as the environment changes, making it nearly difficult to identify all those present.

Microorganisms can be divided into two groups: mesophiles, which thrive at temperatures below 45°C, and thermophiles, which thrive at temperatures between 45°C and 75°C (Miller and Inácio, 2009). Figure 4 shows a temperature variation curve that may be used to determine the thermophilic and mesophilic stages of the composting process.

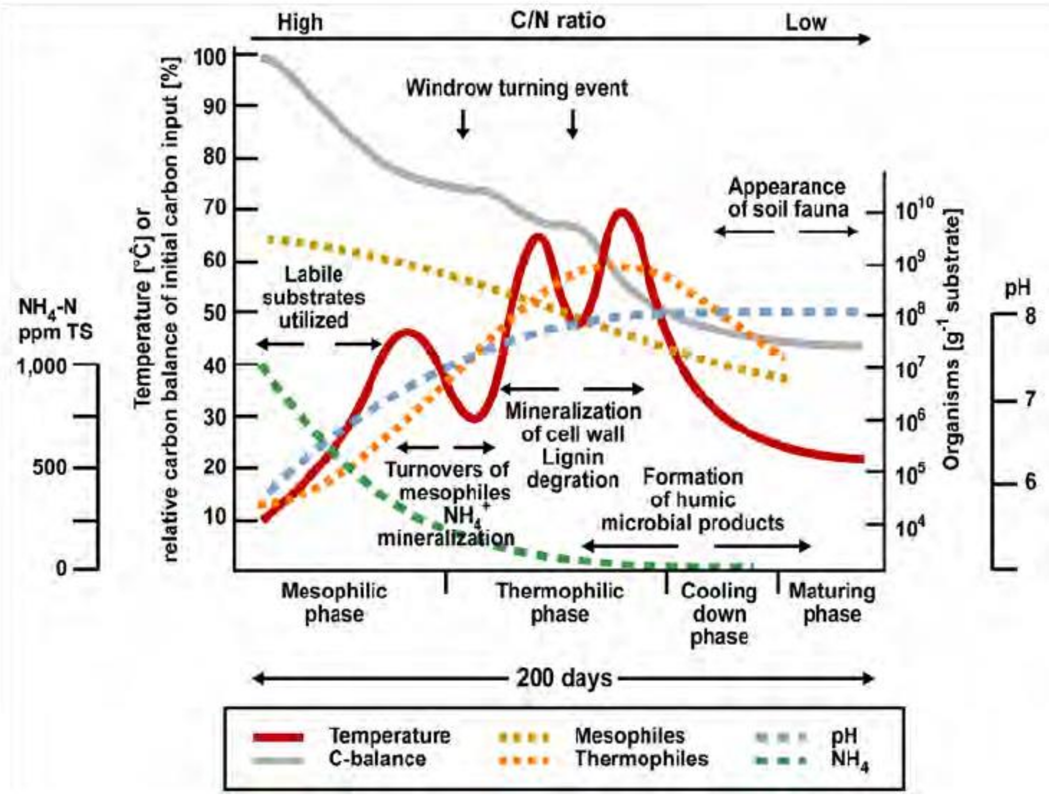

Figure 5. Thermophilic composting processes according to different stages. Source: Fischer, 2012

It's worth noting that this temperature change is caused by microbial activity, which is an exothermic process that primarily emits carbon dioxide and heat, as illustrated in Figure 5. The composting process is made up of a series of microbiological activities in which one group of microorganisms creates an environment that encourages the activity of the next group.

Composting is separated into three steps in some publications and four phases in others, like in the case of Inácio and Miller (2009), who systematized the composting process into four parts. Starting with the early phase, in which the temperature rises quickly from room temperature to 40°C to 45°C, generally in less than 24 hours. This is attributed to the growth of mesophilic microbe colonies. The implantation of a thermophilic microbial community suppresses the activity of mesophiles when the temperature surpasses 45ºC (Tiquia, 2005 apud Chiabi, 2017).

As a result, composting enters the thermophilic phase, which is marked by temperatures over 45 ºC, mostly between 50 and 65 ºC, with temperature maximum exceeding 70 ºC. This phase is critical since it is the time when organic molecules decompose at the fastest rate, resulting in the most oxygen consumption and steam generation (Inácio and Miller, 2009). As carbon reserves dwindle, the quantity of energy available in the windrow diminishes, and as a result, the temperature drops, eventually matching the ambient temperature. Thus, the mesophilic phase begins, which is critical for the breakdown of more resistant organic compounds like hemicellulose and lignin (Vinneras and Jonsson, 2002).

From that point on, the process is characterized by the presence of fungi and actinomycetes, signaling the start of the maturation phase of composting. During this time, humic compounds are formed, the compost is stabilized, and the windrow's self-heating potential is lost. Decomposition occurs at a relatively slow rate during this phase; however it is during this phase that the compost is generated and ready to use (Inácio and Miller, 2009). It should be noted that the compost pile must go through all the steps indicated above in order for the composting process to develop properly. However, for all stages to occur, the composting yard operator must be aware of a number of criteria, including humidity, aeration, organic material composition, C/N ratio, pH, grain size, and windrow form. In order for a well-managed and optimized process to be effective, such parameters must be understood.
The suitable and optimal ranges of the key parameters of composting may be found in the table, ensuring that the process is environmentally friendly and completed in a "short" period of time. Table 2 shows parameters to optimize the composting process and requirements take into account the end outcome of the combination of distinct waste.

Table 2. Suitable range and preferred range for produced compost.

Parameter	**Suitable range** [a]	**Preferable range**
Carbon/Nitrogen Ratio (C:N)	20:1- 40:1	25:1 – 30:1
Moisture content	40 – 65% [b]	50 – 60%
Oxygen concentration	Greater than 5%	Much greater than 5%
Particle size (diameter, cm)	0.3 – 1.5 (1/8” – 1/2”)	Variable
pH	5.5 – 9.0	6.5 – 8.0
Temperature (^{o}C)	43.5 – 65.5 (110 – 150 ^{o}F)	54.5 – 60 (130 – 140 ^{o}F)

Source: Chiabi apud Rynk, 2017.

2.5.1 Aerobic Digestion

Typically, the most common composting processes are conducted with the admission of oxygen through an aerobic digestion. In this case, several parameters including those presented in the Table 2 control a successful composting process, including the activity of a) living organisms (decomposers), the b) carbon/nitrogen ratio, c) moisture content, d) oxygen concentration for aeration, e) particle size, f) pH and g) temperature.

a) Living organisms

The combined activity of macro and mesofauna (worms, ants, beetles, and mites) and distinct populations of microorganisms (including bacteria, actinomycetes, yeasts, and fungus) that prevail in different phases of composting results in the transformation of biowaste. Microorganisms that metabolize organic nitrogen act in compost at first, converting it to ammoniacal nitrogen. As the compost decomposes, the ammonia can be lost through volatilization or converted to nitrates through nitrification, an acidifying process that contributes to the matured compost being more acidic than the original material. However, if anaerobic circumstances exist, the nitrate will be lost by denitrification, which has an alkalizing impact (Oliveira et al, 2002).

The energy provided by microorganisms encourages a rise in temperature throughout the composting process. The thermophilic bacteria, which are responsible for the faster breakdown of biowaste, thrive at temperatures exceeding 40°C. Temperatures in this phase surpass 55°C, facilitating the eradication of harmful bacteria in people and plants. Most microorganisms, including those responsible for decomposition, will be destroyed at temperatures over 65 °C, necessitating temperature management together with humidity and aeration to maintain the correct levels (Oliveira et al, 2002).

b) Carbon/nitrogen ratio

Composting entails generating conditions and disposing of organic and mineral-rich raw materials in an appropriate location, particularly those with a good C:N ratio for the metabolism of organisms that will carry out their biodigestion (Peixoto, 1981 apud Oliveira et, al, 2008). According to Kiehl (1998 apud Oliveira et, al, 2008), monitoring the C:N ratio during composting allows us to track the progress of the process because the C:N ratio is around 18/1 when the compost reaches semi-cure, or biostabilization, and around 10/1 when it reaches maturity, or when it becomes a finished or humified product. An suitable nitrogen and carbon concentration promotes the development and activity of microorganism colonies engaged in the decomposition process, allowing for faster compost generation.

Because these microorganisms take carbon and nitrogen in a ratio of 30 parts carbon to one part nitrogen in trash, this will be the perfect ratio in waste. The ranges between 26/1 and 35/1, on the other hand, are regarded as the most desirable C/N ratios for quick and efficient composting. During the composting process, waste with a low C/N ratio loses nitrogen in the ammoniacal form, lowering the compost's quality. In this scenario, cellulosic vegetable waste should be added to get the value closer to the ideal. When the source material has a high C/N ratio, the process takes longer and the end product contains low quantities of organic matter. Simply add nitrogen-rich items like manure, animal litter, vegetable cakes, and so on to fix these distortions.

c) Moisture content

Moisture ensures microbial activity during the breakdown of organic materials. This is due to the fact that, among other things, the structure of microbes is about 90% water, and water must be taken from the environment, in this case from the compost material, in order to produce new cells. Furthermore, before digestion, all required nutrients for cell formation must be dissolved in water (Alexander, 1977 apud Oliveira et al., 2008).

The ideal humidity range for maximal decomposition is 40-60%, mostly during the beginning phase, because enough water supply is required to encourage the growth of the biological organisms engaged in the process and for correct biochemical interactions to occur during composting (Merkel,1981 apud Oliveira et al., 2008). Because composting is an anaerobic process, the optimal humidity should be regulated based on the compost mass's aeration capability, that is, physical qualities such as porosity and structure should be monitored, with the goal of meeting the microbiological need for oxygen (Pereira Neto, 1998 apud Oliveira et al., 2008). When humidity levels are too high, particles agglutinate, lowering the windrow's structural resistance and limiting oxygen transport (Poicelot, 1975 and Willson et al., 1976 Oliveira et al., 2008). For values less than 5%, this decreases the temperature windrow mean (for the mesophilic range of 20 to 40°C) and oxygen concentration (Hughes, 1980; Poincelot, 1975; Willson et al., 1976 and Diaz et al., 1982 apud Oliveira, 2008). If these issues arise, the rate of organic matter breakdown will slow, and anaerobic conditions will be established in the compost mass, resulting in unpleasant outcomes such as aromas, vector attraction, leachate, and so on (Pereira Neto 1987, 1996; Poincelot, 1975 and Willson et al., 1976 apud Oliveira et al., 2008). Low moisture content (less than 40%), on the other hand, inhibits microbiological activity, lowering the pace of stabilization (Pereira Neto, 1987 apud Oliveira et al., 2008). If there isn't enough water, it may be evenly distributed throughout the composting material, and if there is too much, absorbent items like straw, bedding, and sawdust or wood shavings can be mixed in (Marriel et al., 1987 apud Oliveira et al., 2008).

d) Oxygen for aeration

The biological oxidation of carbon in biowaste is critical for the creation of energy required for the microorganisms that carry out the breakdown process. A portion of this energy is utilized by microbes in their metabolism, while the remainder is emitted as heat.

Organic matter decomposition can take place in two ways: in the presence of oxygen (aerobic) or in the absence of oxygen (anaerobic) (anaerobic). When free oxygen is accessible, aerobic microorganisms prevail, with fungus, bacteria, and actinomycetes being the most important agents (Peixoto, 1981). The anaerobic method has the drawback of emitting a foul odor since the amine nitrogen is not completely released as ammonia, resulting in the creation of incomplete, foul-smelling amines, which must be oxidized to remove this property.
Poor composting can result in anaerobic oxidation, putrefaction, and a foul odor that is released into the environment in the form of hydrogen sulfide gas, mercaptans (dimethyldisulfide, dimethylsulfide, methylmercaptans), and other sulfur-containing compounds, all of which have a "rotten egg" odor (Kiehl, 1998). The aerobic process, according to the same author, is defined by the high temperature created in the compost, the shorter time for organic matter breakdown, and the oxidation and oxygenation reactions that occur during the process, resulting in a pH near to 7 in the substrate at the conclusion. By changing the windrow or using other methods of aeration, the disagreeable odor may be decreased, and the process can be converted from anaerobic to aerobic. Aeration is the most crucial component to consider during composting, and the more humid the raw materials are, the less oxygenation they will have, dictating what actions are done to minimize humidity. Aeration in the composting yard can be accomplished by rotating the windrows or insufflating or aspirating the air trapped in the mass voids.
Aeration eliminates foul odors and the presence of flies, which is beneficial to both the process and the environment. The first turning should be done two or three weeks after the process begins, at which time the most aeration is necessary. When the temperature starts to steadily fall, signaling the beginning of the composting process stability, the second turning should be done around three weeks after the first.

e) Particle size

To minimize compaction during the composting process, which would compromise aeration, particles should not be too tiny. By retaining less moisture and giving a smaller surface for interaction with microbes, leftovers with intact stalks, on the other hand, slow down decomposition (for example, corn stalks). Soybean and bean crop leftovers, as well as grass leaves, can be composted in their whole.

f) pH

The condition of composting of biowaste may be determined by the pH of the compost. According to Jimenez and Garcia (1989), the pH drops to around 5.0 during the initial hours of composting, then steadily rises with the progress of the composting process and compost stability, eventually reaching values between 7 and 8. Low pH readings indicate a lack of maturity as a result of the process's short duration or the presence of anaerobic activities inside the compost pile. As fungus and bacteria consume biowaste, acids are released into the environment, acidifying it. The pH is lowered, which promotes fungus development and the breakdown of cellulose and lignin. After that, the acids are degraded until they are fully oxidized. If there is a lack of oxygen, however, the pH may drop below 4.5, limiting microbial activity and slowing the composting process. The pH must be raised by shaking the batteries in these circumstances.
Animal feces components have a pH value of 7.0 to 8.0, which is neutral or slightly alkaline (Cassol et al., 1994 apud Oliveira et al., 2008). Because the microorganisms that participate in composting have an ideal pH range of growth between 6.5 and 8.0, composting does not offer concerns with pH management when done properly (Peixoto, 1988 apud Oliveira et al., 2008).

g) Temperature

The temperature of the environment in which the process takes place is one of the most important aspects in the transformation of organic materials. When organic matter decomposes, the heat produced by microbial metabolism disappears, and the substance does not generally heat up. However, when composting biowaste in heaps or under regulated settings while working with big volumes, the heat produced builds and the temperature rises to roughly 80 degrees Celsius.

2.3.1 Anaerobic Digestion

An alternative to the aerobic digestion is the performance of composting without the admission of oxygen in a process called anaerobic digestion. In this case, biodigesters are equipment that promote anaerobic processes of degradation of organic matter, where biomass, e.g. commonly manure and animal waste, undergoes the action of anaerobic bacteria, generating biogas and biofertilizer. In this process, the action of anaerobic bacteria will be carried out after the time it takes for the aerobic bacteria present in the raw material to end (Metz, 2013). The digestion process can be divided into three stages:

- liquefaction phase, when complex compounds are transformed into simple ones, using the bacterial capacity to decompose.
- acidogenesis (acute phase), in this phase the amino acids obtained in the first phase are transformed into simple organic acids, of low molecular weight.
- gasification, where methane gas and carbon dioxide are produced.

The factors that influence anaerobic digestion are: temperature, as bacteria are sensitive to changes; types of waste; carbon / nitrogen ratio, very important for the production of biogas; retention time, of the material in the biodigester, usually 4 to 60 days and finally the Ph, whose most suitable range is between 6 and 8 (Metz, 2013).

After composting, vermicomposting can be applied, which is an enrichment process for the organic compound, better known as earthworm humus. In the composting process, the humic phase is reached after the total decomposition of organic matter (end of the carbon cycle), being a delicate phase and dependent on the balanced combination of materials, humidity, temperature and microorganisms. Therefore, with the use of earthworms in the vermicomposting process, the degradation process is accelerated. These specimens streamline the carbon cycle, reducing the time between photosynthesis and humus (Chiabi, 2017).

Earthworms are more similar to compost pans, since all organic matter passed through pre-composting and free from fermentation can be used to feed earthworms. They require a balanced diet, rich in nitrogen, fibers and carbohydrates, and the richer the input, the more successful the final product will be. The waste that can be used are: manure, leguminous remains, fruit peels, agro-industrial waste, household waste and sewage sludge. Humus is the final product, made by earthworms, being an important fertilizer, and a great economic and environmental alternative for problems with biowaste (EMBRAPA, 2018).

2.3.2 Thermophilic composting, vermicomposting and other processes

The thermophilic composting and vermicomposting are both commonly and widely used aerobic composting processes applied worldwide. Both methods involve biological processes using as a raw material organic matter, e.g. manure and food waste, to produce biofertilizers rich in nutrients and minerals. In both cases, the composting process can be carried out in industrial, community or even home scale compost bins. Thermophilic composting is usually carried out by stacking the material in piles, which are turned over every 15 days. This process is carried out with large amounts of material. Vermicomposting can also be applied in homemade compost bin, where the amount of material is less and consists of small boxes. The first box (bottom) with a tap, where the liquid from the compost drips. The middle box, with a perforated bottom is where the humus is. The last box is where we put the waste that will be decomposed (Guide How to Produce Organic Foods, 2016).

And yet, according to the Basic Composting Manual (USP RECICLA, 2009) there are 7 types of compost bin:

- Crate compost and enclosure: large enough for kitchen and garden waste.
- Rotational can: It has a high storage capacity.

- Windmill composting: Ideal for those who have a lot of material and enough space available, such as schools and other institutions. It can be sized according to the volume of waste available.
- About leaf compost: The leaf compost receives brown waste, in general, as leaves, small branches and pruning in general. It needs a larger space, it attracts less unwanted animals and needs less maintenance. Its decomposition period is longer than the domestic one, with about 6 months.
- Compost bin in minimal spaces (apartment): This model of composting can be built in different ways, in box, drum, etc., it only needs to meet the basic needs: delimit a space for waste and be able to circulate the air.
- Drum compost bin: Great for apartments, the drum compost bin has sufficient volumetric capacity for an apartment of 3 to 4 people, to start its activity, it is necessary to drill holes (approximately 1cm in diameter) around the barrel to to allow the passage of oxygen inside and to avoid possible leakage of compounds it is advisable to wrap it with a “mosquito net”, working at the same time as a measure to prevent the generation of flies.
- Box compost bin: ideal for apartments, this compost bin can be assembled in wooden boxes, fair cases or even drawers. This type of composting can take longer due to its small size.

a) Thermophilic composting

The thermophilic composting process can be divided into three phases, namely the initial activation, thermophilic and mesophilic or maturation phases (Chowdhury et al., 2013 apud Lim, 2016). Most of the degradation of biowaste takes place during the thermophilic phase. During this phase, the microorganisms degrade the readily available compounds in the biowaste. Generally, high microbial activity leads to high degradation of biowaste (Fourti, 2013 apud Lim, 2016). This phase is characterized by high temperature in the composting pile due to heat released by microbial degradation of biowaste (Singh and Kalamdhad, 2014 apud Lim, 2016). The high temperature reached at this stage is also crucial for the microbial reduction and sterilization of the biowaste. Temperatures above 55C are required to kill the pathogens in the biowaste (Tian et al., 2012 apud Lim, 2016). Guidelines from APA require composting material to maintain a temperature of 55C for at least 15 days or 5 consecutive days (Jurado et al., 2014 apud Lim, 2016). Some compost heaps are known to reach temperatures up to 70C during the decomposition of animal manure (Tang et al., 2011 apud Lim, 2016) and green waste (Caceres et al., 2015 apud Lim, 2016). The end of the thermophilic phase and the beginning of the maturation phase is indicated by the temperature drop in the composting pile. As the biowaste stabilizes, the temperature continues to drop to the temperature of the ambient air (Sanchez-Monedero et al., 2010 apud Lim, 2016). The decrease in temperature also marks the depletion of the decomposable organic fraction in the waste (Ravindran and Sekaran, 2010 apud Lim, 2016).

Some composting studies reported did not reach thermophilic temperature. For example, Paradelo et al. (2013 apud Lim, 2016) found that temperatures during composting of lignocellulosic wine cellar waste were in the mesophilic range, but evidence of biowaste decomposition was found. Low temperatures during the composting process could be caused by low ambient temperatures or heat retention properties of the composting materials (Singh and Kalamdhad, 2014 apud Lim, 2016). Indeed, low temperature is typical for home composting because the layer for the decomposing material is too thin to retain a significant amount of heat and the heat is quickly dissipated from the pile. Although biowaste could decompose under low temperature conditions, there is no guarantee that the final product will be free of pathogens or weed seeds (Faverial and Sierra, 2014 apud Lim, 2016).

Composting is usually a time-consuming process, but advances in composting technology have reduced the duration of the composting process. Gabhane et al (2012 apud Lim, 2016) showed that additives such as jaggery and polyethylene glycol helped to speed up the composting process and produce a high quality compost. The only drawback was that the additives were not cost effective. In addition to additives, microbial inoculums were also used to shorten the duration of the composting process. For example, the addition of specific strains of a fungal consortium such as *Trichoderma viride* MTCC 793, *Aspergillus niger* MTCC 1344 and *Aspergillus flavus* MTCC 1425 increased the composting rate of municipal solid waste. The resulting compost had lower C/N ratio and germination index values of 84-93% compared to municipal solid waste without fungal inoculation (Awasthi et al., 2014 apud Lim, 2016). Microbes can also be added to the composting process by adding another type of biowaste containing indigenous microbes. For example, Zainudin et al. (2013 apud Lim, 2016) used wastewater from a palm oil mill as a microbial seed to increase the composting rate of empty fruit bunches of oil palm. The continuous addition of palm oil mill effluent reduced the composting time to 40 days.

Considering that the purpose of the composting process is to convert biowaste into fertilizer for agriculture or soil, it is important to take into account that some biowaste contain high concentrations of heavy metal content that are not removed during the composting process. In general, the total heavy metal content increases after the composting process due to the reduction of organic matter, but it is the bioavailability and mobility of heavy metals that provide more important information on toxicity (Singh and Kalamdhad, 2013b apud Lim, 2016). Singh and Kalamdhad (2012 apud Lim, 2016) used Tessier's sequential extraction method to track changes in heavy metal speciation during the composting process. Their study concluded that when an adequate proportion of cattle manure was added, the available heavy metal fractions were significantly reduced due to better humification. The acidic functional groups in humic materials had high complexity capacities with metal ions, so heavy metals could be easily bound to them (Guengor and Bekbolet, 2010 apud Lim, 2016). Lime, an alkaline material, also helped to significantly reduce the bioavailability of heavy metals during the composting process (Singh and Kalamdhad, 2013b apud Lim, 2016).

b) Vermicomposting

Vermicomposting is an aerobic and controlled biological process of transforming biowaste into stabilized waste, where earthworms are used to promote and accelerate the degradation process of organic matter and obtain humus - the main product of the process - odorless fertilizer, rich in nutrients (iron, boron, copper, zinc, molybdenum, chlorine) and macronutrients (potassium, nitrogen, phosphorus) (Bidone, 1999, apud Cotta et al., 2015).
The humus produced by the worms is about 70% richer in nutrients than conventional humus, since the worms are provided with calcareous glands, favoring the correction of the pH of the substrate. The method is usually carried out indoors, to ensure the worms are covered, since excess moisture is not beneficial to earthworms (Longo, 1987 apud Cotta et al., 2015). The waste disposed of in the earthworm receives the addition of dry matter. Vermicomposting presents itself as a domestic alternative to the most useful and appropriate destination for biowaste produced in homes and small communities, in order to generate organic fertilizer (humus), which can be used in the cultivation of plants, vegetable gardens, or even commercialized (Ricci, 1996 apud Cotta et al., 2015).

Vermicomposting is a decomposition process for biowaste similar to composting but with the addition of earthworms to assist and accelerate the stabilization process of the waste (Lim et al., 2015 apud Lim, 2016). Therefore, a suitable biowaste or earthworm source material is crucial to ensure a successful and efficient vermicomposting process (Yadav and Garg, 2011 apud Lim, 2016). Earthworms can eat most organic materials that have a pH in the range of 5 to 8, a moisture content between 40 and 55%, and an initial C/N ratio around 30. However, not all biowaste fall within these parameters. Therefore, in order to make the biowaste more suitable for micro-composting, the waste should be (a) enriched with fillers/biowaste (or amendments) or (b) subjected to some form of pre-treatment process.

During the vermicomposting process, fillers or additives are used to make the biowaste more palatable to earthworms. For example, cow manure is commonly used as an additive in the vermicomposting process because it is the easiest animal waste for earthworms (Edwards, 2004 apud Lim, 2016). Fruit wastes can also be used as additives in vermicomposting of soybean hulls (Lim et al., 2011) and rice husks (Lim et al., 2012) in some cases. Some biowaste that have high

moisture content are supplemented with fillers (or amendments) to reduce moisture content. In fact, liquid wastes, such as the effluent from a palm oil mill, have been absorbed onto a filler material for the vermicomposting process (Lim et al., 2014). Other additives used include soil and matured vermicompost (Huang et al., 2014). Vermicompost is used to provide an initial habitat for earthworms and as a source of microbial inoculum (Castillo et al., 2013 apud Lim 2016). Organic lignocellulose has a high carbon content, so this waste could be mixed with other biowaste that have a low carbon content to improve the initial C/N ratio of the waste mixtures (Castillo et al., 2013 apud Lim, 2016). Another example is animal meat waste from the tanning industry, which has a low C/N ratio and can therefore be supplemented with leaf litter and cow dung (Ravindran et al., 2014 apud Lim, 2016). The optimum initial C/N ratio of feedstock for vermicomposting is about 30, but it is possible to vermicompost biowaste with higher C/N ratio (Pramanik and Chung, 2011 apud Lim, 2016). For example, Lim et al. (2015a) successfully vermicomposted empty fruit bunches and cow dung with an initial C/N ratio of 50. After 12 weeks of vermicomposting, the C/N ratio of the waste mixture decreased to 20. Some biowaste can be vermicomposted without the use of fillers, but some form of pretreatment should be introduced prior to the vermicomposting process. For example, dried cow dung is commonly used as an additive, but fresh cow dung is unfavorable for earthworm growth (Edwards, 2004 apud Lim, 2016). Therefore, cow dung was dried for one week under natural sunlight with periodic turning as a pretreatment process (Lv et al., 2013 apud Lim, 2016). Pretreated cow dung can be used alone (Suthar, 2012) or mixed with other biowaste (Aguiar et al., 2013 apud Lim, 2016) for vermicomposting process. Therefore, in most studies on vermicomposting, it is common practice to pre-treat the biowaste at least by manual turning to eliminate the volatile gasses that are toxic to earthworms (Lim et al., 2014) and to reduce the high moisture content in some biowaste (Yang et al., 2014 apud Lim, 2016). Pretreatment also promotes initial microbial degradation and softening of the waste (Suthar and Gairola, 2014 apud Lim, 2016).
One of the main problems with using the vermicomposting process is that it does not involve a thermophilic phase. However, limited studies showed that vermicomposting can reduce pathogens in biowaste. According to Yadav et al (2010 apud Lim, 2016) did not detect coliforms in mature vermicompost obtained from source separated human feces. It was suggested that pathogens were killed or reduced by the action of gut enzymes in the earthworms and by competition between pathogens and microbes for the limited resources left by the earthworms (Sim and Wu, 2010 apud Lim, 2016). Hill and Baldwin (2012 apud Lim, 2016) demonstrated the feasibility of vermicomposting to convert feces and toilet paper into vermicompost that had less Escherichia coli.

Similar to compost, the presence of heavy metals in worm compost poses a serious threat to humans and the environment due to its agricultural application. Singh and Kalamdhad (2013 apud Lim, 2016) found that the vermicomposting process effectively reduced most of the bioavailable fractions of heavy metals. The heavy metal ions were able to form complexes with the humic substances present in the vermicompost. Various organic functional groups in the humic substances were able to combine with metal ions through ionic forces. According to Singh and Kalamdhad (2013 apud Lim, 2016) the leachable concentration of heavy metals in vermicompost was below the limit. Moreover, earthworms were able to accumulate heavy metals in the biowaste via skin absorption or in their gut (Lim et al., 2015b). Some available fractions of heavy metals were removed by earthworms through intestinal/skin absorption (Suthar et al., 2014 apud Lim, 2016). The heavy metal content found in worm tissues confirmed the theory that earthworms have the ability to regulate metals. Additives such as fly ash and phosphate-containing rock features could also be used as immobilizing amendments to reduce the availability of heavy metals (Wang et al., 2013 apud Lim, 2016).

Earthworms are cylindrical worms, oligochaet annelid animals, long-bodied, slightly tapering at the ends and flattened in the posterior region. At the anterior end, the head is not distinct from the body, and at the posterior, the anus. There are more than 3.000 species, but only 5 or 6 are more widespread.
Earthworms live in almost all regions of the earth, including volcanic islands and sub-arctic regions, abundant in rich, fresh, moist and humus-rich soils, but difficult to find in acidic, poor, dry or sandy soil. They even build the galleries where they live, reaching more than 2 m in depth.
They end up not developing so well in an arid climate, preferring neutral climates, even though they are abundant in places with a high level of organic matter.

When digging their galleries, earthworms ingest a quantity of soil that passes through the digestive tract, becoming a great fertilizer, already ready to be absorbed by the roots of plants. It has been proven in the laboratory (Vieira, 1995) that the soil that has earthworms, when compared to soil without earthworms, has:

- 5 times more nitrogen;
- 2 times more calcium;
- 2.5 times more magnesium;
- 2 times more phosphorus and
- 11 times more potassium

Therefore, the soil has greater recovery capacity, when worn down by the use of earthworms in the soil.

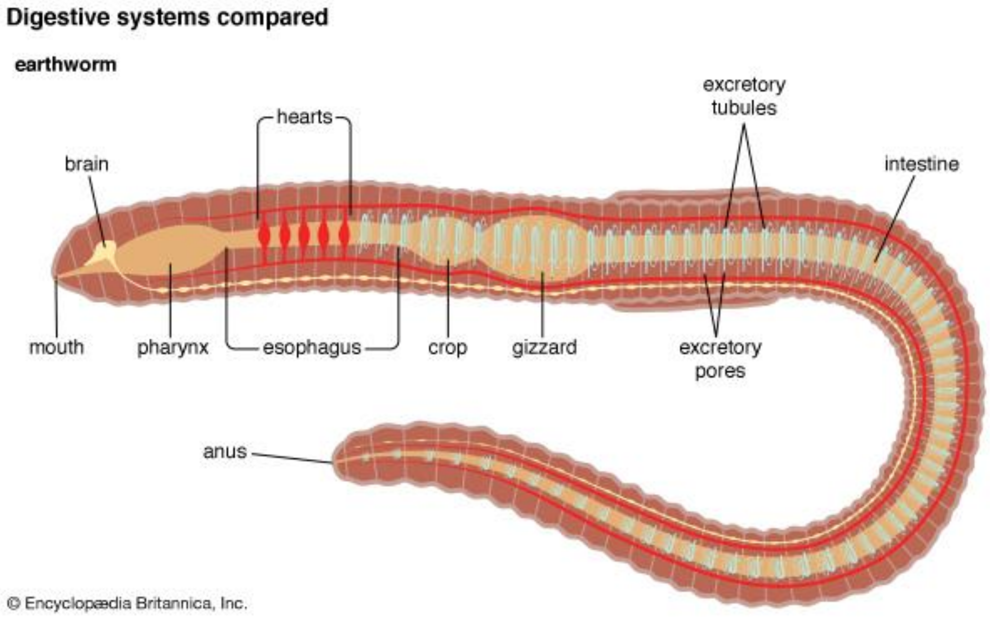

Figure 6. Biology of an earthworm used in vermicomposting. Source: Encyclopædia Britannica

c) Other composting methods

Other composting methods emerge over time as is the case of bokashi composting or methods carried out in other parts of the world, such as the Japanese method, which has become known. Dissimilar from composting, which must have good aeration, in the Bokashi method, the significant thing is to ensure that there is no air inside so that microorganisms can ferment food waste. .
This method is inodorous and can be done in small places. All you need is a bucket with a lid and a tap at the base to drain the liquid that forms during the process. A powder is added to kitchen waste – a vegetable mixture that contains microorganisms. It is these microbes that act on food and ferment it. It is natural to scent vinegar when you open the pail. The advantage of the Bokashi method over vermicompost is that you can put bones, fish, meat, and dairy products. Nevertheless, the final product cannot be used directly on plants; it must be buried for 2 to 4 weeks until it is completely decomposed (City of Vincent).
Composting with the Japanese method takes place in a cardboard box. The secret of this method is the mixture of two ingredients: rice husk ash and coconut ash. Alternatives to these ingredients are wood ash and biochar or biochar. The process does not give rise to unpleasant odors and the addition of ash prevents the formation of liquid. According to Jane Kitagawa, all you need is a cardboard box, tape, and an old towel or T-shirt to cover the box (Kitagawa, 2020).

2.3.3 Advantages and disadvantages of vermicomposting

Both composting and vermicomposting are great methods to reuse the organic residue, but it is seen in research that the humic production of the earthworm produces a better amendment for the soil and growth of the plants (Vieira, 1995). According to Rola (2014) the comparison between vermicomposting and composting showed that the biocomposite of vermicomposting is evidently better regarding the chemical composition and besides that the handling of it is simple, so could be a great alternative.

Some advantages of vermicomposting:

- Elimination of pathogenic agents such as bacteria, viruses and parasites present in biowaste;
- The process of transforming the waste into humus does not generate a bad smell;
- Transformation of unstable and polluting materials into more stable materials;
- Decrease and / or elimination of environmental impact on air, water and soil;
- Recycling of biodegradable household waste;
- Reduction of the volume of waste that would be landfilled;
- Production of an organic additive and natural fertilizer;
- Recovery of biowaste.

Some disadvantages of vermicomposting:

- Biowaste must be selected before going through the vermicomposting process, as the type of organic matter influences the quality and applications of the compost;
- Factors such as temperature, humidity and aeration must be checked and checked regularly.

Studies show that vermicomposting has advantages over normal composting in terms of the chemical composition of the generated by-product. Vermicomposting proves to be a great alternative for the solution of residential, and even industrial waste, due to its simplicity of handling, efficient, economically viable and ecologically correct.
As said before, the chemical and physical composition of the organic matter after vermicomposting has more nutrients than the soil without worms and it is simple to have a vermicompost; the only impasse is the selection of things to place.

The vermicomposting has an advantage of low-cost operation, simplicity of action and relatively high efficiency. The accelerated humidification of the vermi-compound reflects a decrease in the C/N ratio and an increase in mineral nutrients (N, P and K) and is related to the mineralization of organic matter by earthworms (Tiyeh et al., 2001 apud Cotta, 2015).
It is of extreme significance the selection of earthworm for the technological evolution of vermicomposting. Among the 3.000 species, the most used for its large tolerance of temperature variation, wide distribution and for living in organic matter with different types of humidity is the *Eisenia foetida* (Sharma et al., 2005 apud Cotta, 2015).

The process of vermicomposting includes the emission of CO_2 specially biogenic, while the production of CH_4 is emitted on the process itself.

In this context, the use of compost as an organic amendment can help to reduce GHG emissions. Composting can minimize the requirement for chemical fertilizers and pesticides (Martnez-Blanco et al., 2011 apud Barrena et al. 2014). It also has a good effect on soil structure, which helps to minimize the need for water irrigation during droughts and increases soils' ability to retain moisture (Favoino and Hogg, 2008 apud Barrena et al. 2014). Furthermore, one of its highlights is the potential for carbon sequestration in soils where compost has been treated (Favoino and Hogg, 2008 apud Barrena et al. 2014). For all of these uses, compost generated in household and industrial composting should be of excellent quality to ensure that all of the benefits of its application are realized; otherwise, its usage may have a greater environmental effect or lower agronomic output (phytotoxicity) (Barrena et al. 2014).

2.6. Centralized and decentralized waste management

It is known that composting management models can be carried out in two main ways: the centralized model and the decentralized model. In general, the centralized composting model is located outside the urban perimeter, the waste that is sent comes from different sources, and there is a need for environmental impact studies and environmental agency license. Sites licensed to compost with waste with centralized management are called Sorting and Composting Plants (UTC) or Organic Fertilizer Plants (UAO). These locations generally aim to obtain the final product in accordance with legal requirements, in the shortest possible time and space.

Figure 7 represents the difference between the centralized waste management models and decentralized waste management models.

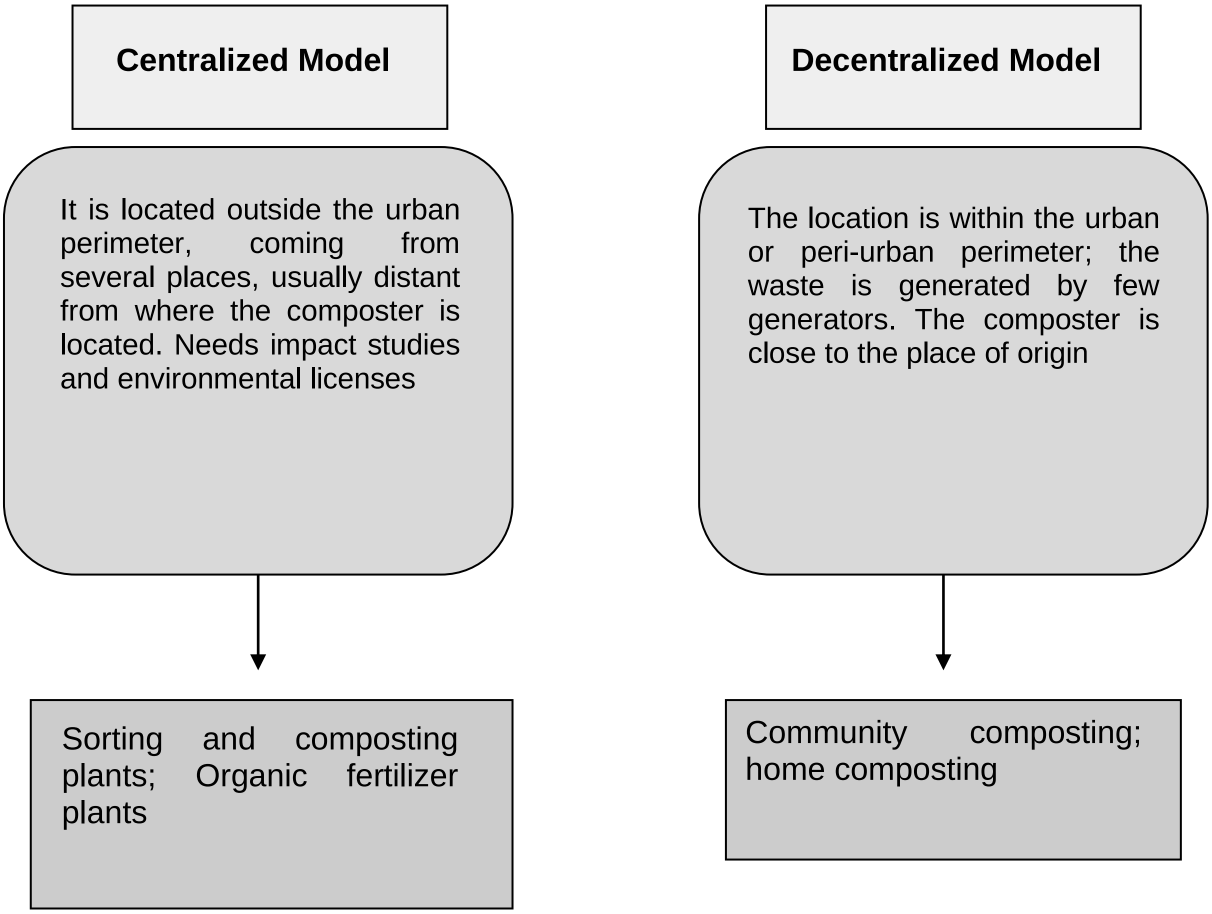

Figure 7. Centralized and decentralized models of waste management. Source: Siqueira and Assad, 2015.

Decentralized models, on the other hand, have a shared responsibility, trying to reduce the impacts caused to the environment and human health. The characteristic that differs most from the centralized model is the location, being that in the case of decentralized management, it is located within the urban perimeter, with a tendency for a smaller number of generators. In these cases, there is not always an impact study or the need for licenses, as they may even end up reducing the cost of collection. What is observed is that this model ends up being based more on a paradigm shift and social changes, and less on engineering works, which does not mean that centralized activities should be dispensed with. These initiatives have been made possible by social participation, in the construction of municipal solid waste management plans, becoming a more environmentally friendly possibility and less dependent on the centralized model. The main decentralized composting models can be fitted as follows:

- Institutional Composting: being developed in a public or private institution, aiming to reduce costs with transportation and final disposal, or even through marketing.
- Community Composting: Initiatives generally developed in neighborhoods, towns, condominiums
- Home Composting: it is a category similar to the community compost, but it is applied inside houses, developed inside homes.

Home and commercial composting have recently been examined and compared in terms of their environmental effect, including energy consumption and environmental consequences (Colón et al., 2010; Martnez-Blanco et al., 2010; Adhikari et al., 2013 apud Barrena et al. 2014). When it comes to the environment, home composting has certain potential advantages, such as avoiding the collection and transportation of biowaste. However, the home composting of OFMSW has significant environmental problems, owing to the lack of gas treatment equipment. Despite the environmental problems, greenhouse gases (GHG) can be created and discharged into the atmosphere during the composting process, contributing to global warming (Colón et al., 2012 apud Barrena et al. 2014).

Barrena et al. (2014) showed in the study comparing industrial composting with home composting that there were no statistically significant differences in chemical characteristics linked to its agronomic usage, such as organic matter and nutrient content. However, there were significant discrepancies in several metal concentrations and, in particular, the amount of stability attained. Some metals were more abundant in industrial compost than in household compost. Industrial composts are classified as Class B due to their Cu, Ni, and Zn concentration (Spanish regulation). However, several household compost samples had Zn levels that were slightly higher than the Class A standard. In terms of the usage of individual or communal home compost bins, compost bins located in schools were found to be of worse quality. In terms of compost stability from different methods (home or commercial), Barrena et al. (2014) study showed that if handled correctly, home compost may attain a degree of stability comparable to or even better than industrial compost, especially when the composting technique is not well maintained. This suggests a significant effort on the part of some composting operations to increase the stability of industrial compost.

Another study referring to the life cycle approach of home composting showed that when compared to composting or incineration of food waste, anaerobic digestion with the use of biogas and digestate as substitutes for motor fuel and chemical fertilizers, respectively, leads in a larger avoidance of global warming and the creation of photochemical ozone (Bernstad et al. 2011). Thus according to Margallo et al. (2014) the primary benefits of incineration are waste bulk reduction and energy recovery (European Commission, 2006 apud Margallo et al. 2014). However, incineration has a negative environmental image due to its emissions of greenhouse gases, acid gases, and dioxins and furans (PCDD/F) (Morselli et al., 2008 apud Margallo et al. 2014).

As a result, many of the components that have a substantial impact on the total environmental impact of the food waste treatment chain are located far from municipal waste management decision-makers. This highlights the need of a comprehensive strategy and the need for wider collaboration among the many agents engaged in the management chain if sustainable management of organic household waste and potential environmental benefits are to be realized (Bernstad et al. 2011).
To maintain a standard quality of the compost it is a good idea to keep track of the amount of biowaste handled each day, as well as the weekly pH and soil temperature. The completed

products can be sent to a qualified laboratory for quality testing, specifically on the organic matter content, moisture, pH, carbon-to-nitrogen ratio, and pathogen concentration, for quality assurance (Keng et al. 2020).
A study that evaluated community-scale composting showed that for effective composting, household waste and the bulking agent should be combined in the proper proportions, resulting in an initial carbon-to-nitrogen ratio of roughly 30 and a moisture content of 50-60% percent. When the composting temperature rises, the moisture level should be kept at roughly 55-60% percent by watering, evaporation, or pile-turning (depending on the local environment) (Keng et al. 2020). This study had the capacity of treating 6 tons of food per month and the process of composting takes around 7 months to complete and generates approximately 11% wet basis (or 30% dry basis) of compost output in relation to total biowaste intake (i.e. approximately 660 kg compost/month). The quality of the finished compost validates the success of this community-scale composting method, which meets the Malaysian SIRIM MS 1517:2012 organic fertiliser standard, with organic matter, C/N ratio, W, TKN, P, and K at 52.5 percent, 12 percent, 2.62 percent, 3.39 percent, and 0.58 percent, respectively. The proposed community-scale food waste composting technology is both technically viable and socially acceptable. This method will become economically viable as soon as proper landfill costs are implemented, which account for the full environmental cost of disposal rather than recycling (Keng et al. 2020).

2.7 Review on composting studies

Considering the relevance of centralized and decentralized biowaste treatment via composting techniques towards the enhancement of the circular economy through an increased efficiency of biowaste conversion in relation to conventional approaches, several studies have been conducted worldwide to characterize the efficiency and emissions from composting systems.

A study conducted by Keng et al. (2020) in the University of Nottingham Malaysia is used as a case study to show and assess the creation and performance of a community-scale aerated static pile composting system for food waste treatment. The study showed that according to the life-cycle assessment, employing composting to substitute landfill for food waste, as well as replacing chemical fertilizers with organic compost created, may significantly minimize environmental consequences, including global warming, ecotoxicity, eutrophication, and fossil fuel depletion. And it showed that the composting process takes around 7 months and yields roughly 30% (on a dry basis) of compost from the entire organic material. The completed compost has been demonstrated to fulfill Malaysia's organic fertilizer criteria. According to the life-cycle assessment, employing composting to substitute landfill for food waste, as well as replacing chemical fertilizers with organic compost created, may significantly minimize environmental consequences, including global warming, ecotoxicity, eutrophication, and fossil fuel depletion. The average daily food waste collected is around 166 kg, with 20% of that being non-food waste (recyclables or rubbish), implying that the real daily food waste creation is approximately 130 kg. The amount of compost created after the composting process is roughly 548 kg/month. The compost yield on a dry basis is determined to be 30%, which is defined as the quantity of compost created from the total dry organic waste input (Keng et al., 2020).

Another study that compared centralized and decentralized approaches for sewage sludge and food waste showed that anaerobic codigestion of dewatered sewage sludge and organic fraction of municipal solid waste (OFMSW) in small facilities, in conjunction with composting post-treatment, may offer an environmentally viable waste management solution in small towns. The total quantity of GHG reduced as a consequence of composting or/and power generation is: -180 t CO_2-eq (Current scenario), -360 t CO_2-eq (Anaerobic Digestion followed by Landfilling scenario), and -460 t CO_2-eq (Anaerobic Digestion followed by Landfilling scenario) (Anaerobic Digestion combined with Composting of digested matter scenario).

A study comparison of biowaste composting (home and full scale) using LCA showed that home composting produced more ammonia, methane, and nitrous oxide than industrial composting, although the latter used or produced between 2 to 53 times more transport, energy, water, infrastructure, trash, and Volatile Organic Compounds (VOCs) than home composting. Therefore, for four of the effect categories studied (abiotic depletion, ozone layer depletion, photochemical oxidation, and cumulative energy consumption), industrial composting was more impactful than home composting, and less impactful for the other three (acidification, eutrophication and global warming). The home composting method consumed 351 MJ eq of energy and emitted 220 kg CO_2 eq per ton of OFMSW, whereas industrial composting consumed 1908 MJ eq of energy and emitted 153 kg CO_2 eq per ton of OFMSW. Furthermore, in the context of global warming, composting contributes to the avoidance of emissions (Martinez-Blanco et al., 2010). For example, Boldrin et al. (2009 apud Martinez-Blanco et al. 2010) demonstrate that when the end use of compost is included, the overall emission factor for composting can range from large savings (-900 kg CO_2 eq ton^{-1} OFMSW) to a net load (300 kg CO_2 eq ton^{-1} OFMSW) (Boldrin et al., 2009 apud Martinez-Blanco et al. 2010).

According to a study conducted by Berstand (2011) the net impact of the management chain on GWP ranges from a contribution of 2.6 kg CO_2-eq/household and year if incineration is used to an avoidance of 5.6 kg CO_2-eq/ household and year if anaerobic digestion is used and generated biogas is used as automobile fuel (Berstand, 2011)

The composting process significantly reduced methane emissions, one of the primary GHG, emitting nearly ten times less than the sanitary landfill. The anaerobic decomposition process that happens in landfills emits a lot of methane into the atmosphere. For this computation, the waste deposit condition was taken into account throughout a 10-year period, as well as the landfill's emission horizon of up to 20 years. In ten years, composting emitted 3,520 tCO_2e, whereas the landfill emitted 28,527 tCO_2e and will continue to leak methane for at least ten years, totaling 35,510 tCO_2 in twenty years (Inácio et al., 2009).

3. Case study

3.1 General description

The present thesis focuses on analyzing the strengths and weaknesses of decentralized composting initiatives taking place in the city of Aveiro, a Portuguese coastal town with a vibrant economic development where several composting initiatives have been taking place during the years 2021 and 2022. The present thesis focuses on decentralized composting initiatives due to their potential to involve citizens living in urban areas for including composting practices in their daily lives. The present thesis considers DCI to be crucial in supporting municipalities in the implementation of national and local biowaste management programs derived by the EU Waste Framework Directive.

The main methodology chosen for this study was the semi-quantitative analysis of socio-environmental perception of citizens about biowaste composting in biological waste treatment systems. The analysis was conducted by applying a questionnaire (Google Forms) and the application of a face-to-face questionnaire in the city of Aveiro. The application SPSS was also used to draw some statistical inferences regarding the data.

The main objective with the development of the questionnaire is to know the main trends and barriers for those who do not compost or stop composting and the main motivations for those who compost. And with that to better understand and map people's motives, in order to find the best ways to create awareness of the subject. This study is expected to provide scientific outcomes to decision makers in municipalities regarding the implementation and relevance of DCI for enhancing biowaste management in the Portuguese context by inquiring the participants both randomly face-to-face and online using the Ciclocompost project platform. The data collected in this study from the participants in the Ciclocompost project is of high relevance due to the fact that this is an ongoing DCI developed by citizens of the city of Aveiro in the context of the participatory budget with direct action of the municipality of Aveiro (OPAD2021).

3.1.1 Context of the study

The research is taking place in the city of Aveiro including questionnaires to participants the project Ciclocompost that is taking place by the collective HortUA, which manages an urban community garden. The Ciclocompost is a pilot project to test innovative solutions for decentralized composting in the city of Aveiro. The project is supported and partially funded via the Participatory Budget for Direct Action from the Municipality of Aveiro. The initiative consists in designing and testing a local low-carbon biowaste management system in the main parish of the city of Aveiro, including the collection and treatment of household biowaste in community composting bins. For the collection of biowaste, a part of participants (40) in the project benefited from a door-to-door collection of their biowaste which is transported in cargo bikes (cargo bicycles) to community compost bins installed in the University Of Aveiro in HortUA, where biowaste is transformed into biofertilizer and then returned to the citizens participating in this pilot project. Another part of the participants use the community compost bins freely, usually transporting their biowaste on foot or with their own ways of transport (e.g. bikes or car).
During the 6 months of the project, Ciclocompost provided 60 families in Aveiro with the possibility of separating their organic waste and composting it in a community way. By avoiding sending this type of waste to a landfill, these families significantly reduced the emission of greenhouse gases and the costs of managing them. Oriented towards the correct sorting of waste, they have contributed to the production of quality compost, which can be valued through use in pots, vegetable gardens and/or agricultural production fields.

Beyond the questionnaires applied with citizens of the city of Aveiro, the present study benefited from the fact that it was developed during the implementation and in partnership with the Ciclocompost project by:

i) Characterizing the perception of local citizens and participants in the project about the importance of citizens participation in biowaste management and composting techniques;
ii) Identifying the critical barriers and motivations for composting.

Additionally, the Ciclocompost project is today considered as an experiment of a low-carbon biowaste collection and treatment system applied to sensitize urban citizens for including composting practices in their daily lives. At the end of the project, the biofertilizer produced in the compost bins will be returned to the participants.

The collection of biowaste is conducted on two cargo bikes provided by *Casa da Bicicleta de Aveiro* (http://casadabicicleta.pt/), an association that collaborates with the project. The collection of biowaste is carried out twice a week at the homes of registered participants. The collection is carried out in reusable plastic buckets with the project logo. Each participant received a stamp signaling their adhesion to the project. The project involves the construction of over eight community compost bins, installed on a land plot located in an urban garden. The composting is produced through two popular composting techniques identified as resource efficient in the previous chapter, i.e. i) thermophilic and ii) vermicomposting mainly using red worms (*Eisenia fetida*), ensuring quality and speed in the decomposition process. After a few months, participants will have in return small amounts of biofertilizer for their potted plants and vegetable gardens. Additionally, surplus biofertilizer production will also be donated to community gardens in the city.

Figure 8. Case study and scheme of the Ciclocompost project.

The general purpose of the Ciclocompost project is to value domestic biowaste through the technique of composting, helping to reduce the waste sent to landfills, consequently contributing to reducing CO_2 emissions into the atmosphere, capturing carbon and fixing nutrients in the soil.

The target audience of the Ciclocompost project are the residents of the city of Aveiro and students from the University of Aveiro, in particular from the parishes of Glória and Vera Cruz and Bairro de São Tiago (University of Aveiro). Despite being open to the participation of the citizens of Aveiro in general, the project aims to reach mainly the young public, namely the students of the University of Aveiro, as they can influence changes in habits and introduce new practices in the scope of sustainability in Aveiro.

Strategic partnerships with the University of Aveiro, Ciclaveiro, HortUA and other local organizations (Association of University of Aveiro Students; Agora Aveiro; Aveiro in Transition; Gretua, IPSS Florinhas do Vouga etc.) were established by the citizens that proposed the project.

With the development of the questionnaires, we intended to define the opinion of local inhabitants and participants and identify the major challenges and reasons for composting in order to better develop this type of initiative, which is gaining in popularity.

3.1.2 Subjects, participants and interviewing strategy

The citizens of Aveiro are the subject of the research, including participants in the Ciclocompost project. In this way, two types of questionnaires were created, i.e. one for face-to-face interviews made randomly in the street and another for an online survey created with Google forms.

The questionnaires were developed and applied according to a random sampling and in two ways online sampling, according to the following ways: the first one, on Google forms that was disclosed in Aveiro by social media, groups of the citizens in the city and the university. Studies that are survey-based are profuse in many fields of study, such as medical, social, economic, psychological, and behavioral research. Questionnaires are widely utilized as a research instrument in these studies to collect diverse information from participants (Yosoff, 2021). The population of the Aveiro municipality is 80,978 inhabitants, while the city center of Aveiro (which is the focus of the study) has 18,756 inhabitants.
The questionnaire was divided in 2 parts:

a) **Random sampling** (made face-to-face in the city).

This format was chosen so that we could have a greater diversity of opinions in the way of obtaining the answers and therefore greater diversity in the answers, without becoming biased.

b) **Online sampling** (in which we have a sample conditioned to who has access to the internet and which ends up including people more familiar with the subject).

To ensure that the responses were not biased, they were distributed to a wide range of organizations, rather than a narrow niche, as was the case of students and staff from the University of Aveiro since some of them are already sensitized about the environmental relevance of composting as a circular biowaste management solution.

a) **For the face-to-face random Sampling conducted in the city, the questionnaire was applied according to the following structure:**

For the face-to-face questionnaire, one of the first objectives was to discover if the person does or does not compost and also understand why. The importance and difference of this way of questioning is that you can see people's reactions to your question and understand better their knowledge on the subject. The questionnaire was carried out in the main areas of the city of Aveiro, mainly: Glicínias neighborhood, Praça do Peixe proximity and neighboring sites close to the ceramic factory and the municipality main building, during the days of 18, 19 and 20 f March of 2022. Figure 9 below shows the map made to develop the face-to-face questionnaire.

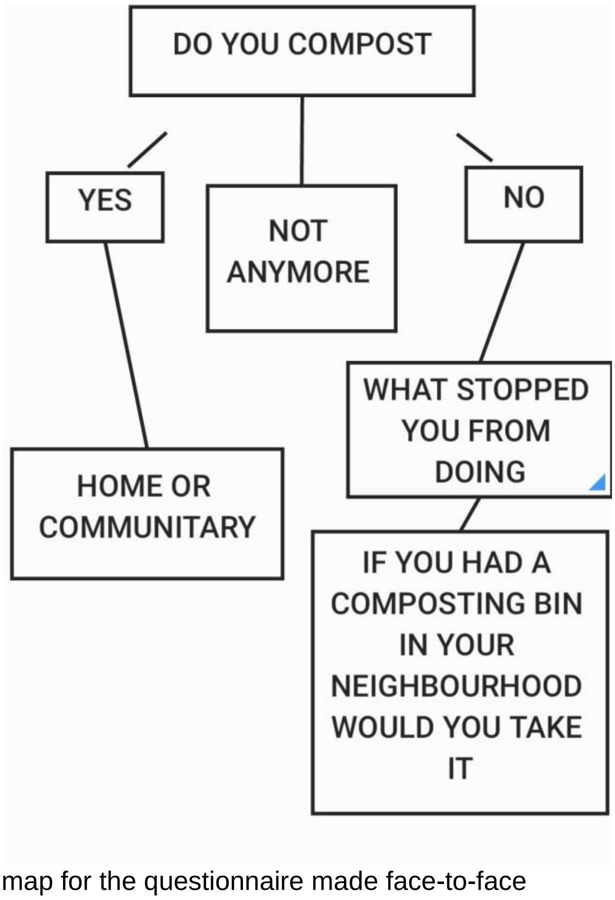

Figure.9 Represent the map for the questionnaire made face-to-face

In this context, with this procedure indicated in this scheme, the survey of the face-to-face questionnaire was carried out in order to allow a better understanding on the knowledge and practices of citizens about composting and how they feel about it.

- Questions asked in the face-to-face questionnaire:

1. Do you compost?

2. What type of compost do you do?
3. If you already did, why did you stop?
4. Would you be willing to take your biowaste to a composting bin in your neighborhood? (This question was asked for all respondents, not only for those who does not compost)

b) For the Online Sampling, the questionnaire was applied according to the following structure:

With this closed type questionnaire, the first part of the questionnaire aimed a more sociological understanding of user behaviors and drivers for composting practices. The second part aimed at determining who composts and who doesn't. In this case the persons composting were also invited to respond to the third part of the questionnaire. Those who said that they do not compost were invited to respond to the fourth part of the questionnaire. In the case of the third part the goal of the questionnaire was to evaluate the profile of people that do not compost, so we also asked some sociological questions to better understand the reasons behind it.

- First part of the questionnaire:

1. What is your age group?
2. What is your gender?
3. Number of people in the accommodation?
4. Do you separate all the waste you generate?
5. Would you be willing to take your biowaste to a composting bin?

- Second part of the questionnaire:

1. Do you compost?

- Third part of the questionnaire:

1. What is your level of education?
2. What type of compost do you use?
3. If others, indicate which ones:
4. Which composting technique applied?
5. In the case of composting in a community compost bin or directly in an open space (eg in the garden), how is the waste taken?
6. In the case of community composting, what would be the approximate distance between your house and the compost bin (in meters)?
7. How many kg of biowaste is placed in a week, approximately?
8. What is the origin of the most generated biowaste?
9. In the case of biowaste from the kitchen, what is the origin of the food that gave rise to it?
10. According to the question above, what is the approximate proportion (in %) of each, if any?
11. Do you use the produced compost? If yes, briefly describe the application (community garden, at home, among others)
12. What motivated you to compost?
13. If you chose "others" in the previous question, briefly describe

- Fourth part of the questionnaire:

1. Have you ever composted?
2. If you have ever or never done it, what did you consider the biggest barrier/difficulty to compost?

4. Results

This chapter will present a detailed analysis of the results regarding the application of the questionnaire developed to better understand the barriers and motivations for the citizens of Aveiro to compost.

In total, the number of respondents, including the two questionnaires, was 105, and the number of people who answered the face-to-face questionnaire was 52 while the number of people who answered the online questionnaire was 53.

The total number of respondents is 105 with both questionnaires. The number of respondents that do not compost is 76, and the number of the ones that compost is 27, while the number of the ones that already did is 2. Which means statistically that 72% don't compost, 26% compost, and 2% have already composted.

With the intersection of both questionnaires, we also had barriers for the ones that don't compost. In that case, for the majority of people that do not compost, the main reasons for that are:

- Lack of space; live in an apartment;
- No knowledge of the subject;
- Never thought about it;
- Increase of flies, Initial lack of suitable place;
- Bad odors, Lack of space;
- Increase of flies, Bad smells, Other pests, Discouragement to maintain the process, Lack of time, Lack of space.

Since many respondents are Ciclocompost project participants, there are certain biases in the samples that must be considered. For example, the random sampling of men and women or the participants' ages make it difficult to determine whether there is any relationship between them. The most crucial aspect of the samples was to see what the participants' reasons and constraints were for composting or not. In addition to the graphs, some interesting results were obtained using the SPSS statistical program.

a) Face-to-face random Sampling conducted in the city

In Figure 10 the results for the question “Do you compost?” shows that 83% does not compost, 13% do compost and 4% already did. There is a significant difference between individuals who compost and those who do not, indicating that it is still a niche activity. This type of information is critical for understanding the implementation of national and international waste guidelines, as well as the improvements that can be made in the implementation of new public policies and giving people more training, because, as seen here, most people do not compost and are very likely to continue doing so if they do not have enough information. This emphasizes the significance of developing programs, such as Ciclocompost, that provide more information to residents.

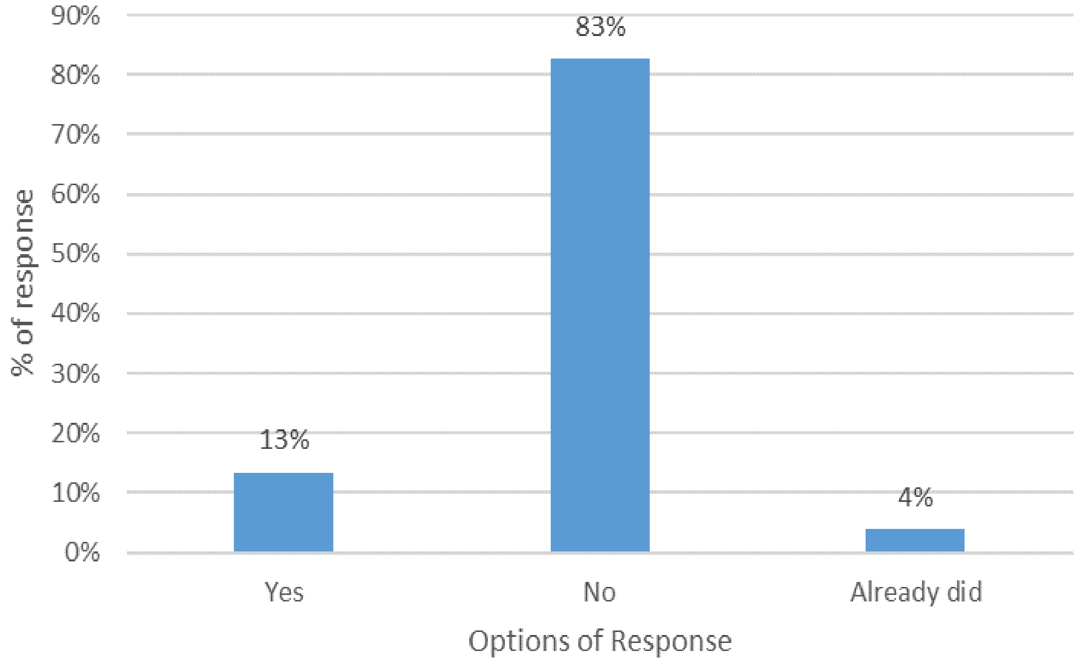

Figure 10. Results regarding the answers for face-to-face questionnaires to the question "do you compost?".

For those who responded that they compost, Figure 11 below shows the kind of method used to compost. In this case, it is possible to see that the most used is home composting, with 88% while for community composting, only 13%. Here are various explanations for such a low level of community composting adherence. The convenience of not having to leave the house is the first benefit of having your own composter at home. However, there may be a dearth of understanding regarding the city's current composting bins, or even their absence. Despite the expansion of composting projects, there may still be a disconnect between people and this type of project, as well as a lack of public support and outreach. When there is a shortage of public investment, many local groups feel compelled to establish programs that link people with these concerns, hence expanding social engagement in the creation of public policy.

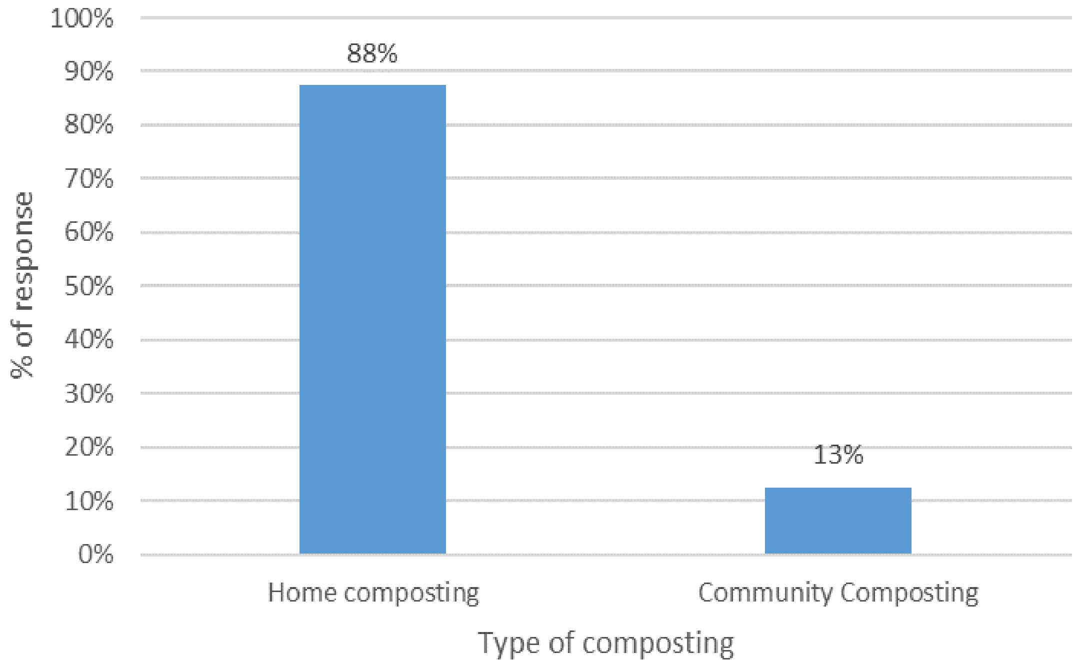

Figure 11. Results regarding the answers for face-to-face questionnaires to the question "What method do you use?".

Figure 12 shows the results regarding the responses for the question "What do you consider as a barrier to composting?" and as the leading response was lack of space with 42% because they live in apartments. With 37% came lack of knowledge in the subject, then 7% said that they never thought about it, then 5% said lack of space with lack of time to do it, also 5% was moving out, 2% said lack of time with lack of knowledge in the subject and 2% said just lack of time. In SPSS, it was possible to validate the relevance of a lack of space ($r=-0,252$; $p=0,014$) as the primary reaction of people who do not compost, and a lack of space is also related to a lack of understanding (see correlations in Annex). Recognizing the barriers that people have on the subject is critical in determining where to best act to bring knowledge and make people want to participate. In this example, because lack of space was identified as the primary barrier, it is even more crucial to engage in community composting to demonstrate to people that if they cannot compost at home due to a lack of space, there are locations in the city where they may do so. Of course, the way the information is disseminated is critical in order to inspire individuals to carry the composting materials to a certain location.

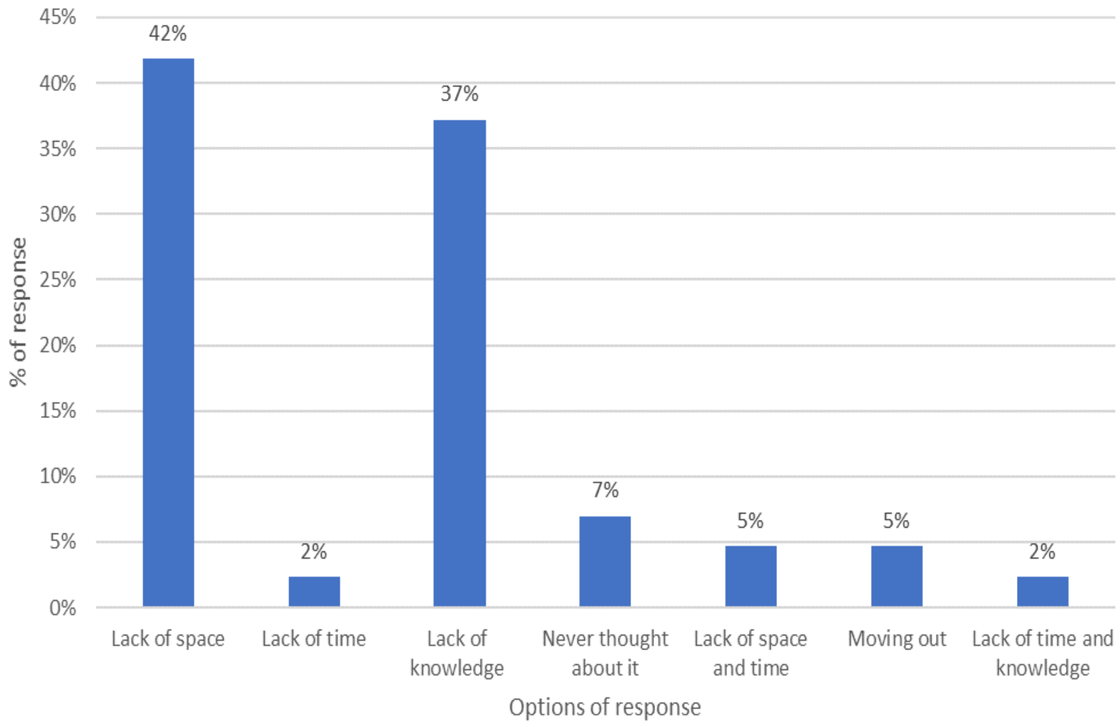

Figure 12. Results regarding the answers for face-to-face questionnaire to the question “What do you consider as a barrier to composting?”.

Figure 13 illustrates the responses for the question “Would you be willing to take your biowaste to a composting bin in your neighborhood?”. Here, 48% of responses indicate citizens “didn’t know what to say’’ about the question, 23% of the citizens said “yes”, 15% said “maybe”, 12% had “no answer” and 2% said “hardly” do, because they think changes do not depend only on them. It is clear from questioning people face-to-face that they still don’t know much about the subject and couldn’t give an objective response, because of many factors of daily life. These findings indicate a likely lack of topic understanding, resulting in people not knowing what to answer appropriately. In this sense, advertising the issue is critical, so that people first learn about the relevance of the subject and then incorporate it into their daily routines.

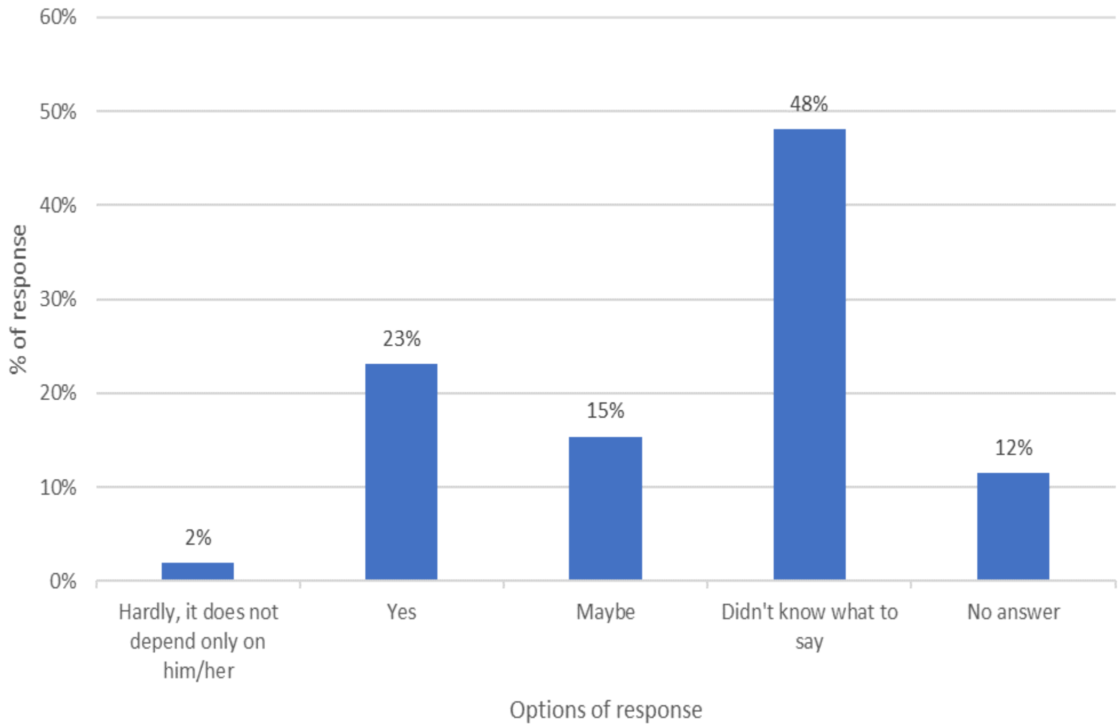

Figure 13. Results regarding the answers for face-to-face questionnaire to the question “Would you be willing to take your biowaste to a composting bin in your neighborhood?”.

It is important to notice that while doing the face-to-face questionnaire, we could see the reactions of the respondents to the subject. It was noticed that a great portion of the respondents didn’t know what composting was, or thought that the undifferentiated container was a kind of composting process. Another topic developed for the face-to-face questionnaire was to discover if the respondents would take their biowaste to a specific composting bin. In the data analysis, it was possible to observe some interest of a niche of the urban community composting for instance according to the questionnaires applied to participants in the Ciclocompost project, as a substantial part of the participants in the project took their waste to a location in the neighborhood. Overall, for-the-face-to-face survey, for the 52 respondents to the questionnaire the respondents reported:

- Yes, they would take them there (12 respondents);
- Didn't know if they would take there (25 respondents);
- Maybe (7 respondents);
- No answer (6 respondents);
- Hardly, because it does not depend only on him (1 respondent);
- Yes, but they would hardly take it if it went far. It would have to be something close, just like the regular container bin (1 respondent).

b) Online sample

- **First Section of Questions**

The first section of questions consists in a total of 53 respondents.

Figure 14 illustrates the results of age group of the respondents. In this case in this group of respondents, 53% are between the younger ages of 18-29, followed by 26% between 30-39, 2%

between 50-59 and 2% of 60 or more. In this sample, a bias in the data is present with a higher proportion of young individuals.
SPSS findings reveal that age group is inversely associated to those who replied the "discouragement to keep the process going" as a barrier to composting (r=-0,309;p=0,026); younger people are more discouraged to keep the process going (see correlations in Annex).

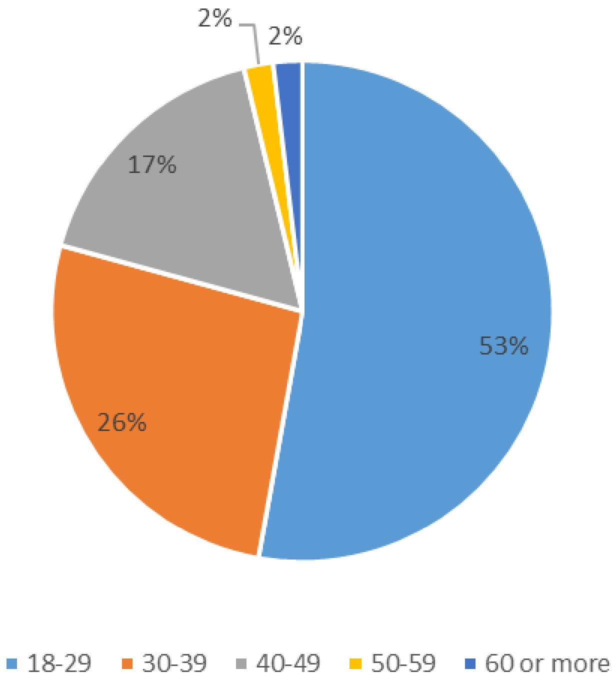

Figure 14. Results to the question “What is your age group?”.

Figure 15 illustrates the results regarding the gender of the respondents, where 70% are female and 30% are male. This data may reflect the possibility that women are more interested in the subject and/or have more sensitivity on the topic. SPSS showed significance of age , where as the age group increases, the number of female respondents increases. SPSS correlation between “gender’’ and “Do you compost?”, shows results close to being relevant (r=0,225;p=0.06), showing that the number of women that compost is higher than men. This demonstrates that, in this issue, women may be powerful agents of change and citizenship while also contributing to a regenerative city.

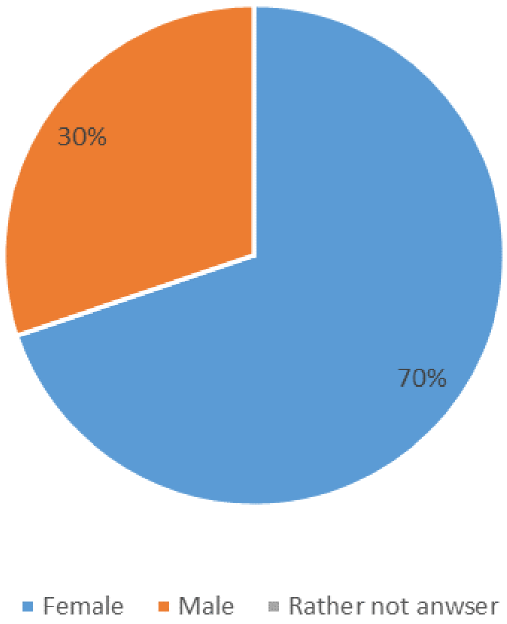

Figure 15. Results to the question “What is your gender?”.

Figure 16 shows how many people live in the accommodation. For this case it is possible to see that 2, 3 and 4 people in the accommodation are the main results with 28%, 25% and 28% respectively. 5 people in the accommodation came with 11% and 1 person in the accommodation with 8%. Considering the 28% (4 people in the house) and 25% (3 people in the house), it is critical to emphasize the role of families in creating a more resilient city, with a focus on children and young people in households. Environmental education is vital for developing awareness, according to studies, because the youngest grow up with this knowledge, but they also end up passing it on to their parents (Cortesão, 2017). Therefore, we can say that schools have a fundamental role, and the municipality could invest more in them to raise awareness. And also, as seen in Figure 15, the importance of empowering women in this context, as agents of change.

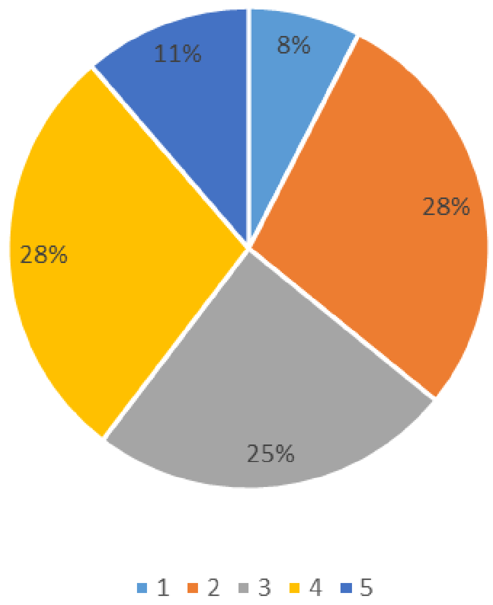

Figure 16. Results to the question ''Number of people in the accommodation?''.

In the Figure 17 are the results for type of waste sorted by the respondents: 3% don't separate at all the waste, 27% separate plastic/metal and paper cards, 28% separate glass and 14% separate biowaste. As already described in the bibliographic references, Portugal has a reduced number of recycling, when compared to other EU countries, and bio-waste has an even lower rate, even though it is a large part of the waste characterization and lack existence of biowaste recycling (but there will be). Therefore, the findings are crucial for comprehending the causes and pinpointing potential areas of attention in order to improve bio-waste management.

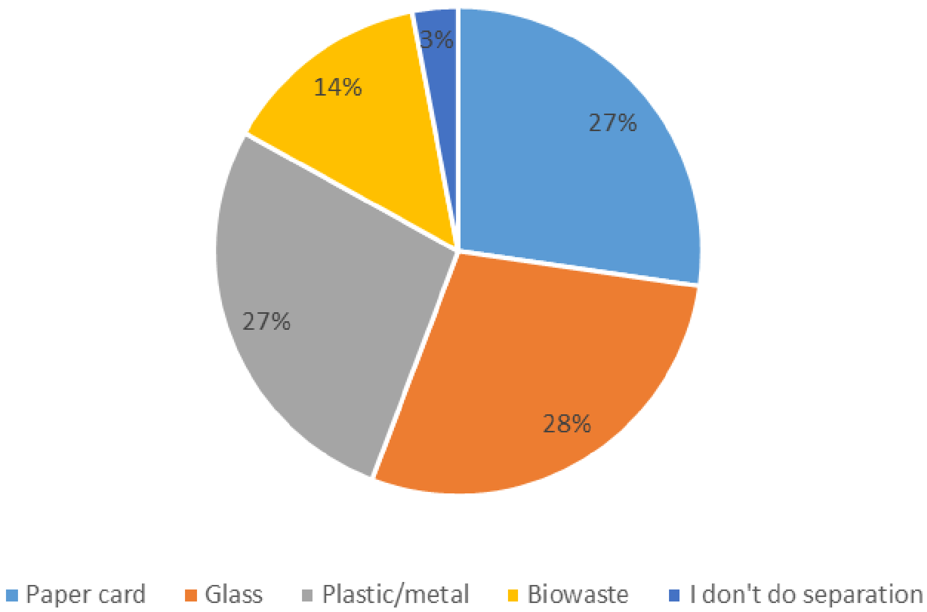

Figure 17. Type of waste sorted by the respondents that are used to sort their waste.

The Figure 18 below shows results of ''If there was a community compost bin in your parish, would you be willing to take your biowaste to it?'' In this case, 70% would take it, 6% would not and 25% it depends. For the last one, talking with people on the face-to-face questionnaire, they have the same concern, it really depends. According to the SPSS results, respondents that *would take their compost to a composting bin* has a significant relationship to those composting for the "environmental benefits" motivation (r=0,465; p=0,039). And those who answered that *they would not take it* have a significant relationship with the barrier "lack of knowledge" (r=0,366; p=0,0001). This shows us that if there were more municipal incentives on the subject, it is possible that would increase interest and the possibility of more people using community composters.

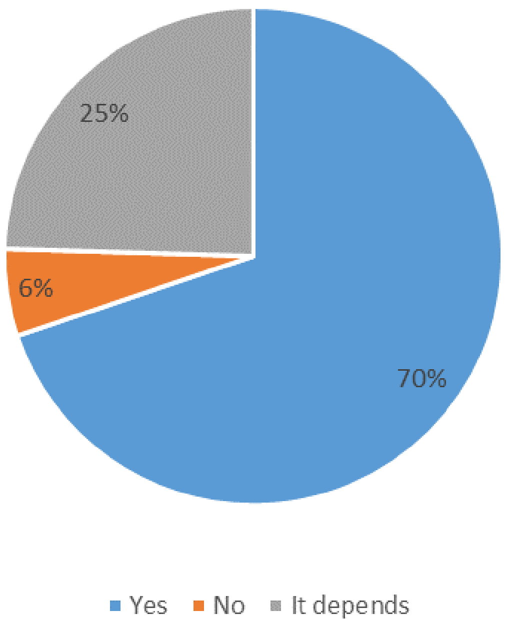

Figure 18. Results to the question ''If there was a community compost bin in your parish, would you be willing to take your biowaste to it?''.

- **Second Section of Questions**

In the second section of questions, we have only the question shown in the Figure 19 to know the respondents who compost (38%) and who do not compost (62%). More than half of people do not compost and according to SPSS results the main barrier is "lack of space'', demonstrating that this is a strong limitation to start the composting process. An incentive for this is the possibility of investing in more composters spread across strategic locations in the city, as well as bio-waste collection projects, such as Ciclocompost.

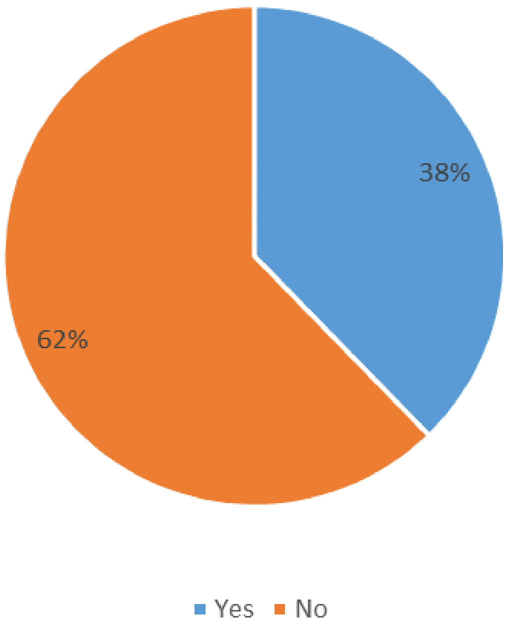

Figure 19. Results to the question ''Do you compost?".

- **Third Section of Questions**

The third section of questions is for those who, in the question above, answer that they do compost, in that case, 38% of the respondents. Figure 20 shows the responses according to the educational level of the respondents (bachelor's or equivalent, 18 respondents; Secondary Education, 2 respondents). In this case, it is possible to observe that 90% of the respondents has a bachelor's or equivalent degree and that 10% finished the secondary education. As mentioned in Figure 16, environmental education is vital for developing awareness. However, it is important to mention that the online questionnaire is clearly biased in this variable, maybe indicating higher willingness to respond to this survey be more educated people or just the higher access to the communication media by this group.

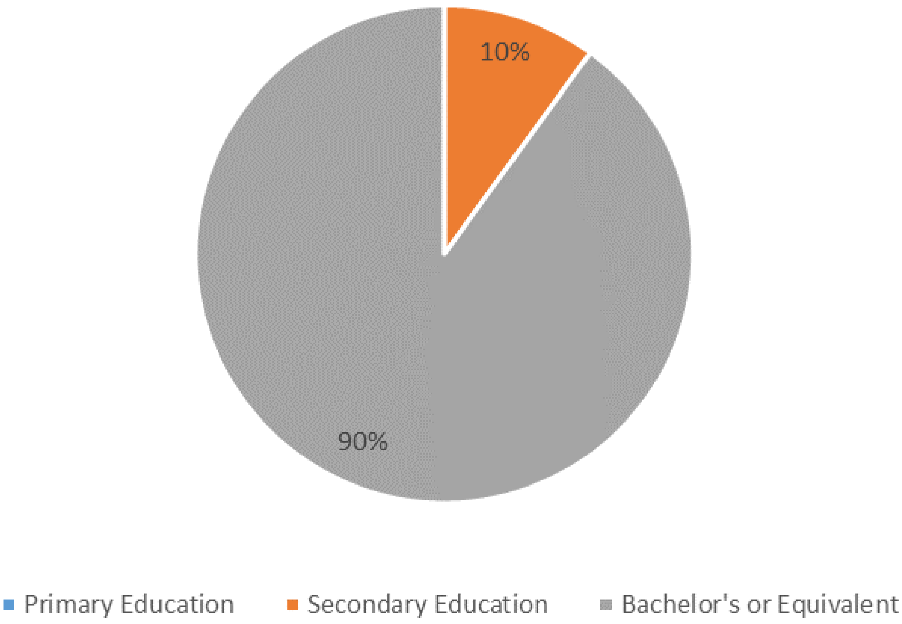

Figure 20. Results to the question “What is your education level?”.

Figure 21 (20 respondents in total) shows that 85% of the respondents that compost use home composting, 10% use community composting and 5% use both options. With this question we wanted to know the option used, and for this the home composting is the most used one. Thus, it is possible to understand the trend for using home composting as it is more practical to be conducted in the routine as biowaste is produced at home and can in this way be treated at the same place. Thinking about the Figure 18 (If people would take their biowaste to community composting if the neighborhood had it), we can consider that maybe the numbers of respondents for ‘’community composting’’ and ‘’both’’ would rise.

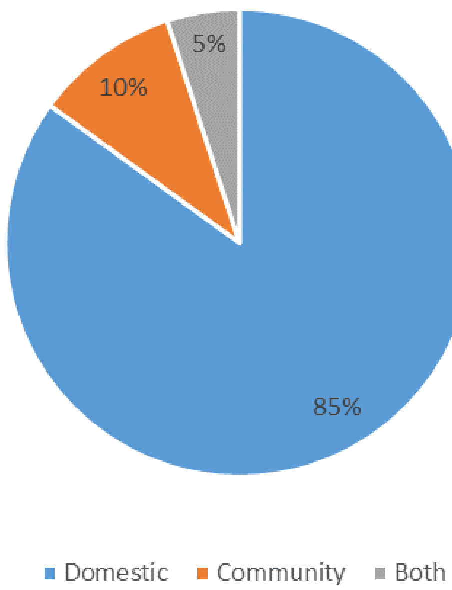

Figure 21. Results to the question “Which compost do you use?”.

Figure 22 shows the results for the composting technique applied by the (Simple thermophilic, 10 respondents; Vermicomposting, 6 respondents; Other, 4 respondents) respondents, and responses are ''simple thermophilic'' (50% use this option), ''vermicomposting (30% use this option) and ''other'' (20% use this option). The technique's simplicity impacts the number of individuals who use it. However, further efforts may be done to make effective composting methods more feasible and practicable, since vermicomposting can be more efficient, cleaner, and quicker than basic thermophile.

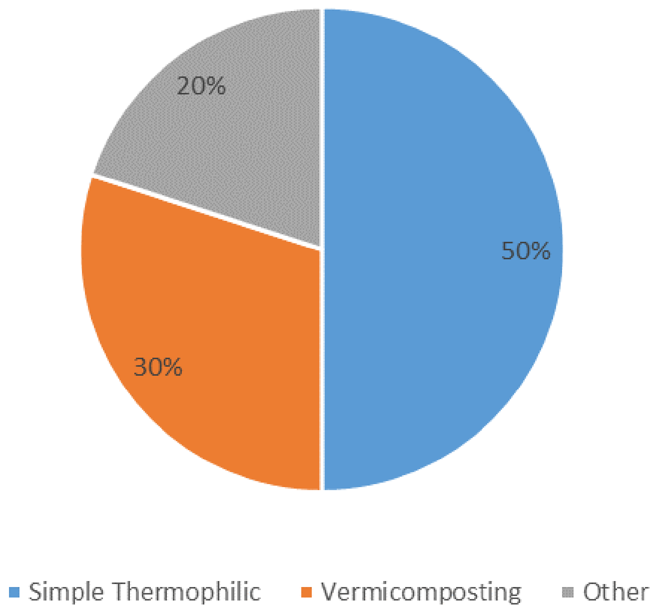

Figure 22. Results to the question "Which composting technique applied?".

Figure 23 below illustrates that 50% of the respondents take their biowaste by car and 50% by bike. Aveiro is friendly city for walking or even riding bikes with facilitates for it that can contribute to enhance community composting. None of the respondents take their biowaste on foot due to the relatively long distance from people's households to the compost bin (Total of 6 respondents).

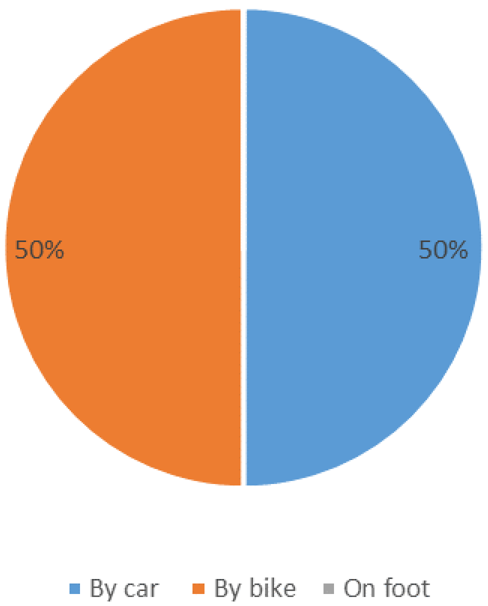

Figure 23. Results to the question “In the case of composting in a community compost bin or directly in an open space (e.g. in the garden), how is the waste taken?”.

Figure 24 illustrates the usual distances to take the biowaste to the community compost bin for those who use it (Total of 5 respondents). And for that 40% is between 500m and 1km, 20% for each less than 100m, between 100m and 500m and more than 1km. 40% of the replies indicate that the distance from the community composting bin is between 500m and 1km, which may lead to individuals not taking their compost. A strategy that the municipality may do is to invest in community composters strategically placed across the city to cover each neighborhood.

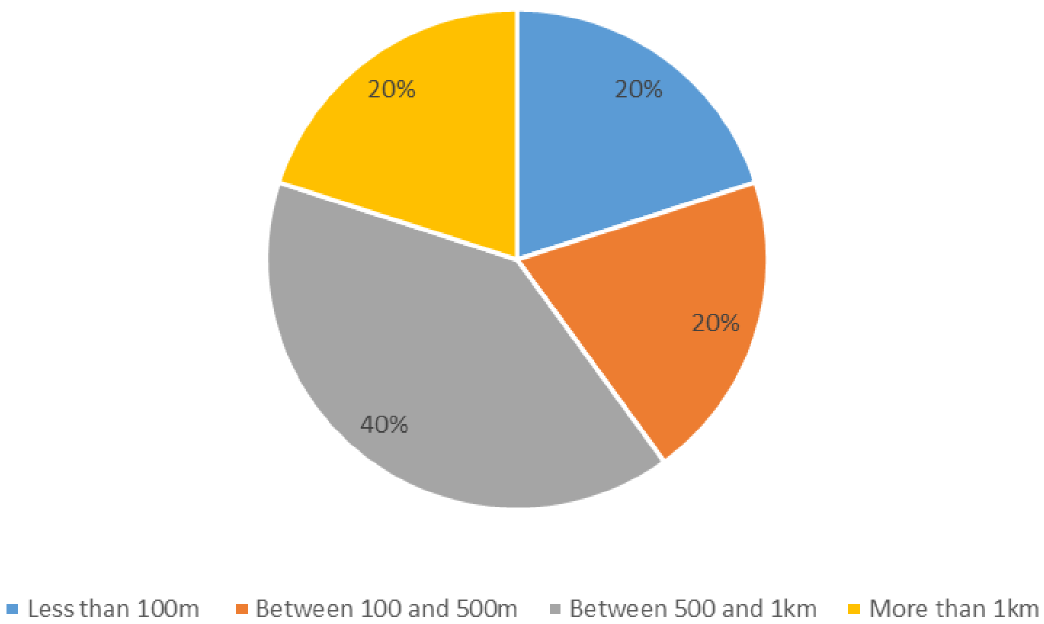

Figure 24. Results to the question “In the case of community composting, what would be the approximate distance between your house and the compost bin (in meters)?”.

Figure 25 illustrates the ranges for the average amount of biowaste produced. The amount of biowaste produced by each household ranges between 300g and more than 2kg, being between 300g - 700g, 800g - 1.2kg and 1.3kg - 1.7kg with 25%, for more than 2kg it is 20% and other has 5%. The average amount of biowaste produced in each household depends on the average food consumption per capita and the amount of people living in each household. Exploring the data, we have an approximate total of 26 kg/week produced by the 32 respondents who answered this question. With a population of approximately 80000 inhabitants it is possible to estimate a production of 2.080.000 kg/week of biowaste. Another parameter surveyed was the average number of people per accommodation compared to the average waste produced, thus verifying the amount produced per person. Respondents who produce an average of 0.5 kg the average number of people in the accommodation is 3, respondents who generate an average of 1 kg also have an average of 3 people in the accommodation, respondents who produce an average of 1.5 kg have 2 people on average in the accommodation and lastly people who produce an average of 2 kg have an average of 4 people in the accommodation. Finally, because of these data, it is possible to identify the average generated bio-waste per inhabitant, with an average of 0,437 kg/week. First, it is very interesting to check the amount produced and say that this amount is produced by people who compost, so it is a good amount of waste avoided in landfills.

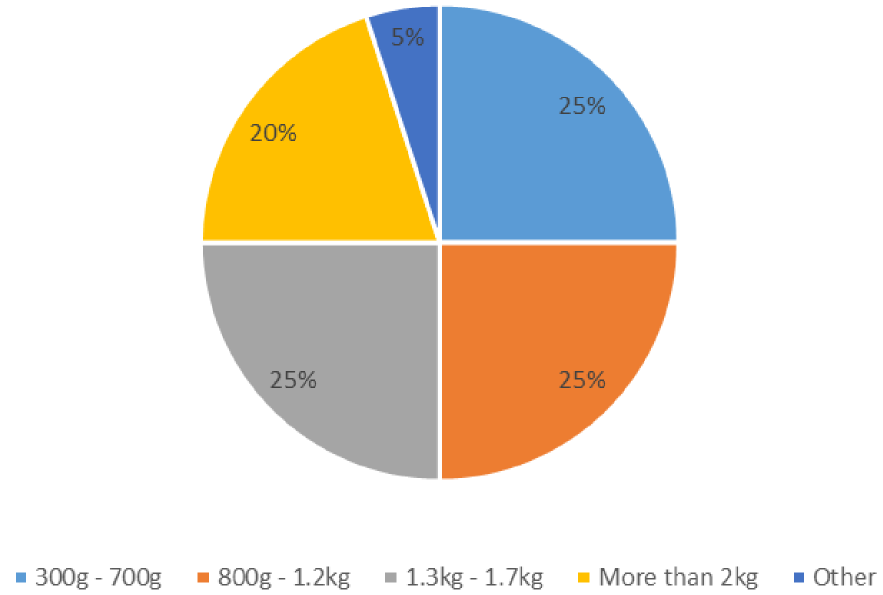

Figure 25. Results to the question “How many kg of biowaste is placed in a week, approximately?”.

The results for the Figure 26 (total of 20 respondents) indicate that the main biowaste produced is from kitchen with 70% of respondents, while from garden has 25% and other option, 5%. It can be observed that there is a greater amount of food in the compost. Since most people live in cities or flats and do not have a yard, kitchen trash will always be more prevalent. However, it is necessary to look for alternatives to manage ”browns” in community composting bins, as the process requires these browns. A better option would be to work with the company in charge of urban cleaning, or even the local council, to segregate the gathered dry leaves for community composting programs, or the cardboard in collection centers. Another option was to contact people who transport their biowaste to community composting bins and have a garden to separate ”browns”.

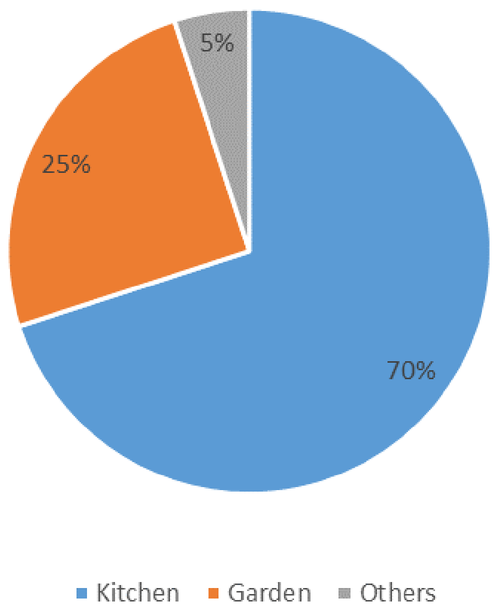

Figure 26. Results to the question “What is the origin of the most generated biowaste?”.

Figure 27 shows that supermarkets and local markets are the main options regarding the origin of the food consumed in each household which means that most parts of the citizens still purchase their food locally (Total of 24 respondents). Supermarket represents 42%, local market 17%, local producers with 13% and local producers (organic certificate) and 29% of the food bought in local market. Despite that supermarket (large surface) has 19% it is possible to highlight the consumption of local places pointing out the local circularity. The engagement of the city's actors is critical for the building of a regenerative city, particularly in the case of biowaste, it is critical to boost local markets and restaurants, as well as their inclusion in composting programs. This can also happen with government programs or businesses that promote local trade. This is the instance of the Aveiro City Council's previous effort, "Buy from a Local Trade," which included the distribution of a voucher and a drawing for cash rewards. It is likewise the case with applications built in other nations that promote and provide prizes or discounts to individuals who use the program.

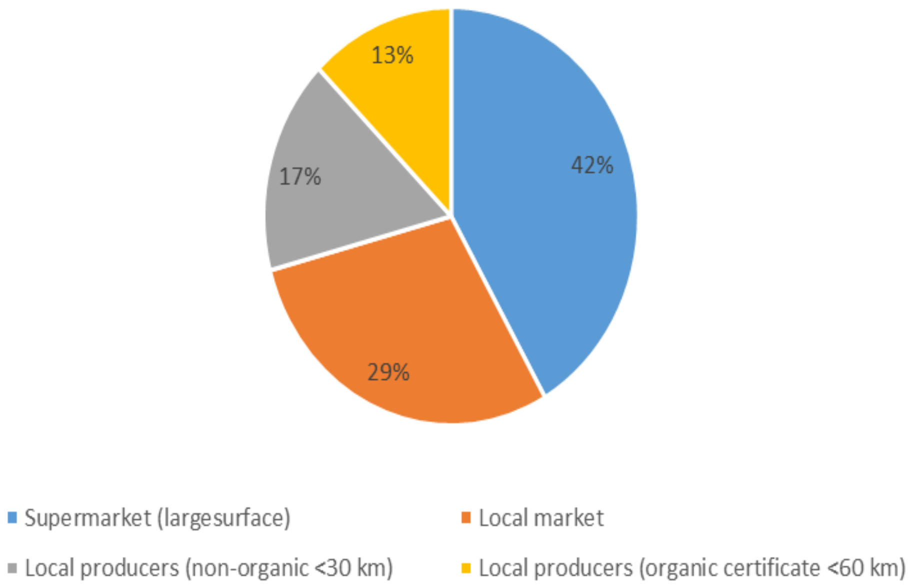

Figure 27. Results to the question “In the case of biowaste from the kitchen, what is the origin of the food that gave rise to it?”.

In the Figure 28 (total of 20 respondents) shows that the answer is balanced between the three options which are: 50% of greens and 50% of brown (30% of the responses), 20% of greens and 80% of browns (35% of the responses) and 80% of greens and 20% of browns (35% of the responses). This situation shows that part of 30% of the respondents are following the best composting practices and that the other 70% still needs training to perform composting in an appropriate manner.

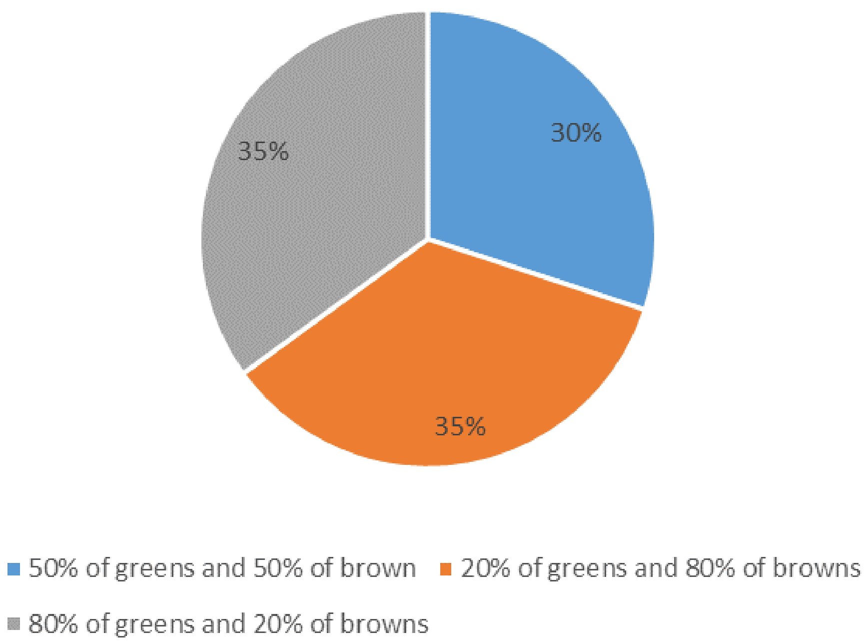

Figure 28. Results to the question “According to the question above, what is the approximate proportion (in %) of each, if any?”.

Figure 29 (total of 20 respondents) illustrates the use of produced compost which could be ''Use in a pot/garden'', ''Use in community garden'' and ''Donation''. In this case, most of the usage for the compost produced is used in pots for plants in the household or even in the garden, with 90% of response, while the use in community garden and donation has 5% each. Thus, it is interesting that most people that compost is mostly used in people´s gardens nearby where the compost is produced. Knowing this can be a game changer in the establishment of public policies that encourage individuals to engage in composting programs or composting themselves. As there are existing situations, mostly in the recycling of materials, and which are becoming more prevalent today with biowaste.

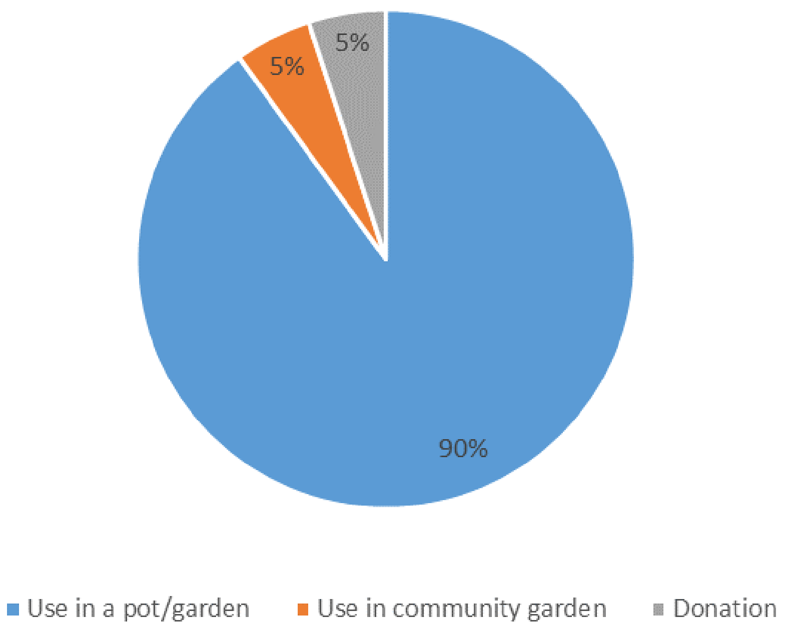

Figure 29. Results to the question "Do you use the produced compost? If yes, briefly describe the application (community garden, at home, among others)".

Figure 30 (total of 41 respondents) shows the results for what motivated people to compost? In this case, 39% of respondents said for environmental benefits, which shows the concern for environmental issues. 29% of respondents said to use the compost in the garden/pots, 25% said to be more connected to earth and 7% for other matters. In SPSS results, the answer "Environmental benefits" is significatively related with people that would take their biowaste to the community composting bin (r=0,465; p=0,039). Here it is possible to understand the importance of environmental education, especially in schools, because the main motivation to compost is "Environmental benefits''. And that is why it is so important to develop public policies to increase environmental awareness.

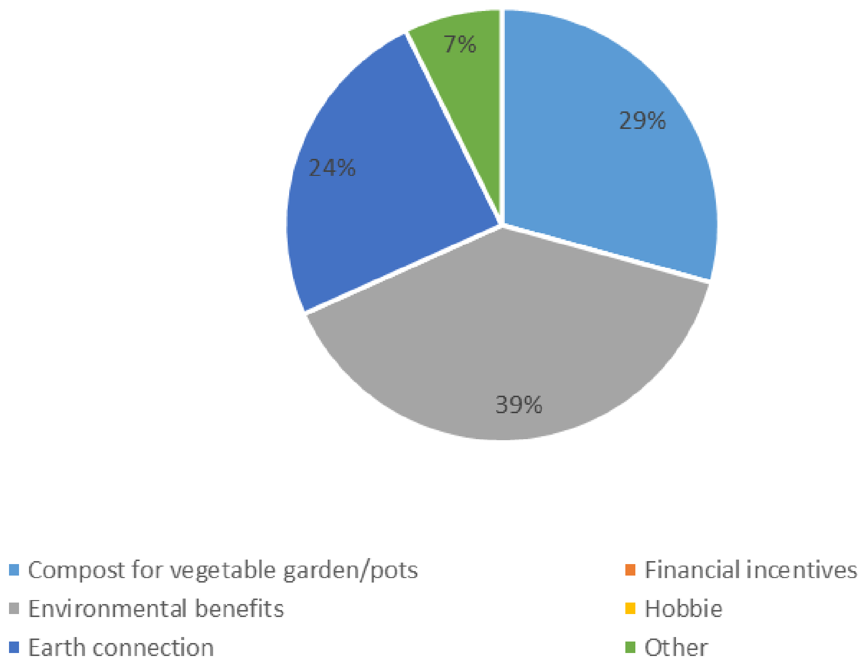

Figure 30. Results to the question “What motivated you to compost?”.

- **Fourth Section of Questions**

For this section the total number of respondents were 38.

The fourth section shows the results of those who in the second section said they don’t compost. The Figure 31 shows the results of the question “Have you ever composted?’’ Even among those who do not compost, 47% have composted in the past, indicating that there is a sizable number of individuals who do not compost but are aware of the procedure. Additionally, 53% of those polled have never composted. As the main limitation for people not to compost is "lack of space", which indicates greater difficulty in composting at home, and therefore the alternative is to invest in more composters or in projects that collect bio-waste, as is the case with Ciclocompost.

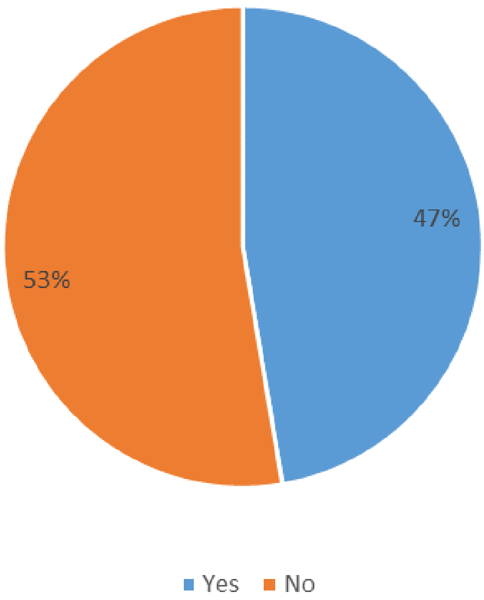

Figure 31. Results to the question “Have you ever composted?’’.

The results of Figure 32 for the question “If you have ever or never done it, what did you consider the biggest barrier/difficulty to compost?” reveals that the major obstacle is bad odors and a lack of space, both with 23%, the emerge of flies with 22%, a lack of time with 17%, discouragement to continue the process with 9%, and other pests with 7%. The SPSS results show, as mentioned before, that the most significant result for those who do not compost is "lack of space" (r=-0,252; p=0,014). And besides that "lack of space" is also related to "lack of knowledge" (r=0,392; p=0,0001). Another significant fact is that those who answered ‘’other pests’’ also answered ‘’increase in flies’’ (r=0,503; p=0,0001) and ‘’bad odors’’ (r=0,383; p=0,0001). And the ‘’discouragement to maintain the process’’ is significantly related to ‘’lack of time’’ (r=0,215; p=0,036). With this information, it is possible to consider possible action strategies. In the case of "lack of time", the ideal is to encourage projects such as Ciclocompost, which collects bio-waste at home, or encourage the implementation of more composters in the city. In the case of "lack of knowledge", "increase in flies", "other pests" and "bad odors", the focus should be on projects that encourage awareness and clarification on the subject, since a composting following certain parameters would hardly develop pests, bad odors and other problems.

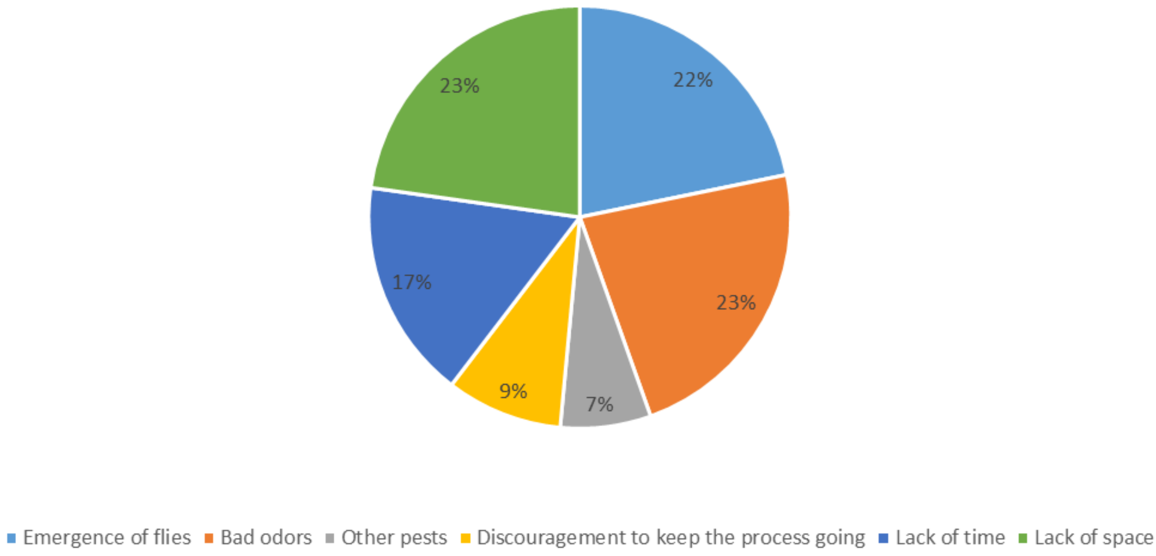

Figure 32. Results to the question “If you have ever or never done it, what did you consider the biggest barrier/ difficulty to compost?”.

Totaling the respondents of the two questionnaires, we have the result that 72% of the respondents do not compost, 26% do compost and 2% already did. Individuals who compost and those who do not differ a lot, demonstrating that it is still a niche practice. Since, as can be seen here, the majority of people do not compost and are very likely to keep doing so if they lack sufficient information, this kind of information is crucial for understanding the implementation of national and international waste guidelines as well as the improvements that can be made in the implementation of new public policies and giving people more training. This demonstrates the need of creating initiatives that inform locals more, like Ciclocompost. The respondents that would be willing to take biowaste to a composting bin in their neighborhood have a significant connection with the motivation ‘’Environmental benefits’’ (r=0,465; p=0,039) and who would not be willing to take has a significant connection with the barrier ‘’lack of knowledge’’ (r=0,366; p=0,0001). For the most part of respondents in the face-to-face questionnaire, they didn’t know much about composting, some even thought that the undifferentiated container was a kind of composting, or that the selective collection was also conducted for biowaste treatment through industrial composting.

For the online questionnaire it is evident that the main group age of respondents is younger (between 18 and 39) and despite that the youngest are the ones with the limitation ‘’discouragement to keep the process’’. The SPSS revealed a significant relationship between gender and age group (r=0,342; p=0,012), with an increase in the proportion of female respondents as the age group rises. Additionally, despite using SPSS with the "gender" and "Do you compost?" questions, the results of the online questionnaire are relevant, demonstrating that more women than males respond positively to composting, this result is almost significant and it is important to mention that there could be a bias. This illustrates that, in this case, women may be effective change agents and active citizens who also support a regenerating city. It is crucial to point the role of families in building a more resilient city, with a focus on children and young people in households, considering the 28% (4 people in the home) and 25% (3 people in the house) and also woman, as said before. Studies show that environmental education is essential for fostering awareness since the smallest children inherit this information from their parents as they grow older (Cortesão, 2017). We may thus conclude that schools play a crucial role, and that the municipality should make greater investments in them to increase awareness. School education must prepare subjects for life in society, and in turn providing them not only with knowledge, but with skills and conscious know-how, education for citizenship must be integrated into the students' school subjects (Cortesão, 2017).

The major reason why more than half of respondents does not compost, according to SPSS results, is "lack of space" (r=0,252; p=0,014) indicating that this is a significant barrier to beginning the composting process. The potential for more composters to be placed strategically across the city as well as biowaste collecting initiatives like Ciclocompost are incentives for this. The most used type of composting is domestic, with 85% while community composting has 10% and the respondents that use both are 5%. Given that biowaste is generated at home and may thus be handled there, it is feasible to explain the trend toward employing home composting. It is more practicable to carry out routinely. 50% of respondents use a car, and 50% use a bike to transport their biowaste. Aveiro is a welcoming city with facilities for biking, walking, and other modes of transportation that might help to improve community composting, and that's why project's like Ciclocompost can work well in a bike friendly city. Due to the relatively great distance from respondents' homes to the compost container, none of them transport their biowaste on foot. 40% of the responses state that it is between 500m and 1km to the community composting bin which may discourage people from bringing their compost. The city should seek to put into practice a plan that entails getting communal composters and arranging them thoughtfully in each neighborhood. For the question "How many kg of biowaste is placed in a week, approximately?" have an approximate total of 23 kg/week produced by the 32 respondents who answered this question, an amount that is diverted to nutrient recycling, as these respondents use home or community composting. First, it is very interesting to check the amount produced and say that this amount is produced by people who compost, so it is a good amount of waste avoided in landfills. Building a regenerative city depends on the participation of the city's stakeholders. In the case of biowaste, it is essential to support neighborhood markets and eateries and include them in composting initiatives. This may also occur with government initiatives or organizations that support local commerce. In this case, the Aveiro City Council's earlier campaign, "Buy from a Local Trade," which featured the distribution of a voucher and a raffle for cash prizes, was being used. The same holds true for programs created in other countries that advertise and offer rewards or discounts to users.

The responses to "Have you ever composted? Even among those who do not compost, 47% had done so in the past, showing that there are numerous people who are aware of the process but do not compost. In addition, 53% of respondents said they had never composted. Because "lack of room" is the biggest reason individuals don't compost, which suggests increasing difficulties with home composting, the alternative is to invest in more composters or in initiatives that collect bio-waste, as is the case with Ciclocompost.

According to the results, "lack of space" is the factor that has the greatest impact on individuals who do not compost. Additionally, "lack of space" and "lack of knowledge" are connected. Another interesting finding is that respondents who selected " other pests " also selected "increase in flies" and "bad odors". And "lack of time" is strongly connected to "discouragement to keep the process". With this knowledge, potential course of action strategies may be thought up. The optimal solution in the event of "lack of time" is to support initiatives like Ciclocompost, which collects bio-waste at homes, or to promote the installation of more composters in the city. The emphasis should be on "lack of understanding," "growth in flies," "other pests," and "poor scents."

5. Conclusion

This thesis followed a holistic approach for analyzing motivations and barriers for the deployment of DCI to support public biowaste management policies in Aveiro and possibly in Portugal in the context of the EU waste framework directive. The methodology applied is based on application of two types of semi-quantitative questionnaires in the form of face-to-face and online surveys, respectively. This work also included analyzing data generated during the Ciclocompost Project by looking at major barriers and motivations for decentralized composting by the citizens of the city of Aveiro. With the Ciclocompost project, 5.5 tons of CO2eq were avoided, 1.2 tons of compost were produced and with that 7 tons of biowaste were diverted from the landfill. This research aimed to give a contribution to raise scientific knowledge about composting behaviors and trends in the city of Aveiro, where it was observed the potential of composting initiatives to enhance circular economy solutions in the urban context that can be disseminated in other cities in Portugal as well as in the Southern European context, supporting the implementation of innovative municipal waste management systems by involving and sensitizing people for enhancing and improving biowaste sorting behaviors as well as decreasing the deposition in landfills.

On this background, the implementation of decentralized biowaste management measures targets at increasing public engagement through local alternatives that contribute to lowering the quantity of waste delivered to centralized collection, transportation, and waste disposal systems, such as landfills, which can be an important contribution to reduce the environmental footprint of citizens living in urban areas. Few studies have documented the potential of DCI to complement municipal waste treatment systems in Portugal.

For this matter, the development of this study in parallel with the Ciclocompost Project (project funded by the participatory budget of the city of Aveiro) consists in a single scientific research involving the collection of real data on citizens behaviors, barriers, and motivations for composting, allowing a better understanding of composting practices and processes in a Portuguese urban context. An important parameter raised in the context of this study was to identify the average generated bio-waste per inhabitant, with an average of 0.437 kg/day.

The face-to-face questionnaire showed a more realistic perspective covering a random set of respondents asking about people perceptions and perspectives about DCI, because this consisted in a campaign conducted in a random way, being able to collect data regarding waste management practices in diverse socio-economic contexts. Some people of the face-to-face questionnaire showed a lot of interest in the subject in the possibility of compost bins being built in the city and near their neighborhoods, but they don't believe in the full participation of the general public at the current stage of societal environmental awareness. Additionally, it was possible to see that some people had awareness of the topic and an interest in the subject. However, for the most part of respondents, they didn't know much about composting, some even thought that the undifferentiated waste they usually dispose in the municipal containers has in end-of-life in waste treatment solutions such as biowaste composting, or that the selective collection is also ending into biowaste treatment through industrial composting.

Another matter that is important to mention as a major conclusion of this study is that, with the questionnaire survey, people that do compost are mostly used to do it at home, probably since biowaste is produced at home, with no need to leave the house to put the biowaste in the community compost bin. However, if the cities had more community compost bins distributed closer to the neighborhoods and households even those that do not compost would think about separating their biowaste and start to sort and compost the biowaste they produce. That is why projects like Ciclocompost are so important for the community, because they demonstrate a way to highlight a topic that citizens, municipalities and governments are still not strongly conscious about. The SPSS statistical analysis of the results also showed significant results especially regarding those that do not compost and the main limitation for those respondents is "lack of space". With the results was possible to see that "lack of space'' relates to "lack of knowledge''. Additionally, it was possible to identify relations between gender and age group and gender with the question ''Do you compost?'', showing that there is a positive relation between respondents that are woman and do more composting. Furthermore, "lack of time" is strongly connected to "discouragement to keep the process". For those who do compost the main motivations for composting are related with the perceived ''environmental benefits' associated with DCI. The identification of the main limitations and motivations that this study highlight was the main goal of this work, and further work is suggested to be conducted to better understand how decision makers and community stakeholders can work together for complement public policies in the domain of biowaste management. This study suggests that future research can generate more knowledge on citizens perspectives for biowaste sorting and treatment, highly contributing to improve the implementation of upcoming biowaste collection and treatment systems in the city of Aveiro in the next years.

The results of this study showed that improvements should be mainly focused on environmental education and public policy management campaigns including decentralized initiatives with citizens such as the Ciclocompost project and other community initiatives taking place in the urban context, aiming at raising citizen awareness and a better understanding about the importance of selective biowaste collection towards both decentralized and centralized composting, which is still a very abstract and relatively unknown subject in most people's routines. Furthermore, a specific focus on environmental education in schools are expected to have a high potential to increase citizens´ awareness. On this background, further scientific research should improve the understanding regarding citizens´ perceptions and participation in community composting initiatives by performing research with a higher amount of citizens and by involving municipalities, as well as supermarkets, industry (e.g. waste collection and treatment companies) and community stakeholders in such work. Additionally, there is a demand for scientific research on studies to characterize the environmental footprint of DCI in relation to centralized biowaste management options. Such studies will be important to show the most sustainable options from an environmental perspective, in order to support decision making to implement and scale-up sustainable circular economy solutions in the scope of biowaste management.

Bibliography

APA, Gestão e Gerenciamento de Resíduos <https://apambiente.pt/sites/default/files/_Residuos/Producao_Gest%C3%A3o_Residuos/Dados%20RU/RARU%202020_V1.pdf> Last seen 20/06/2022

APA. Caracterização e análise dos resíduos urbanos. Available on <https://participa.pt/contents/consultationdocument/Caraterizac%CC%A7a%CC%83o_ana%CC%81lise%20RU_APA.pdf> Last seen 11/04/2022

APA. Produção e Gestão de Resíduos Municipais <https://rea.apambiente.pt/content/municipal-waste-production-and-management?language=en> Last seen 20/06/2022

APA. Webinar sobre Resíduos. Estratégia Nacional para os Biorresíduos <https://ecreshot.ccdr-alg.pt/sites/default/files/2020-12/20201126-APA.pdf> Last seen 20/06/2022

Barrena, Raquel Font, Xavier Gabarrell, Xavier Sánchez, Antoni. Home composting versus industrial composting: Influence of composting system on compost quality with focus on compost stability. Waste Management. Volume 34, Issue 7, July 2014, Pages 1109-1116z

Bernstad, A., & La Cour Jansen, J. (2012). Review of comparative LCAs of food waste management systems - Current status and potential improvements. *Waste Management*, *32*(12), 2439–2455. https://doi.org/10.1016/j.wasman.2012.07.023

Bernstad, A., & La Cour Jansen, J. (2012). Review of comparative LCAs of food waste management systems - Current status and potential improvements. *Waste Management*, *32*(12), 2439–2455. https://doi.org/10.1016/j.wasman.2012.07.023

Bernstad, A.la Cour Jansen, J. A life cycle approach to the management of household food waste - A Swedish full-scale case study. Waste Management 31. 2011.

Chiabi, Lucas Ciclo Orgânico: Um Empreendimento Social, de Compostagem e Gestão de Resíduos. / Lucas Chiabi – Rio de Janeiro: UFRJ/ Escola Politécnica, 2017.

Christiane, Luciana Ramos, Monica Parente Bessa, Ricardo Sigulem, Daniel. (2016). Papel do tratamento mecanico e biologico na gestao de residuos. oai:repositorio-aberto.up.pt:10216/85183

Cortesão, Sara Filipa Bento. 2017. A importância da educação ambiental no ensino básico. Escola Superior de Educação. Coimbra, 2017. https://comum.rcaap.pt/bitstream/10400.26/20012/1/SARA_CORTESAO.pdf?fbclid=IwAR0cIEkQEd0XCLd5fc0-uVPFaRTgzcYwORnIJOn8BOsdW0P4byT_S-SRNu4

Cotta, Jussara Aparecida de Oliveira et al. Compostagem versus vermicompostagem: comparação das técnicas utilizando resíduos vegetais, esterco bovino e serragem. Engenharia Sanitaria e Ambiental [online]. 2015, v. 20, n. 1 [Acessado 11 Outubro 2022] , pp. 65-78. Disponível em: <https://doi.org/10.1590/S1413-41522015020000111864>. ISSN 1809-4457. https://doi.org/10.1590/S1413-41522015020000111864.

Digestive system of an earthworm <https://kids.britannica.com/students/assembly/view/52904>last seen 12/07/2021

EMBRAPA. Compostagem < https://ainfo.cnptia.embrapa.br/digital/bitstream/item/189621/1/CPAF-AP-2018-FDR-Compostagem.pdf> last seen 12/07/2021

EMBRAPA. Minhocultura ou Vermicompostagem**.** Disponível em <https://www.embrapa.br/documents/1355054/1527012/4b+-+folder+Minhocultura+ou+vermicompostagem.pdf/323fbedc-7b3c-4d89-bccd-70b490b8e88b> Last seen 20/06/2022

Fact Sheet Using Bokashi - City of Vincent. Available on <https://www.vincent.wa.gov.au/Profiles/vincent/Assets/ClientData/Documents/Environment/Green_Resources/VIN001000135_A4_BOKASHI_LR.pdf> last seen 12/07/2021

Feliz Mil-Homens, professor do ISEL, assessor da Direção da AVALER. OPINIÃO: "O BALANÇO CARBÓNICO DA VALORIZAÇÃO ENERGÉTICA DE RESÍDUOS URBANOS EM PORTUGAL". Available on <https://www.ambientemagazine.com/opiniao-o-balanco-carbonico-da-valorizacao-energetica-de-residuos-urbanos-em-portugal/> Last seen 11/04/2022

Hoornweg, D., Bhada-Tata, P., 2012. What a Waste: a Global Review of Solid Waste Management. World Bank, Washington, DC, USA.

Inácio, C. T.; Miller, Paul Richard M. Compostagem: ciência e prá tica para a gestão de resíduos orgânicos. Rio de Janeiro: Embrapa Solos, 2009.

Inácio, Caio de Teves. Gas dynamics and methane emissions in composting of organic waste. Rio de Janeiro, 2010. (Dissertation - Master in Science in Environmental Engineering) – Polytechnic School and School of Chemistry. Federal University of Rio de Janeiro, Rio de Janeiro, 2010

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

J. Martínez-Blanco et al. Life cycle assessment of the use of compost from municipal organic waste for fertilization of tomato crops / Resources, Conservation and Recycling 53 (2009) 340–351. 2009

J. Martínez-Blanco et al. The use of life cycle assessment for the comparison of biowaste composting at home and full scale /Waste Management 30 (2010) 983–994. 2010

Jane Kitagawa. How to compost in a cardboard box at home. June 28, 2020. Available on <https://www.japantimes.co.jp/life/2020/06/28/food/how-to-compost-cardboard-box/> last seen 12/07/2021

Keng, Zi Xiang Chong, Siewhui Ng, Chee Guan Ridzuan, Nur Izzati Hanson, Svenja Pan, Guan Ting Lau, Phei Li Supramaniam, Christina Vimala Singh, Ajit Chin, Chiew Foan Lam, Hon Loong. Community-scale composting for food waste: A life-cycle assessment-supported case study. Journal of Cleaner Production 261, 2020.

Khandelwal, H., Dhar, H., Thalla, A. K., & Kumar, S. (2019). Application of life cycle assessment in municipal solid waste management: A worldwide critical review. *Journal of Cleaner Production*, *209*, 630–654. https://doi.org/10.1016/j.jclepro.2018.10.233

Khandelwal, H., Dhar, H., Thalla, A. K., & Kumar, S. (2019). Application of life cycle assessment in municipal solid waste management: A worldwide critical review. *Journal of Cleaner Production*, *209*, 630–654. https://doi.org/10.1016/j.jclepro.2018.10.233

KIEHL, E. J. Manual de Compostagem: maturação e qualidade do composto. Piracicaba,:E. J. Kiehl, 1998.

Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., Hauschild, M.Z., Christensen, T.H., 2014. Review of LCA studies of solid waste management systems - Part I: lessons learned and perspectives. Waste Manag. 34, 573e588. https://doi.org/10.1016/j.wasman.2013.10.045.

Diretiva 2008/98/CE. Legislação da UE em matéria de gestão de resíduos <https://eur-lex.europa.eu/legal-content/PT/TXT/?uri=legissum:ev0010> last seen 12/08/2022

Lim, P.N., Wu, T.Y., Sim, E.Y.S., Lim, S.L., 2011. The potential reuse of soybean husk as feedstock of Eudrilus eugeniae in vermicomposting. J. Sci. Food Agric. 91, 2637e2642.

Lim, S. L., Lee, L. H., & Wu, T. Y. (2016, January 10). Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: Recent overview, greenhouse gases emissions and economic analysis. Journal of Cleaner Production. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2015.08.083

Lim, S.L.,Wu, T.Y.,Sim,E.Y.S., Lim, P.N.,Clarke, C.,2012. Biotransformation of rice husk into organic fertilizer through vermicomposting. Ecol. Eng. 41, 60e64.

M. Schwarz & J. Bonhotal (2018) Carbon Footprint of a University Compost Facility: Case Study of Cornell Farm Services, Compost Science & Utilization, 26:2, 128-143, DOI: 10.1080/1065657X.2018.1438934

Manual adaptado de MEIRA, A. M.; CAZZONATTO, A. C.; SOARES, C. A**.** Manual básico de compostagem – série: conhecendo os resíduos. Piracicaba, USP Recicla, 2003, com contribuições de: Anne Caroline Malvestio Caio Souza Pires Fernando William Ka Heng Mo Giulio de Manincor Capestrani.

Margallo, M. Aldaco, R. Irabien, A. Carrillo, V. Fischer, M. Bala, A. Fullana, P. Life cycle assessment modelling of waste-to-energy incineration in Spain and Portugal. Waste Management & Research 2014, Vol. 32(6) 492 –499.

Metz, L. H. Construção de um biodigestor caseiro para demonstração de produção de biogás e biofertilizante em escolas situadas em meios urbanos. 2013. Monografia apresentada á Universidade Federal de Lavras, Minas Gerais.

Oliveira E., Sartori R., Garcez T. (2008). COMPOSTAGEM. Universidade de São Paulo, Piracicaba, São Paulo.

Peixoto, J. O. Destinação final de resíduos, nem sempre uma opção econômica. Engenharia Sanitária, (1): 15-18, 1981.

PERSU 2030 <https://participa.pt/contents/consultationdocument/PERSU%202030.pdf> Last seen 20/06/2022

Estatísticas sobre Portugal e Europa. PORDATA <https://www.pordata.pt/Portugal/Res%c3%adduos+urbanos+total+e+por+tipo+de+opera%c3%a7%c3%a3o+de+destino-1105-9533> Last seen 20/06/2022

Rola M. O. R.; SILVA R. F. da. Vantagens da vermicompostagem sobre a compostagem tradicional. Revista F@pciência, Apucarana-PR, ISSN 1984-2333, v.10, n. 1, p. 40 – 48, 2014 40

Seadon, J.K., (2006). Integrated waste management – looking beyond the solid waste horizon. Waste Management 26 (12), 1327-1336.

Sempiterno C. Compostagem . INIAV, I.P. Technical File. Vida Rural. 2016

Silva J D P da (2016). Papel do Tratamento Mecânico e Biológico na Gestão de Resíduos. Master Thesis in Environmental Engineering. Department of Engineer - Porto University.

Siqueira T.; ASSAD M. Compostagem de resíduos sólidos urbanos no estado de São Paulo (Brasil). Ambiente &Sociedade. São Paulo v. 28, n. 4, p 243-264, 2015.

Solino, ATMAN COUTINHO Análise de Modelos e Técnicas de Compostagem para o Gerenciamento dos Resíduos Sólidos Domiciliares Orgânicos. [Distrito Federal] 2018.

Themelis, N.J., Ulloa, P.A., 2007. Methane generation in landfills. Renew. Energy 32 (7), 1243–1257.

Vieira M. I. 1995. Criação de Minhocas. 1 Edição 1. Prata Editora e Distribuidora LTDA. São Paulo.

Weetman, Catherine. Economia circular: conceitos e estratégias para fazer (Khandelwal et al., 2019)negócios de forma mais inteligente, sustentável e lucrativa/ Catherine Weetman; tradução Afonso Celso da Cunha Serra. -- 1. ed. -- São Paulo: Autêntica Business; 2019.

Yusoff MSB, Arifin WN, Hadie SNH. ABC of questionnaire development and validation for survey research. Education in Medicine Journal. 2021;13(1):97–108. https://doi. org/10.21315/eimj2021.13.1.10

ANNEX

ANNEX I. Model of structure of the face-to-face questionnaire

1. É DE AVEIRO?
2. FAZ COMPOSTAGEM?
    a. SIM
        i. COMUNITÁRIA
        ii. DOMÉSTICA
    b. NÃO
        i. QUAL FOI O IMPEDIMENTO
        ii. SE TIVESSE NO SEU BAIRRO, FARIA?
    c. JÁ FIZ, MAS DESISTI
        i. POR QUE?

ANNEX II. Model of structure of the online questionnaire

Questionário - sustentabilidade da compostagem comunitária

Este questionário está a ser realizado pela aluna de mestrado da Universidade de Aveiro Fernanda Almeida com a colaboração do Professor José Martins e o investigador em Pós-Doutoramento Ricardo Carvalho no contexto do trabalho desenvolvido pelo coletivo de agroecologia (hortua).

O objetivo do estudo é identificar os projetos de compostagem e analisar a sua sustentabilidade, com o objetivo de avaliar os benefícios desta opção de valorização de resíduos e reciclagem de nutrientes no âmbito da tese de mestrado em Biologia Aplicada.

*Obrigatório

Sem título

Sem título

Primeira Parte

1. 1. Qual seu grupo etário? *

Marcar apenas uma oval.

- ◯ 18-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60 ou mais

2. 2. Sexo *

Marcar apenas uma oval.

- Feminino
- Masculino
- Prefiro não responder

3. 3. Número de pessoas no alojamento? *

Marcar apenas uma oval.

- 1
- 2
- 3
- 4
- 5
- Outro: ____________

4. 4. Vive na cidade de Aveiro? *

Marcar apenas uma oval.

- Sim
- Não

5. 5. Faz a separação de todos os resíduos que gera? *

Marque todas que se aplicam.

- [ ] Papel/cartão
- [ ] Vidro
- [ ] Plástico/metal
- [ ] Bioresíduo
- [ ] Não faço separação

6. 6. Se na sua freguesia existisse um compostor comunitário. você estaria disposto a levar seus bioresiduos até ele? *

Marcar apenas uma oval.

- Sim
- Não
- Depende

Segunda Parte?

7. 1. Faz compostagem? *

Marcar apenas uma oval.

- Sim *Pular para a pergunta 8*
- Não *Pular para a pergunta 21*

Terceira Parte

8. 1. Qual a sua escolaridade? *

Marcar apenas uma oval.

- Ensino básico
- Ensino secundário
- Ensino Superior

9. 2. Qual compostor utiliza? *

Marque todas que se aplicam.

- [ ] Doméstico
- [ ] Comunitário
- [ ] Os dois tipos
- [ ] Outros

10. 3. Se outros, indicar quais:

____

11. 4. Qual técnica de compostagem aplicada? *

Marcar apenas uma oval.

- ( ) Termófila simples (compostagem comum)
- ( ) Vermicompostagem
- ( ) Outros

12. 5. No caso de fazer compostagem em compostor comunitário ou direta em espaço aberto (p.e. na horta), os resíduos são levados como?

Marcar apenas uma oval.

- ( ) De automóvel
- ( ) De bicicleta
- ( ) A pé
- ( ) Outro: _______________________________

13. 6. No caso de fazer compostagem comunitária, qual seria a distância aproximada entre sua casa e o compostor (em metros)?

Marcar apenas uma oval.

- ( ) Menos de 100 m
- ( ) Entre 100 e 500 m
- ( ) Entre 500 e 1 km
- ( ) Mais de 1 km

14. 7. Quantos kg de resíduo orgânico é colocado em uma semana, aproximadamente? *

Marcar apenas uma oval.

- ( ) 300g - 700g
- ( ) 800g - 1,2kg
- ( ) 1,3kg - 1,7kg
- ( ) Mais de 2kg
- ( ) Outro: ________

15. 8. Qual a origem do bioresíduo mais gerado? *

Marque todas que se aplicam.

- [ ] Cozinha
- [ ] Jardim
- [ ] Outros

16. 9. No caso dos bioresíduos da cozinha, qual a proveniência dos alimentos que lhes deram origem? *

Marque todas que se aplicam.

- [ ] Supermercado (grande superfície)
- [ ] Mercado local (pequenos supermercados, mercados municipais)
- [ ] Produtores locais (não biológico <30 kms)
- [ ] Produtores locais (biológico certificado <60 kms)

17. 10. De acordo com a questão acima, qual a proporção aproximada (em %) de cada um, se for o caso?

Marcar apenas uma oval.

- ( ) 50% de verdes (p.e. cascas, restos legumes) e 50% de castanhos (p.e. folhas secas, palha)
- ( ) 20% de verdes e 80% de castanhos
- ( ) 80% de verdes e 20% de castanhos

18. 11. Usa o composto produzido? Se sim, descreva brevemente a aplicação (horta comunitária, em casa, entre outros) *

Marque todas que se aplicam.

- [ ] Uso em vaso/horta própria
- [ ] Uso em horta comunitária
- [ ] Doação
- [ ] Venda
- [ ] Outro: ______________________

19. 12. O que o motivou a fazer compostagem? *

Marque todas que se aplicam.

- [ ] Composto para horta/vasos
- [ ] Incentivos financeiros
- [ ] Benefícios ambientais
- [ ] Hobbie
- [ ] Ligação à terra
- [ ] Outro: ______________________

20. 13. Caso tenha optado por "outros" na questão anterior, descreva brevemente

____

Quarta Parte

21. 1. Já fez alguma vez compostagem?

Marcar apenas uma oval.

- ( ) Sim
- ( ) Não

22. 2. Se já fizeste alguma vez ou então nunca fez, o que considerou a maior barreira/dificuldade para compostar? *

Marque todas que se aplicam.

- [ ] Surgimento de moscas
- [ ] Maus odores
- [ ] Outras pragas
- [ ] Desânimo para manter o processo
- [ ] Falta de tempo
- [ ] Falta de espaço
- [ ] Outro: ____________________

23. 3. Caso tenha optado por "outros" nas questões anteriores, descreva brevemente *

____

ANNEX III. Pictures of the Ciclocompost project during it's implementation.

ANNEX IV. Significance SPSS data for the intersected data for the union of the online and face-to-face questionnaires (in page 67).

							Motivations					Limitations										
		Do_Compost	type_composter	from_Aveiro	Gender	Age_group	garden_vase	Environmental benefits	ground_connection	less_landfill	others	Lack_of_space	Lack_of_time	lack_of_knowledge	Never_thought_about_it	Emergence_of_flies	Bad_odors	Other_pests	Discouragement_to_keep	Others	Would_take_to_composting_bin	online
Do_Compost	r	1,000		-,268**	0,258	0,225						-,252*	0,113	-0,129	-0,093	0,177	0,036	-0,028	0,122	0,075	0,002	,278**
	Sig			0,006	0,063	0,105						0,014	0,274	0,212	0,369	0,087	0,729	0,788	0,238	0,468	0,985	0,004
	N	105	27	105	53	53	20	20	20	20	20	95	95	95	95	95	95	95	95	95	100	105
type_composter	r		1,000	0,171	-0,196	0,237	0,419	-0,303	0,419	-0,096	0,303	-0,209	0,015	0,303		0,293	-0,242	-0,096	-0,176	0,196	0,140	0,018
	Sig			0,395	0,409	0,315	0,066	0,195	0,066	0,687	0,195	0,376	0,949	0,195		0,210	0,304	0,687	0,458	0,409	0,523	0,931
	N	27	27	27	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	23	27
from_Aveiro	r	-,268**	0,171	1,000	-0,152	0,099	-0,408	0,272	0,000	0,281	0,068	0,051	-0,043	0,179	0,108	-0,102	-,373**	-,238*	-,249*	0,049	-,289**	-,568**
	Sig	0,006	0,395		0,277	0,481	0,074	0,246	1,000	0,230	0,776	0,626	0,678	0,082	0,298	0,326	0,000	0,020	0,015	0,636	0,004	0,000
	N	105	27	105	53	53	20	20	20	20	20	95	95	95	95	95	95	95	95	95	100	105
Gender	r	0,258	-0,196	-0,152	1,000	,342*	-0,140	-0,140	-0,140	0,096	0,140	0,124	-0,068	-0,083		0,013	0,039	0,110	-0,062	-0,103	0,017	
	Sig	0,063	0,409	0,277		0,012	0,556	0,556	0,556	0,686	0,556	0,381	0,630	0,557		0,926	0,783	0,436	0,661	0,466	0,905	
	N	53	20	53	53	53	20	20	20	20	20	52	52	52	52	52	52	52	52	52	53	53
Age_group	r	0,225	0,237	0,099	,342*	1,000	0,009	-0,262	0,268	0,042	0,262	0,240	-0,076	0,200		-0,050	-0,144	-0,077	-,309*	-0,060	0,021	
	Sig	0,105	0,315	0,481	0,012		0,969	0,265	0,253	0,859	0,265	0,087	0,591	0,154		0,723	0,308	0,589	0,026	0,675	0,882	
	N	53	20	53	53	53	20	20	20	20	20	52	52	52	52	52	52	52	52	52	53	53
garden_vase	r		0,419	-0,408	-0,140	0,009	1,000	-0,333	,600**	-0,229	0,000	0,250	-0,218	0,333		0,105	0,115	0,229	-0,420	-0,140	-0,080	
	Sig		0,066	0,074	0,556	0,969		0,151	0,005	0,331	1,000	0,288	0,355	0,151		0,660	0,628	0,331	0,065	0,556	0,738	
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Environmental benefits	r		-0,303	0,272	-0,140	-0,262	-0,333	1,000	-0,333	0,076	-,444*	-0,250	-0,145	-,444*		0,245	-0,192	0,076	0,140	0,140	,465*	
	Sig		0,195	0,246	0,556	0,265	0,151		0,151	0,749	0,050	0,288	0,541	0,050		0,299	0,416	0,749	0,556	0,556	0,039	
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
ground_connection	r		0,419	0,000	-0,140	0,268	,600**	-0,333	1,000	-0,229	0,000	0,250	0,000	0,333		0,314	0,115	-0,229	-0,420	-0,140	-0,438	
	Sig		0,066	1,000	0,556	0,253	0,005	0,151		0,331	1,000	0,288	1,000	0,151		0,177	0,628	0,331	0,065	0,556	0,053	
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
less_landfill	r		-0,096	0,281	0,096	0,042	-0,229	0,076	-0,229	1,000	-0,076	,459*	-0,150	-0,076		-0,168	-0,132	-0,053	-0,096	-0,096	0,183	
	Sig		0,687	0,230	0,686	0,859	0,331	0,749	0,331		0,749	0,042	0,527	0,749		0,478	0,578	0,826	0,686	0,686	0,440	
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
others	r		0,303	0,068	0,140	0,262	0,000	-,444*	0,000	-0,076	1,000	-0,167	,509*	,444*		-0,245	-0,192	-0,076	-0,140	0,327	-0,033	
	Sig		0,195	0,776	0,556	0,265	1,000	0,050	1,000	0,749		0,482	0,022	0,050		0,299	0,416	0,749	0,556	0,160	0,889	
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Lack_of_space	r	-,252*	-0,209	0,051	0,124	0,240	0,250	-0,250	0,250	,459*	-0,167	1,000	-0,096	-,392**	-0,161	-0,044	0,088	0,030	-0,194	-0,167	0,119	-0,085
	Sig	0,014	0,376	0,626	0,381	0,087	0,288	0,288	0,288	0,042	0,482		0,356	0,000	0,120	0,674	0,398	0,771	0,060	0,105	0,250	0,414
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
Lack_of_time	r	0,113	0,015	-0,043	-0,068	-0,076	-0,218	-0,145	0,000	-0,150	,509*	-0,096	1,000	-0,194	-0,093	0,050	-0,026	-0,028	,215*	-0,093	-0,040	,314**
	Sig	0,274	0,949	0,678	0,630	0,591	0,355	0,541	1,000	0,527	0,022	0,356		0,060	0,369	0,630	0,801	0,788	0,036	0,370	0,703	0,002
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
lack_of_knowledge	r	-0,129	0,303	0,179	-0,083	0,200	0,333	-,444*	0,333	-0,076	,444*	-,392**	-0,194	1,000	-0,090	-,258*	-,266**	-0,130	-0,152	-0,171	-,366**	-,444**
	Sig	0,212	0,195	0,082	0,557	0,154	0,151	0,050	0,151	0,749	0,050	0,000	0,060		0,384	0,012	0,009	0,210	0,142	0,097	0,000	0,000
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
Never_thought_about_it	r	-0,093		0,108								-0,161	-0,093	-0,090	1,000	-0,093	-0,096	-0,047	-0,055	-0,062	-0,169	-0,199
	Sig	0,369		0,298								0,120	0,369	0,384		0,369	0,354	0,652	0,598	0,551	0,102	0,054
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
Emergence_of_flies	r	0,177	0,293	-0,102	0,013	-0,050	0,105	0,245	0,314	-0,168	-0,245	-0,044	0,050	-,258*	-0,093	1,000	,596**	,503**	0,029	-0,093	,257*	,470**
	Sig	0,087	0,210	0,326	0,926	0,723	0,660	0,299	0,177	0,478	0,299	0,674	0,630	0,012	0,369		0,000	0,000	0,778	0,370	0,012	0,000
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
Bad_odors	r	0,036	-0,242	-,373**	0,039	-0,144	0,115	-0,192	0,115	-0,132	-0,192	0,088	-0,026	-,266**	-0,096	,596**	1,000	,383**	0,113	-0,100	0,156	,484**
	Sig	0,729	0,304	0,000	0,783	0,308	0,628	0,416	0,628	0,578	0,416	0,398	0,801	0,009	0,354	0,000		0,000	0,278	0,335	0,132	0,000
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
Other_pests	r	-0,028	-0,096	-,238*	0,110	-0,077	0,229	0,076	-0,229	-0,053	-0,076	0,030	-0,028	-0,130	-0,047	,503**	,383**	1,000	0,077	-0,089	,253*	,236*
	Sig	0,788	0,687	0,020	0,436	0,589	0,331	0,749	0,331	0,826	0,749	0,771	0,788	0,210	0,652	0,000	0,000		0,458	0,391	0,013	0,021
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
Discouragement_to_keep	r	0,122	-0,176	-,249*	-0,062	-,309*	-0,420	0,140	-0,420	-0,096	-0,140	-0,194	,215*	-0,152	-0,055	0,029	0,113	0,077	1,000	-0,104	0,151	,276**
	Sig	0,238	0,458	0,015	0,661	0,026	0,065	0,556	0,065	0,686	0,556	0,060	0,036	0,142	0,598	0,778	0,278	0,458		0,316	0,144	0,007
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
Others	r	0,075	0,196	0,049	-0,103	-0,060	-0,140	0,140	-0,140	-0,096	0,327	-0,167	-0,093	-0,171	-0,062	-0,093	-0,100	-0,089	-0,104	1,000	,204*	0,105
	Sig	0,468	0,409	0,636	0,466	0,675	0,556	0,556	0,556	0,686	0,160	0,105	0,370	0,097	0,551	0,370	0,335	0,391	0,316		0,048	0,310
	N	95	20	95	52	52	20	20	20	20	20	95	95	95	95	95	95	95	95	95	95	95
Would_take_to_composting_bin	r	0,002	0,140	-,289**	0,017	0,021	-0,080	,465*	-0,438	0,183	-0,033	0,119	-0,040	-,366**	-0,169	,257*	0,156	,253*	0,151	,204*	1,000	,394**
	Sig	0,985	0,523	0,004	0,905	0,882	0,738	0,039	0,053	0,440	0,889	0,250	0,703	0,000	0,102	0,012	0,132	0,013	0,144	0,048		0,000
	N	100	23	100	53	53	20	20	20	20	20	95	95	95	95	95	95	95	95	95	100	100
online	r	,278**	0,018	-,568**								-0,085	,314**	-,444**	-0,199	,470**	,484**	,236*	,276**	0,105	,394**	1,000
	Sig	0,004	0,931	0,000								0,414	0,002	0,000	0,054	0,000	0,000	0,021	0,007	0,310	0,000	
	N	105	27	105	53	53	20	20	20	20	20	95	95	95	95	95	95	95	95	95	100	105