



## Selective collection of bio-waste in a non-intensive urban region – Producers' characterization

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### ABSTRACT

The European circular economy targets and waste policies have gradually focused on bio-waste, which is considered one of several key waste streams and is urgently needed to develop strategies for their selective collection. In non-intensive urban regions, a selective collection is a challenge due to the dispersion of bio-waste producers. This work intended to characterize the bio-waste producers, in Planalto Beirão region (Portugal) and define strategies for their management. Planalto Beirão is a non-intensive urban region in the center of Portugal composed of 19 municipalities. The methodology involved collecting data from non-domestic bio-waste producers in Portuguese databases. The data of non-domestic producers were divided into 4 categories: HORECA sector (hotels, restaurants and coffee shops), Food commerce (wholesale and retail sale), Tea houses and Social services (education and activities in social support with and without accommodation).

The analyzed data from the 4 categories of non-domestic bio-waste producers indicated that hotels, restaurants and coffee shops represented 46% of producers, followed by Food commerce, Social services and Tea houses with 33%, 17% and 4%, respectively. Viseu was determined as the municipality with the highest potential to implement a successful selective collection of bio-waste. In the Planalto Beirão region, the selective collection from non-domestic bio-waste producers must be done door-to-door, in higher-density areas. In rural areas, valorization should be introduced locally by the producers or the community.

### 1. Introduction

Waste management in the European Union (EU) should be improved with sustainable management, to protect, preserve and improving the quality of the environment, human health, the efficient and rational exploration of natural resources, the use of renewable energy, providing new economic opportunities and promoting the principles of a circular economy. To implement a circular economy, it is necessary to establish measures on sustainable production and consumption, by focusing on the life cycle of products in a way that preserves resources and prioritizes a closed loop. Efficient use of resources would also bring substantial profit for businesses, public authorities, and consumers while reducing total annual greenhouse gas emissions. Therefore, European circular economy and waste policies increasingly focus on bio-waste as one of several key waste streams. These include new collection targets for the reutilization and recycling of urban bio-waste and the obligation to collect differentiated bio-waste. Bio-waste accounts for more than

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34% of urban waste generated, amounting 86 million tonnes in 2017 in the EU (EEA and European Environment Agency, 2020). Bio-waste is essentially green waste and food waste that has considerable potential to contribute to the circular bioeconomy, namely by the production of fertilizers, soil correctors and non-fossil fuels (EC and European Commission, 2015). Under EU's circular economy action plan, efforts to use bio-waste as a resource have gained additional interest, with the development of new technical innovations, going beyond the current end products of bio-waste treatment, such as biogas and compost (EC and European Commission, 2015).

In the European Directive 2018/98/EC of May 30th, the target regarding bio-waste management is that by December 31, 2023, this fraction of waste should either be separated and recycled at the source, or be collected separately from other types of waste. To reach these goals, in the Portuguese Strategic Plan for Municipal Solid Waste 2020 (APA and Agência Portuguesa do Ambiente, 2020a) there are a set of targets to increase recycling by 55%, 60% and 65% until 2025, 2030 and 2035, respectively. Furthermore, it proposes a change in the method for calculating recycling rates and a new guideline for landfilling, only inert materials without the possibility of recovery can be lodged, in a maximum of 10% of the wastes produced (APA and Agência Portuguesa do Ambiente, 2020b).

The collection process is one of the most relevant in this bio-waste management, due to both the cost and the potential impact on the quantity of bio-waste from the urban/rural areas. The levels of differentiated bio-waste collected differ considerably across Europe, and it has been implemented in some areas for more than 20 years (Di Maria et al., 2020). However, many countries are far from capturing the full potential of bio-waste (EEA and European Environment Agency, 2020). Portugal is one of these countries, where the bio-waste separation collection is scarce and must be significantly increased to reach the European goals. According to Di Maria et al. (Di Maria et al., 2020), depending on several socio-economic aspects, different processes were adopted for this important phase of waste management such as road, proximity, and door-to-door collection. Road collection refers to the use of large containers, up to 3000 L, able to serve many users, positioned in specific areas along main roads. This is the lowest cost strategy due to the rapid collection rate and the reduced number of operators and trucks involved (large size up to 30 m<sup>3</sup>) (Di Maria and Micale, 2013). Due to many factors such as the lack of adequate control and possibly the need for residents to transport bio-waste in bags, the percentage of impurities in the biowaste is superior in road collection. Thus, the planning of waste collection models requires information on environmental impacts, economic indicators, technical aspects and efficiencies, to understand the best collection strategy to implement it (Rodrigues et al., 2016). Moreover, several key factors of the bio-waste collection and treatment options should be considered (Gomes and Silveira, 2014): social factors, since it is the population that does the separation at source; cultural influences; building typology; selection of deposition equipment, among others. According to the Portuguese Environment Agency (PEA), there is a need to collect this type of waste at large producers as there is a higher rate of capture with reduced contamination (APA and Agência Portuguesa do Ambiente, 2019).

The Association of Municipalities of the Planalto Beirão Region (AMPBR) is an inter-municipal system in Portugal, representing 19 municipalities of Viseu, Guarda and Coimbra districts, which manage the collection, treatment, and valorization of waste in these regions. The AMPBR has an organic recovery plant that is dimensioned to receive and valorize 130 000 tonnes of urban waste per year. This plant has a pre-treatment and sorting line with the purpose of recovering a significant number of materials with recyclable potential. With the new goals, it is expected that beyond 2023 the bio-waste produced from domestic and non-domestic producers in the AMPBR region will be separately collected, with the expected improvement of the quality and quantity of the final products resulting from organic valorization. With the present work, it was intended to characterize the non-domestic bio-waste producers in the Planalto Beirão region (Portugal) and define strategies for its selective collection or local treatment, according to their location and amount of bio-waste produced. With this information will be possible to achieve the reduction target to be met by 2030 of wastes deposition in landfill, and increase of the re-use and the recycling of municipal waste.

## 2. Methodology

The methodology to carry out the study was divided in two tasks. First, the economic activities of non-domestic producers, equivalent to domestic producers, were identified. Then, a survey was conducted in Portuguese databases such as SABI, between January and March 2021, to collect all the important information from the producers to plan the feasible bio-waste collection. SABI is a platform that contains comprehensive information on companies in Portugal and Spain, which permits simplified research by imputing

**Table 1**  
Description of Economic Activity Codes (EAC) selected as having high production of bio-waste.

Sector	EAC	Description
HORECA	551	Hotel Establishments
	561	Restaurants
	562	Provision of meals
	56301	Coffees
Food Commerce	461	Wholesale agents
	462	Wholesale of raw agricultural products and live animals
	463	Wholesale of food, beverages, and tobacco products
	471	Retail trade in non-specialized establishments
	472	Retail sale of food, beverages, and tobacco in specialized establishments
Social Services	87	Social support activities with accommodation
	88	Social support activities without accommodation
	85	Education Institutions
Tea houses	56303	Pastries shops and teahouses

variables of interest to the study. From SABI platform, detailed data, such as, location, district, number of employees and contact information of companies was obtained by filtering general information with the geographic location of the area of intervention of the AMPBR. The non-domestic bio-waste producers were divided into four categories: the HORECA sector (hotels, restaurants, and coffee shops), the Food Commerce sector (wholesale, retail sale), Tea Houses sector and Social Services sector (education and social support activities). Each of the 4 categories includes several economic activities with a code as described in Table 1, that were selected because of their specific production of organic waste.

The database was developed to provided a total number of establishments from the 19 municipalities (Aguai da Beira, Carregal do Sal, Castro Daire, Gouveia, Mangualde, Mortágua, Nelas, Oliveira de Frades, Oliveira do Hospital, Penalva do castelo, Santa Comba Dão, São Pedro do Sul, Sátão, Seia, Tábua, Tondela, Vila Nova de Paiva, Viseu e Vouzela), with the potential of bio-waste production in higher amounts relatively to domestic producers. The location of each company, which was also collected, allowed the development of collection and transport methods considering geographical characteristics, industrialization and population density.

Thematic charts were built in a GIS (Geographical Information System) environment, using the QGIS application, version 3.10.14. SRC ETRS89\_PT\_TM06 was considered, according to the recommendations of the General Directorate of the Territory, to elaborate cartography in mainland Portugal.

### 3. Results

The municipalities need to develop strategies to recover all the valuable content from urban wastes. From paper or cardboard to plastic, glass or metallic wastes and organic matter, all these fractions must be recovered. If the former fractions have been selectively collected for several years, the same effort should be applied to bio-waste. The maximum recovery of bio-waste collected separately from urban waste will increase the AMPBR organic recovery plant productivity, resulting in higher biogas production and the optimization of the end product - an organic fertilizer, to be reintroduced in a circular economy system.

The region under study, Fig. 1, is mostly rural, located in the interior of Portugal, with 348 876 inhabitants, along an area of 4660 km<sup>2</sup> (INE Instituto Nacional de Estatística, 2011). The population density in the AMPBR region is approximately 75 inhabitants/km<sup>2</sup>, except for Viseu, with 28% of the area's population (97 207 inhabitants), with 191 inhabitants/km<sup>2</sup>. In Portugal, there is no specific legal definition for low-density territories with the assumption of a multicriteria based on population density (demography, settlement), territories' physical characteristics, accessibilities, or the population per capita economic income. All the municipalities under study, except Viseu, are classified as low density (CIC Comissão Interministerial de Coordenação, 2015).

Other than Viseu, the municipalities of Tondela, Seia, Oliveira do Hospital and Mangualde, are more representative in terms of population density, with 8.2%, 6.8%, 6.0% and 5.7% of the inhabitants of the region, respectively. The municipalities with lower population density are Penalva do Castelo, with 2.2%, Aguiar da Beira, with 1.5% and Vila Nova de Paiva, with 1.4% of the population. Moreover, while these municipalities have the lowest territorial occupation, they are the municipalities furthest from the waste treatment plant, once the AMPBR treatment plant is in Tondela. This implies the need for the transportation of bio-waste over longer distances, which can bring an additional economic challenge (Fig. 1b).

Also, the high or low population density influence the number of economic activities in the different municipalities. Given that, it may be assumed that Viseu will also have more non-domestic bio-waste producers.

Following the definition given by the European Directive 2018/98/EC of May 30th, 2018, biowaste is understood as the

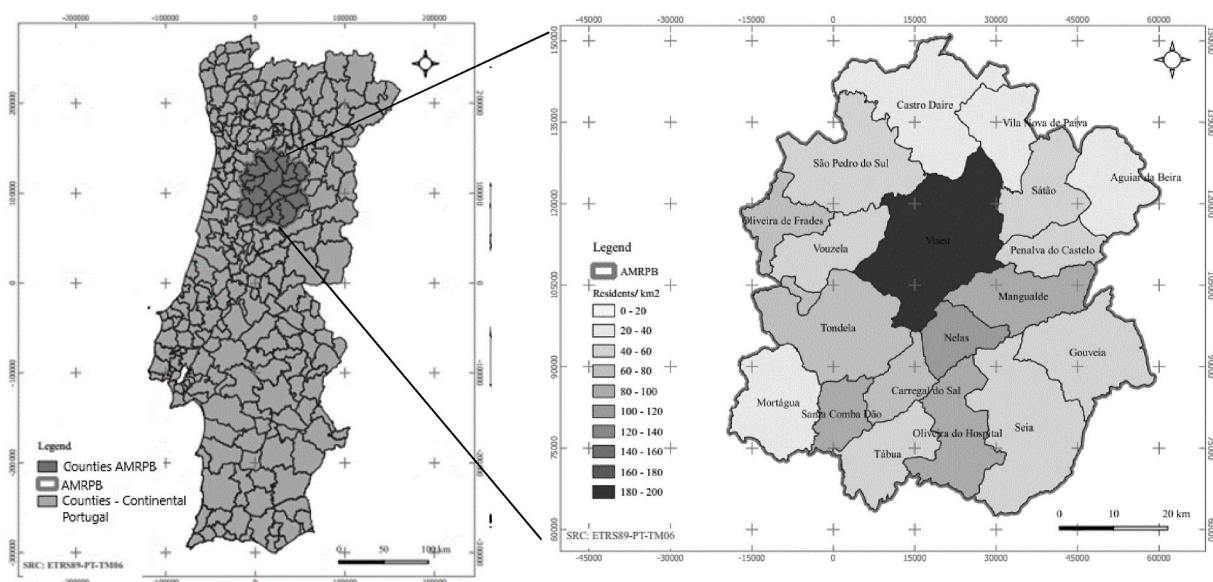


Fig. 1. Representation of the region under study: (a) localization in Portugal; (b) definition of the evolved municipalities and the population density.

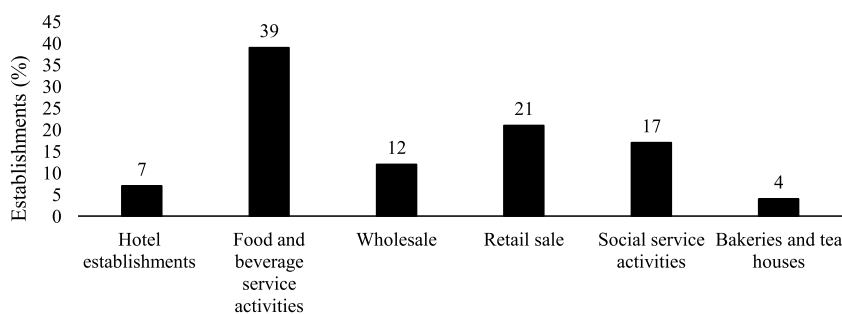


Fig. 2. Representativity of the economic activities under study in Planalto Beirão region.

“biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants”. Bio-waste is the major component of urban waste in the EU, and about 60% of bio-waste is food waste (EEA, 2020). For this work, the focus was food waste. According to the 2019 annual report on urban waste from the Portuguese Environment Agency (APA and Agência Portuguesa do Ambiente, 2020c), in the AMPBR area, the production of approximately 133 018t of urban waste was accounted, with nearly 12 000t of paper, plastic, metal and glass containers being selective collected, representing 9% of the waste. In Portugal, bio-wastes represent 36.6% of urban wastes (APA and Agência Portuguesa do Ambiente, 2019). Considering these data is possible to estimate production of bio-wastes in the AMPBR of about 49 000t.

One of the problems of developing strategies for selective collection based on individual behaviours, is the high risk to be far from the expected collected amounts or the low quality of bio-wastes collected due potential deficient selective disposal by users. Furthermore, due to the high population dispersion (Fig. 1b), the economic viability would also be compromised. Therefore, one methodology that can be followed to override this setback would be the collection of bio-waste in producers from economic activities that produce high quantities of organic waste (non-domestic producers). In the area under study, the data collected from SABI showed a total of 2935 companies, where 210 are hotels, 1139 correspond to food and beverage service activities, 343 companies are classified as wholesale of food products, 629 as retail sales focused on food products in specialized and non-specialized establishments, 498 are in social support (where 229 are schools), and finally, 116 companies are bakeries and tea houses. Given these data, it was accounted that the wider universe of companies (39%) with potential for high production of bio-waste comes from food and beverage activities (Fig. 2).

Looking at the overall region, the most representative activities were hotels, restaurants, and coffee shops (HORECA sector) with 46% of the non-domestic producers, followed by Food commerce activities (wholesale and retail sale) and social service activities with 33% and 17%, respectively. The tea houses sector had the lowest percentage of companies in the overall area of the AMPBR, with 4%.

A more detailed analysis by municipality allowed the identification of areas where the selective collection of organic waste should be more reliable, due to the greater number of establishments with high bio-waste production. Fig. 3 shows the number of establishments by municipality, according to economic activity, considering four categories: HORECA sector; food commerce sector (wholesale and retail grocery), social services sector (activities in education and social support with or without accommodation) and tea houses sector.

As described above, the total number of non-domestic bio-wastes producers was 2935 and Viseu has more than 31% of these

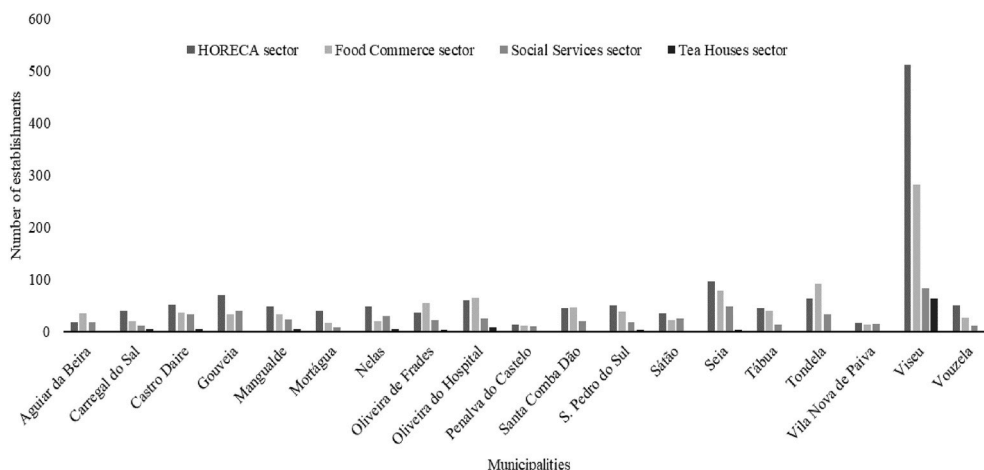


Fig. 3. Distribution of non-domestic bio-wastes producers in Planalto Beirão region by economic activity.

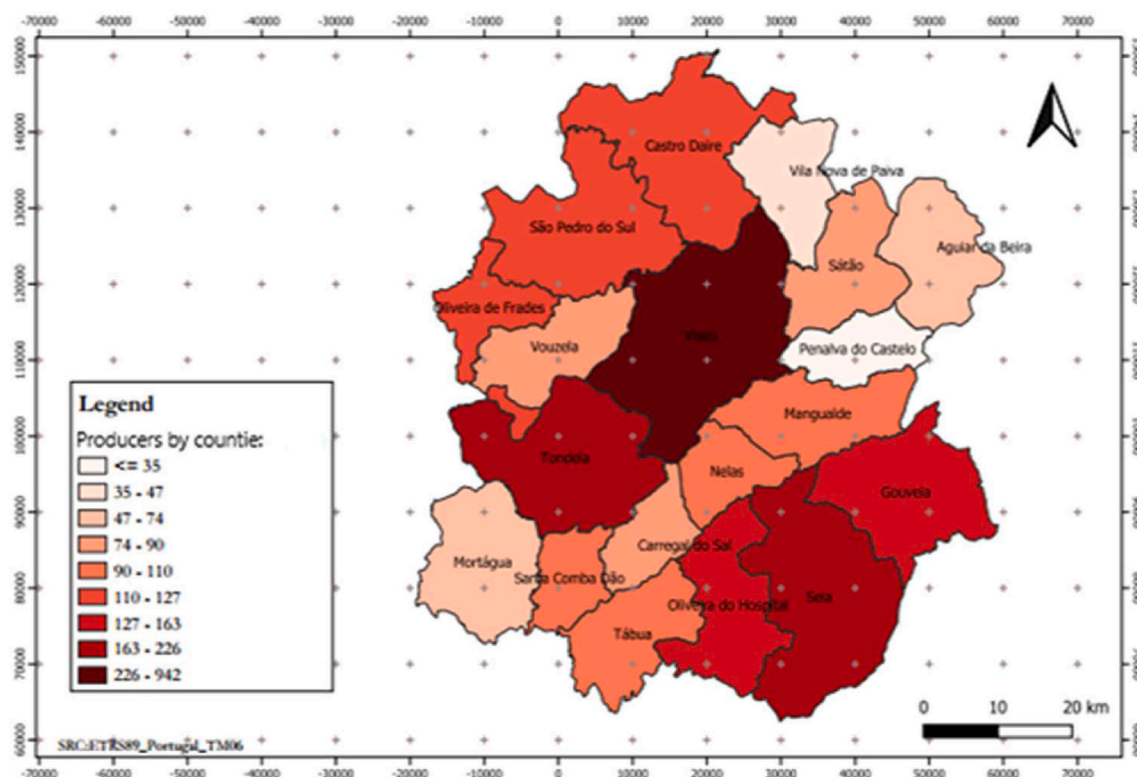


Fig. 4. Distribution of non-domestic bio-waste producers in planalto beirão region.

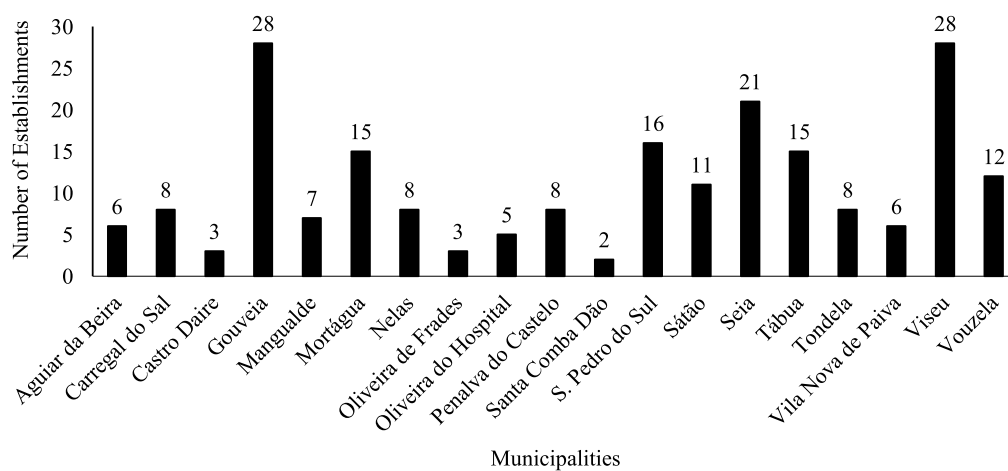


Fig. 5. Distribution of hotels and accommodation in the municipalities under study.

producers (Fig. 3). Tondela and Seia follow this trend with a greater number of establishments. On the other hand, as expected, Aguiar da Beira and Vila Nova de Paiva, two of the municipalities with the lower population density, had fewer establishments. Moreover, these municipalities are very distant from the Urban Solid Waste Treatment Center (USWTC) in Tondela. The former is at 68 km and the second is at 58 km from Tondela, by road. Penalva do Castelo could be a municipality with an underestimated number of establishments, given the lack of data on some hotels and restaurants in the SABI database.

Considering an average production of 3.77 t/year per producer of the HORECA sector and 2.00 t/year for the other producers (AMPBR Associação de Municípios da Região do Planalto Beirão, 2021), it may be considered that approximately 8.3 kt can be selectively collected which represent approximately 6.2% of the undifferentiated wastes collected in 2019 and 17% of the bio-waste



produced in the region. These data show a significant amount of high-quality waste for recycling and valorization (AMPBR Associação de Municípios da Região do Planalto Beirão, 2020). Fig. 4 is shown the establishments' distribution in the overall region.

It is possible to realize that the producers in the region are scattered, arising several difficulties to organize an economically viable strategy for selective collection. Therefore, it is important to study different strategies to manage this waste – door-to-door collection in higher density areas with their transport to the USWTC of AMPBR, and local composting by producers or communities, in rural areas with lower density.

An analysis of HORECA sector was made to understand the potential of bio-waste production by these establishments. According to Fig. 5, Viseu and Gouveia were the municipalities with the higher number of hotels, a total of 13.3%. Seia had also a high number of this type of establishments (21). Consequently, Viseu, Gouveia and Seia will be the municipalities with the highest bio-waste production due to the higher tourism activities. In fact, Gouveia is a municipality with a low population density, with 3.8% inhabitants, but the city has vast and valuable infrastructure and magnificent natural heritage, that contribute to the local tourism. Although its distance from USWTC could be a handicap given the economic and environmental impacts, the potential amounts of bio-waste produced may imply the implementation of door-to-door collection and further centralized treatment.

Hotels with restaurants have a higher production of organic waste. A study carried out in Macedonia on the prospects for energy recovery from food waste generated in hotels, shows that the daily production of bio-waste in 1195 hotels with around 88 196 beds, in a period of 6 months, was 68t (0.77101 kg/bio-waste.bed). According to the authors, this bio-waste had the potential for energy recovery of around 15.2 MWh, which would reduce the amount of bio-waste deposited in landfills by up to 10% (Perkoulidis and Moussiopoulos, 2017).

Fernandes et al. (2021) referred in their study carried out in a 3-star hotel in Viseu, with 20 220 overnight stays in 2018, that the highest waste produced was bio-waste (76%), followed by glass (10%), paper (9%), undifferentiated urban (3%) and plastic (2%). Moreover, the authors reported an amount of bio-waste produced of 27.6t (1.365 kg/bio-waste.bed). Styles et al. (2013) also reported several results with high production of bio-waste, from different types of hotels in different countries. The authors showed that in small hotels in the United Kingdom, an average of 6.9 t/year of waste was produced with almost 40% being bio-waste. However, in Danish hotels, the authors indicated that more waste was produced (around 58 t/year), with less than 20% being bio-waste (Styles et al., 2013).

Just like in the accommodation sector, food, and beverage service activities (including restaurants and coffee shops) have high bio-waste production that is easily accessible and can be collected under controlled conditions. Mahro and Timm (2007) stated that the use of this waste as a source of biomass can reduce the costs of deposition in landfills and allow the production of energy (Mahro and Timm, 2007). For the economic activity of food and beverage services, Viseu has a total of 42.4% of establishments, which is a much higher value compared to the other municipalities (Fig. 6).

Once again it could be inferred that the municipality of Viseu will be the greater source of bio-waste (mainly food waste), but other municipalities should not be neglected. Total establishments with a high potential of bio-waste production, in the remaining municipalities, are a total of 57.6%. As represented in Fig. 7, restaurants are the most representative activity, assuring the highest production of bio-wastes.

As mentioned previously, other than hotels, restaurants, and coffee shops (HORECA sector), there are also bakeries and tea houses, which were considered as non-domestic producers of bio-waste. The bio-waste of pastries and tea houses includes stale bakery products and dropped raw materials (e.g., dough). According to the database, Viseu was again the main area of bio-waste producers, with 54.3%. On the other hand, Penalva do Castelo, Vila Nova de Paiva and Aguiar da Beira had the lowest number of HORECA establishments, with 1.0%, 1.2% and 1.4%, respectively. These municipalities have the lowest population and are farthest from the treatment plant.

The food commerce sector (wholesale and retail sale) is the second category with the highest number of producers in the AMPBR region. These activities can also produce significant quantities of bio-waste. In this sector, as in the others, Viseu was the most

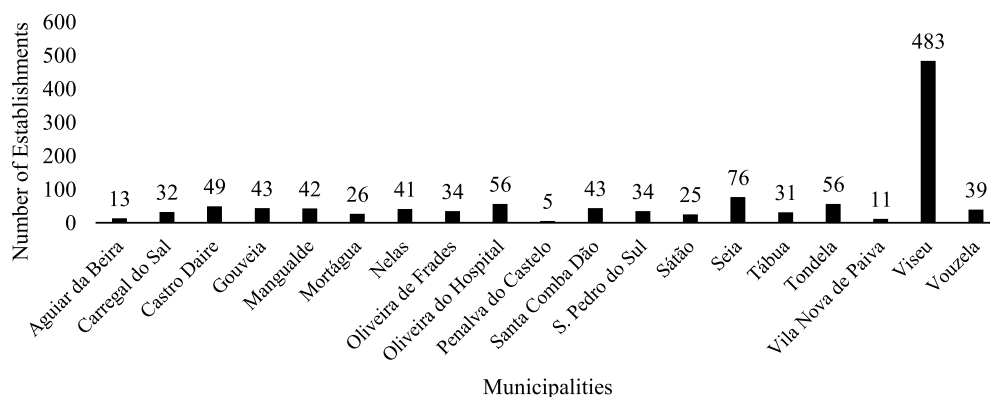


Fig. 6. Number of companies in the activity of Food and Beverage services in each municipality.

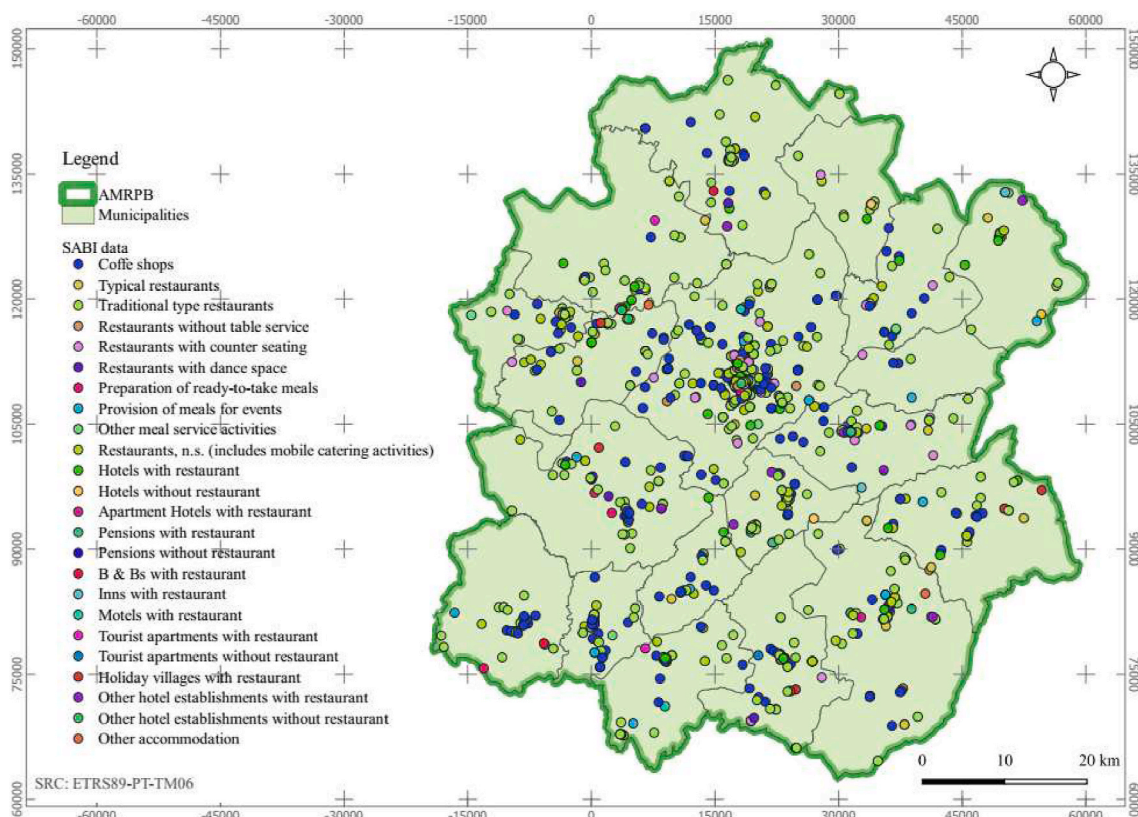


Fig. 7. Geographical distribution of the activities from the HORECA sector in Planalto Beirão region.



Fig. 8. Number of companies in the activity of wholesale and retail sale of food products.

representative of the 19 municipalities, with 23.6% in wholesale of food products and 31.8% in the retail sale of food products in specialized and non-specialized establishments. The municipalities of Tondela, Oliveira de Frades and Seia followed Viséu, in the number of companies in wholesale of food products, with 12.8%, 9.3% and 9.0%, respectively. In retail sale, Tondela (7.6%), Seia (7.6%) and Oliveira do Hospital (6.5%) are the municipalities more representative after Viséu (Fig. 8).

For the food commerce sector, Vila Nova de Paiva and Penalva do Castelo were once again the municipalities with the lowest number of establishments, 1.3% and 1.2%, respectively.

The retail sale and wholesale of food products were shown to have a high number of companies in almost all the municipalities, which indicates that this sector could provide a higher quantity of organic waste, to be collected by AMPBR. Laaksonen et al. reported

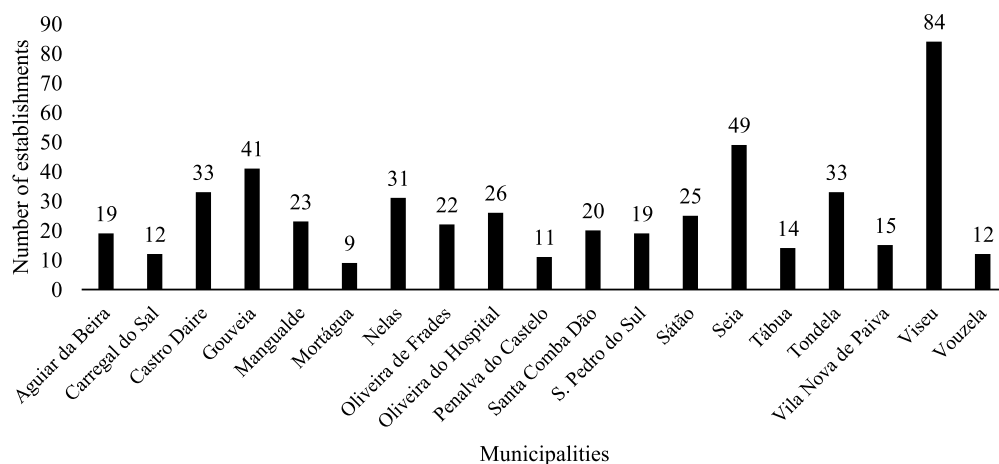


Fig. 9. Distribution of non-domestic producers from Social service activities in each municipality of the Planalto Beirão region.

that the destination of bio-waste produced in the wholesale or retail sale may be energy utilization, treatment, or landfilling, partly governed by specific regulation, but very often managed by waste producers and handlers themselves (Laaksonen et al., 2013).

Despite the activities already discussed (HORECA, food commerce and tea houses) being a representative source of bio-waste for the AMPBR, it was also studied specific activities in social services that could also be a source of organic waste even if in lower amounts. These activities are included schools with canteens and social support activities with and without accommodation (day centers for the elderly and nursing homes, continuous care facilities, among others). These economic activities were included once the food is provided to the users and, consequently, bio-waste is produced. In Fig. 9 it is possible to realize the distribution of these producers in the different municipalities under study.

According to the results, Viseu, Seia and Gouveia had the highest number of bio-waste producers in these activities, with 17%, 10% and 8.2%, respectively. These values are proportional to the number of inhabitants and the area of each municipality.

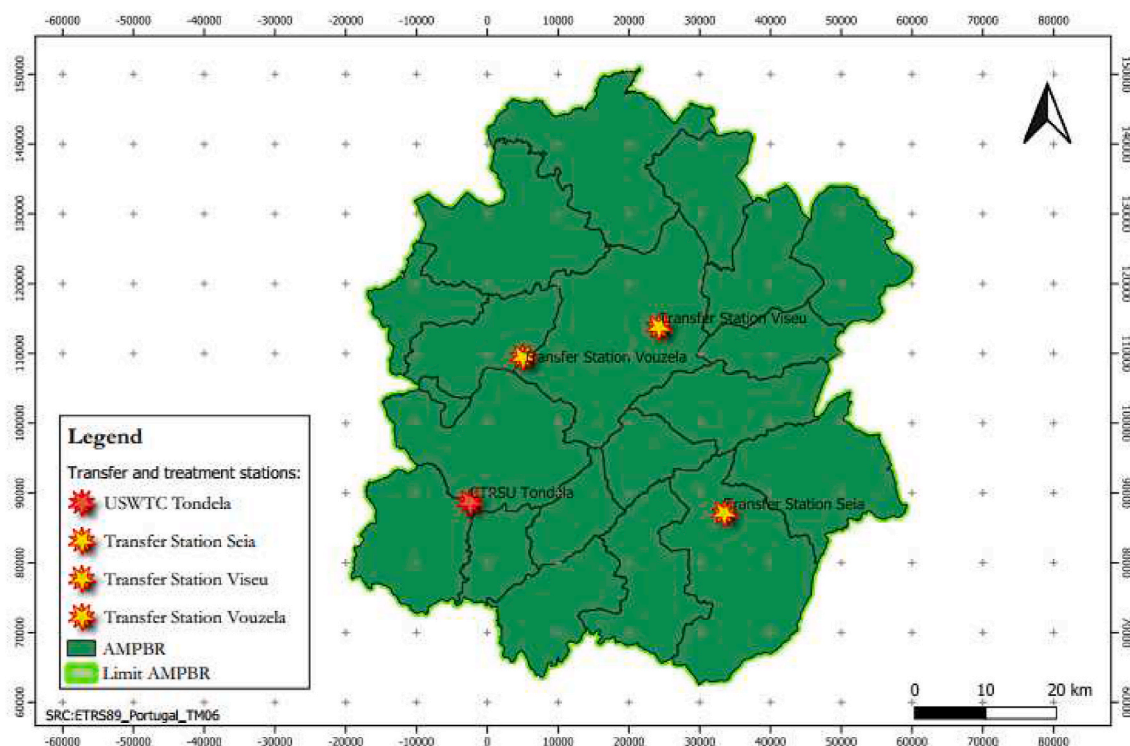


Fig. 10. Localization of the waste transfer stations and the Urban Solid Waste Treatment Center (USWTC) in the AMPBR management area.



Overall, Viseu, Seia and Gouveia showed the highest potential for bio-waste production, in opposition to Penalva do Castelo, Vila Nova de Paiva and Aguiar da Beira. This knowledge is very important in the planning of the best collection practices, once it indicates the municipalities with higher of bio-waste produced and the need for resources namely containers, collection trucks and manpower.

#### 4. Discussion

As mentioned, bio-waste is the major component of urban waste in the EU, and about 60% of bio-waste is food waste. Currently, the most common management processes for organic waste in the EU are composting and/or anaerobic digestion. Composting has the goal of producing organic fertilizer. The anaerobic digestion is carried out in controlled infrastructures, and has the advantage of biogas production, for electricity generation or fuel use in the fleet vehicles as a replacement of fossil fuels (AMPBR Associação de Municípios da Região do Planalto Beirão, 2020). These bio-waste management practices operations may be accomplished in dedicated facilities or locally in community composting areas (composting near the producers, applying an on-site composting, also called local recycling).

The organic fertilizers resulting from local or central composting and from the stabilization process of the biodigestate, if compliant with regulations, can be used as organic fertilizer and soil amendments. Compost and biodigestate both contain carbon and nutrients, which in turn can balance the composition of the soils and stimulate the natural recycling process of nutrients in the soil (Taffuri et al., 2021). With these procedures, it is possible to enhance a circular economy in bio-wastes management.

Currently, in the AMPBR, the organic waste valorization takes place in a dedicated facility, the USWTC in Tondela (Fig. 10). Nowadays, the selective collection of bio-waste is limited to green waste delivered by the producers in specialized collecting centers for further transport and treatment. Due to the high dispersion of urban waste producers in the region, there are three transfer stations where the wastes are temporarily stored and then shipped in high-volume trucks for the USWTC (Fig. 10), enhancing their management. The fourth highlighted is the USWTC.

USWTC has the Mechanical and Biological Treatment plant (MBT) that treats 130 000 t/year of undifferentiated urban waste, with the ability to recover valuable materials (plastic, metals, etc.) and organic waste (organic fraction). The organic fraction (OF) resulting from the mechanical treatment feeds the anaerobic digester, which has a treatment capacity of 35 000 t/year. The material resulting from the anaerobic digestion (AD) (biodigestate) is further stabilized and matured, through composting, to produce compost. The AD process produces biogas that, together with the captured from the technique confinement unit (landfill), is used for electric energy generation in the energy recovery plant (ERP), which has a nominal power of 3 MWe (Fig. 11) (AMPBR Associação de Municípios da Região do Planalto Beirão, 2021).

With the implementation of a selective collection of the bio-waste produced in the territory, it would be possible to optimize the feeding of the digester (Fig. 12) and optimize the anaerobic process with the enhancement of the compost quality (AMPBR Associação de Municípios da Região do Planalto Beirão, 2021). It would also increase the biogas produced with the consequent economic benefit.

In low density regions, the local recycling is advantageous (Fig. 13), based in the proximity between the producers and users of the final compost. In fact, these areas are mainly rural, with agriculture as the main activity.

The municipalities' urbanization and their distance to the USWTC are key factors to define the strategy to be followed. The territories under study, have many rural areas with fewer non-domestic producers. In rural areas, where the producers are more dispersed, establishments could be contemplated with individual-specific containers and be encouraged to carry out domestic composting through the raising of awareness.

According to Torrijos et al. (2021) the local composting (home, community, and small-scale applications) is considered a sustainable option for bio-waste recovery and is receiving increasing demand from society. In Ireland, the city of Sligo, an awareness campaign significantly increased the number of households participating in separate collection of bio-waste and reduced the level of impurities in the selectively collected fraction of bio-waste from 18% to 1% (Eionet, 2019). Similar results were reported in Pontevedra, Spain, where the *Revitaliza* program adopted a decentralized system - a combination of home composting, community composting and small composting facilities, with extensive awareness and training activities (Mato et al. El-Din Mostafa Saleh, 2019). This program inspires the development of valorization strategies in less urban areas. The development of home and community composting solutions in rural areas can decrease the investment in transportation, resources investment, energy consumption, manpower, and other resources as well as reduce the greenhouse gas emissions related to this activity. In these areas, it could be possible to aggregate the non-domestic bio-waste from the aforementioned economic activities with others, like green wastes from gardening and pruning (Dogan and Suleyman, 2003; Ghose et al., 2006). The linkage between local composting and urban agriculture was pointed out by several authors (Torrijos et al., 2021). Menyuka et al. (2020) stressed out that urban agriculture presents an opportunity to explore other means of sustainable food production as well as managing organic waste in cities. Another benefit is the proximity between waste producers and compost users, encouraging a circular economy.

Other than rural areas, there are also urban agglomerates with many producers located in proximity to each other. Given the size and territorial occupation of each municipality, it would be possible to implement a door-to-door strategy of bio-waste collection, at least in clusters in which the producers are closer together. In terms of door-to-door collection, the AMPBR has already implemented a system of paper, plastic, metal, and glass containers selective collection with around 400 producers registered. These producers may also separate bio-waste into an individual container. The characterization of bio-waste producers, done in the present work, will allow the expansion of this system. The AMPBR should provide to the producers' specific bags or containers, where the bio-waste is disposed and then collected periodically. In AMPBR, Viseu, Tondela, Mortágua, Santa Comba Dão and Oliveira de Frades are relatively closer to the USWTC. Also, have a higher number of non-domestic bio-waste producers and population density. In these municipalities, it is

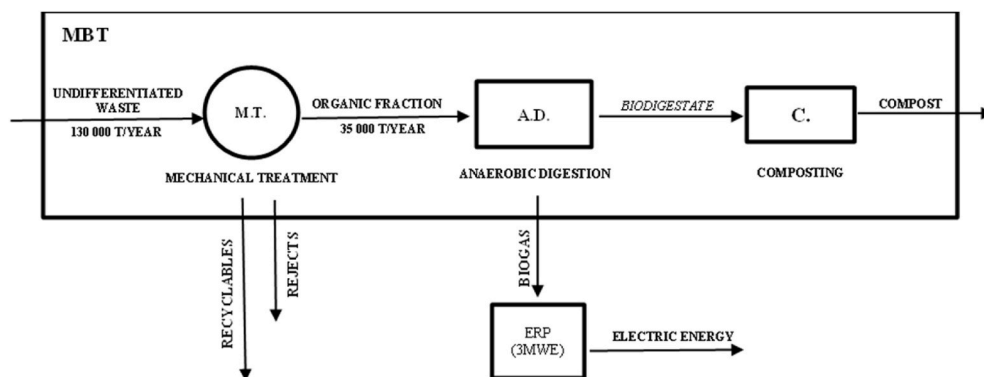


Fig. 11. Conceptual scheme of the functioning of the Mechanical and Biological Treatment plant (MBT) in the Urban Solid waste Treatment Center of Tondela with capacity values.

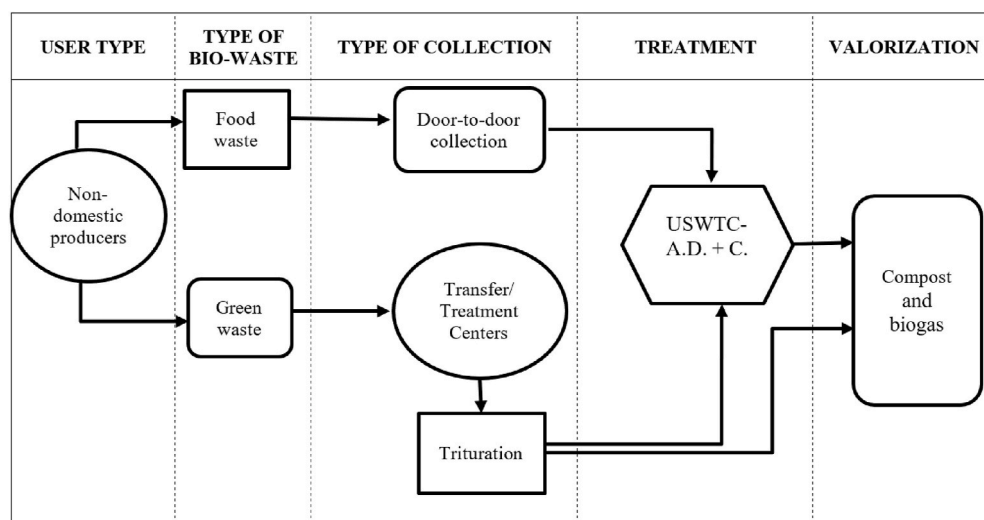


Fig. 12. Conceptual scheme of the strategy for selective collection of bio-waste.

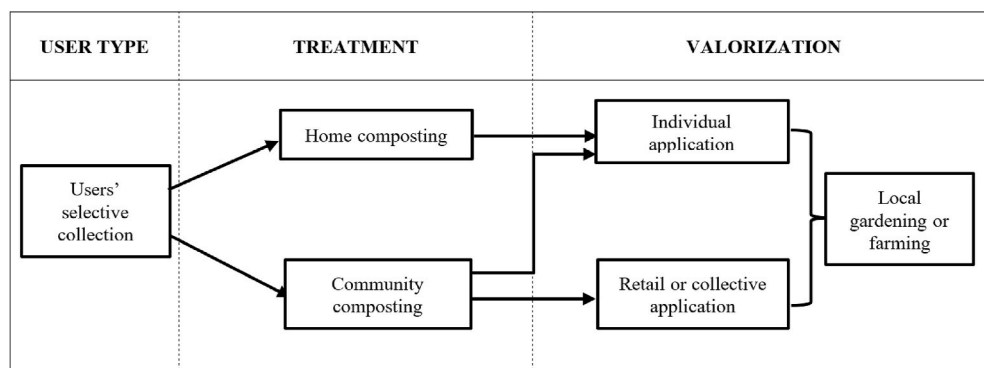


Fig. 13. Conceptual scheme of the strategy for local recycling of bio-waste.

possible to implement a door-to-door collection system given the proximity between producers and the waste treatment center. The municipalities of Seia, Gouveia, Oliveira do Hospital, Tábua, Nelas and Mangualde had a substantial number of producers and are located near transfer stations, which can temporarily store bio-waste for further treatment in the USWCT. Here, it could be important to implement the door-to-door collection. On the other hand, in Penalva do Castelo, Sátão, Vila Nova de Paiva, Aguiar da Beira and

Carregal do Sal, it could be implemented a local valorization strategy, given the lower number of producers and the greater distances between the producers and the treatment center. In intermediate cases, like Vouzela, São Pedro do Sul and Castro Daire, the two methods (door-to-door collection and local valorization) could be applied according to the region's urbanization. The bio-waste selectively collected in these municipalities could then be transported to the transfer station of Viseu, which is the closest to these municipalities.

Despite the importance of implementing a collection system for bio-waste, the economic analysis resulting from this activity must be considered. For the selective collection in the studied establishments, some technical issues should also be assured namely the distribution of clearly labeled bins, for separation of bio-waste in kitchens and the motivation of workers and staff in these procedures. These types of equipment should be provided by the local government, as well the logistics for door-to-door selective bio-waste collection service, with a specific schedule, encouraging bio-waste producers to separate organic waste and comply with the requirements of the collection service.

The selective collection must be accomplished with detail analysis and planning based on the type of containers to use, vehicles, teams, and collection period. The method should consider the roads, the proximity, the urbanization, the approximate amount of bio-waste to collect. For door-to-door collection in the non-domestic producers, it would be necessary the acquisition of 10 m<sup>3</sup> rear cargo vehicles with a maximum load capacity of 5 t/route, for primary transportation (local production-transfer station) and 15 m<sup>3</sup> containers and rear cargo vehicles for the secondary transport (transfer station-USWTC). These vehicles need periodic maintenance and washing with manpower to monitor and work the equipment. In addition, it is also necessary conventional washing vehicle (rear) for standard containers. The containers should be washed in a period of 45 days (AMPBR Associação de Municípios da Região do Planalto Beirão, 2021). The cost projection is fundamentally based on the estimate of the number of routes necessary for the collection of the bio-waste. The number of routes is, in turn, conditioned by two factors: the maximum transport capacity of the standard vehicle (mass) and the maximum length of a route (distance). In the case of container washing vehicles, the number of routes is conditioned by the maximum (standardized) capacity for washing containers in each collection route (AMPBR Associação de Municípios da Região do Planalto Beirão, 2021). But investment and operational means are also fundamental for the implementation of local recycling, composting near the producer. Along with the composting equipment, with the dimensions depending on the propose is to implement the composting by the producer or by the community, is also important the tools distribution for proper management of the composting process and the distribution of the compost produced. Also, specialized human resources are fundamental for the follow-up of the overall composting process in the community case.

According to APA, about half of the municipalities of Portugal (49%), would be covered by the mandatory implementation of selective collection of bio-waste (APA and Agência Portuguesa do Ambiente, 2019). The model proposed comprises a population of 7.5 million inhabitants, with an annual capture of 624.5 thousand tonnes of bio-waste at an average cost of 99.38 €/t. This analysis allows the balancing of the advantages and disadvantages of this type of waste collecting system at an economic and social level. According to several authors, collection can account for up to 70% of the whole waste management costs, ranging from about 70 €/Mg to 140 €/Mg (Menyuka et al., 2020; Tavares et al., 2009; Langer, 2017; Di Maria et al., 2018). Furthermore, as reported by Di Maria and Micale (Di Maria and Micale, 2013), collection costs are also greatly affected by the source segregation level and the optimization of the waste collection vehicles. The strategies to be followed must keep in mind the economic viability of the overall process.

The reduction of waste collection fees could be interesting to encourage the selective deposition in dedicated bins, but also the charging of an additional fee to those producers that do not implement a bio-waste selective collection would give a signal for adopting best practices. The on-the-spot monitoring is an essential part, being necessary to rely on updated data to help the producers, to maintain the desired behaviors, allowing to implement of the corrective measures on time. Whatever the strategies applied for selective bio-waste collection and valorization, the greater role is always played by the producer. So, an effort should be done for the sensibilization and education of the hotels, restaurants, coffee shops managers and staff, as well as school and social support activities workers, with the definition of responsibilities in coordination, training and involvement of the teams in the separation, disposal and treatment of bio-waste.

## 5. Conclusions

An overall analysis of non-domestic bio-waste producers showed that the economic activities of food and beverage service activities and retail sale focused on food products in specialized or non-specialized establishments, are the most representative in the 19 municipalities managed by the AMPBR, with 39% and 21% of the establishments accounted, respectively. Food and beverage are part of the HORECA sector, while the retail sale is part of the food commerce sector.

Considering the number of entities by the municipality, it was concluded that Viseu had the higher number of establishments in all the economic activities under research, which was justified by its higher population percentage (28%). Seia and Tondela also showed to have a higher number of establishments in the economic activities under analysis.

This study will provide information to AMPBR, enhancing the development of strategies for the collection and valorization of bio-waste with high quality, and a lower degree of contamination. Special focus should be pointed out in the reduction of bio-wastes produced namely by the decrease of food overplus. Another advantage would be the reduction of bio-waste collected with undifferentiated waste, that otherwise if collected selectively, could be directly uploaded to the organic recovery process. With the selective collection of bio-waste, it is expected that beyond 2023, in the AMPBR region, the quality of the final product of the organic valorization, biogas and compost, will be improved and the goals of landfill deposition may be accomplished.

Overall, Viseu, Seia and Gouveia are the municipalities with the highest potential to implement a successful selective collection of bio-waste. Also, Tondela, Mortágua, Santa Comba Dão and Oliveira de Frades are relatively closer to the UWTC, justifying the

implementation of selective collection. In the AMPBR region, the selective collection from non-domestic bio-wastes producers must be done door-to-door, in higher density areas, but local valorization by producer or community, should be invigorated in rural areas like Penalva do Castelo, Sátão, Vila Nova de Paiva, Aguiar da Beira and Carregal do Sal. In municipalities like Vouzela, São Pedro do Sul and Castro Daire, the two methods (door-to-door collection and local valorization) could be applied according to the local urbanization characteristic.

### Statement of novelty

The increasing concern with the negative impacts of bio-waste on the environment has heightened the demand for strategies for selective collection and valorization of this fraction of waste. Because most of the environmental impacts of bio-waste come from food production, food waste prevention at all stages of the food value chain is highly relevant. Preventing food waste can mitigate environmental pressures but the fraction produced must be valorized. Given this, the identification of producers of high amounts of bio-waste and the proper collection and valorization, as studied in this work, can be a pivot method for preventing the deposition of biodegradable waste in landfills. Landfilling of bio-waste has very high negative environmental impacts (produces gas that mainly consists of methane, a powerful greenhouse gas). This paper discusses the methodologies that can be followed for the identification of non-domestic bio-wastes producers and the definition of the best selective collection and valorization technologies to be applied according to their geographical localization and population density.

### Data availability statement

All data generated or analyzed during this study are included in this published article.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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