Data Analysis for Home Composting Implementation

Municipality Decision Support Tool

Mateus Bastos

DEI

Instituto Superior Técnico/Universidade Aberta

Lisbon, Portugal

mmab1997@gmail.com

ABSTRACT

These days, biowaste in Portugal is still collected and treated mixed with unsorted waste. There is a need to implement solutions that make the waste profitable for use in agriculture and other applications. One of the possible solutions is home composting. However, there have been obstacles to the possibility of implementing this solution in Portugal. One of the obstacles is the lack of support for decision making to invest in composting implementation, due to lack of information and knowledge about the conditions under which it can be effectively done. It is in response to this need that, at the service of civil society, a solution was developed that supports the decision of municipal managers in the implementation of home composting within their municipality. The developed solution is both important and useful, as it gives the user the possibility, through a simplified interface, to consult the results of calculations carried out on municipal data stored in complex databases, with variables representing information about the population, type of housing, amount of waste produced, ways of treating this waste, etc. This information displayed in a clear and understandable way, in the form of a report, that will allow the manager to make informed decisions about the feasibility of implementing home composting in the municipality. The final result is a tool supported by databases relating to all municipalities in Portugal, with inherent flexibility in the possibility of inserting the data itself into certain categories, having as output a report with details to allow an informed decision-making for the implementation of home composting. This work intends, therefore, to leverage and be an unlocking element for the implementation at municipal level of home composting in Portugal.

KEYWORDS

Home Composting, Data Analysis, Microsoft Excel, Data Bases

1 Introduction

Currently, biowaste in developed countries is still mostly collected and treated in an undifferentiated manner (landfills, incineration, etc.), leading to pollution and waste of fertilizer potential [1]. Biowaste has a high potential as a fertilizer after organic recovery that is being wasted, since the MBT (Mechanical and Biological Treatment) units lead to the production of a compound of low quality and applicability due to the high degree of contamination of undifferentiated waste, in addition to the high number of rejects associated with mechanical treatment (MT), which ends up in landfills. On the other hand, biowaste, because it has a high percentage of moisture, which makes the combustion process in incinerators difficult, which makes its incineration not the best solution [2].

The implementation of home composting represents a necessary advance to be made by the municipalities in order to reduce costs and increase the profitability of the composting process for the population. However, for this implementation to take place, a prior analysis of the characteristics of the existing housing in each municipality is necessary, and the possibility of these housing composters to be used by the respective inhabitants. In addition, it will also be necessary to calculate and analyze the costs associated with the purchase and installation of composters, which may have different characteristics, as well as costs related to the education of the population in terms of their use.

However, at the moment, in Portugal, there are no technologies or tools that allow this collection, treatment, analysis and presentation of information about the feasibility of implementing home composting in each region. Therefore, the technology of composting is very little used and the municipal management bodies do not want to commit to the implementation of projects, in this case of composting, without knowing whether in fact this investment will have financial and environmental returns or not.

In this sense, this dissertation proposes a solution aimed at Civil Society, implemented in Microsoft Excel, for collecting, processing and presenting data for analysis in order to find out, first, what are the possibilities of installing home composters in each municipality in the country and then, the costs that these projects will have for them, as well as the associated environmental advantages. The goal will be to allow the municipal management bodies to move forward with good levels of confidence towards an investment and implementation of home composting, supported by the detailed information made available about their municipality, as well as by the data entered by the mayors themselves about the conditions to be respected for this same implementation.

In short, the objective of the dissertation is to develop a tool that, after the user introduces a small set of data about a particular municipality, can return information about the feasibility of implementing home composting in that municipality. The report obtained can then be analyzed by the user in order to make an informed decision about the investment in home composting and its economic and environmental benefits.

2 State of the Art

2.1 Urban waste/biowaste management in Portugal and problems caused by inadequate treatment of biowaste

The management of urban waste in Portugal comprises a set of technical activities, administrative and financial requirements for disposal, collection, transport, treatment, recovery and waste disposal [3]. The total production of urban waste in Portugal was, in the year 2019, of approximately 5.28 million tons, which corresponds to a daily production of 1.4 kg per inhabitant. The direct destinations of this urban waste were the landfill (57.8%), energy recovery (17.4%), recycling (13.1%), composting/anaerobic digestion (8.4%) and others (3.3%) [3]. show that waste management options in Portugal still follow the opposite direction. established by the "Waste Hierarchy", which determines that the first recycling and recovery, with disposal being the last option to be taken. In this context, it is essential that the entities responsible for the management of urban waste, namely the municipalities, among others, promote and adopt solutions for recovery at origin and selective collection of recyclable fractions such as biowaste.

Biowaste is the biodegradable waste from green spaces, in particular from waste gardens, parks, sports fields, as well as biodegradable food and kitchen waste housing, catering and retail units and similar waste from food processing units [4]. And, as shown in [3], they represent 38.56% of the totality of urban waste in Portugal. Currently, despite the huge recycling potential, the most Portuguese municipalities still do not have implemented recovery and treatment solutions of these biowaste. However, Directive 2018/851 of the European Parliament and of the Council, of 30 May of 2018 (which amends directive 2008/98/EC on waste [5], transcribed in Portugal by Decree Law 102-D/2020 [4]), establishes that by December 31, 2023, bio-waste must be separated and recycled at source, or selectively collected. This time, the municipalities now find themselves in a crossroads and have two options for the management of biowaste produced in their territories: i) implementation of recovery systems at source, such as home composting and/or ii) collection selective on public roads or door-to-door. Both solutions have different economic costs associated with them, and environmental impacts that have to be estimated so that the municipality can adopt the best treatment option.

Fig 1. Example of a home composter [6]

2.2 Types of compost as a valuation solution for biowaste

The implementation of composting solutions is necessary to achieve real recycling rates of the urban waste. [7] points out as difficulties encountered on the way to the implementation of the composting: the scale of treatment, the lack of specific infrastructure, associated costs or even possible economic crises. Home composting consists of treating the generated bio-waste by individual people or families, made by applying composting processes in their own houses, terraces, gardens, etc. It implies particular use of the resulting compound. Industrial composting is large-scale composting that handles large volumes of organic waste. The compost produced can then be sold to agricultural and horticultural companies. An industrial composting operation normally consists of collecting waste from stores, restaurants or containers and corresponding selective treatment regarding the characteristics of each set of waste. The treatment can be carried out in windrows, in which the waste is disposed in long lines and periodically watered, in silos, in which they are stored in condition-controlled environments, or in static piles outdoors, with layers of branches or papers allowing air filtration through the stacks, air that is pumped through pipes to speed up the process of composting, or in aerated and stirred reactors. Community composting is about composting developed by different generators (mostly families), in each area, being, thus, the biowaste generated jointly treated in a single module, in a common area. This composting results in several advantages, such as increased awareness. public environmental, transparency in management and costs, creation of jobs (contributing for the social inclusion of people at risk of exclusion), better management of the collection of other factions in qualitative and quantitative terms, improvement of the legal and agronomic quality of the final product (compound), the possibility of being a viable alternative to waste management models (including collection and transport, mainly in semi-urban and rural areas) [7].

2.3 Comparison of costs between collection and recovery options in the origin

In [8], an extensive investigation was carried out on the costs of collecting waste, mainly to differentiate the costs of distinct waste streams and spatial optimization of collection services (for example, routes, number and location of waste facilities). However, the Garbage collection managers also face the challenge of optimizing assets over time, for example, decide when to replace and how to keep, or which technology solution to adopt. These questions require a more detailed knowledge of the cost analytical structure of data collection services waste.

Regarding the comparison of costs, [9] states that the collection of biowaste, when introduced in the current collection system does not necessarily mean an increase in total service costs. In fact, a cost reduction can be achieved if the fraction of the population adheres to the scheme exceed certain values (in this case study, 40%). This study thus concludes that the cost global for the selective collection of bio-waste is not necessarily higher than the cost related to the collection. traditional, adding that the overall cost associated with home or community composting it may also be less than the cost of traditional collection. [7], through an economic study concerning Catalonia, points out that the general management costs of door-to-door selective collection models and public road containers for municipalities with populations of less than 20 000 inhabitants, show average values of €68.40 and €69.47 per inhabitant per year, respectively. Regarding the revenues, emphasizes that “the influence of population size on the overall costs of the two models of collection was not considered as significant in the results obtained, and the authors consider that, on average, the general management costs of the different models are similar for the authorities. locations. The door-to-door collection model presents average costs, associated with collection, higher than the system by containers on public roads. However, the costs related to the treatment and the income generated by the door-to-door model are superior since it usually reaches levels of separation superiors. Therefore, and according to the results presented, the door-to-door collection models and on public roads have average general management costs of €252.72 and €381.44 per tonne of waste selectively collected, respectively”.

Finally, [1] concludes that the treatment of urban organic waste through home compost or community reduces management costs by 50% in developed European countries, 37% in countries less developed Europeans, and 34% in Canada, adding that composting can reduce greenhouse gas emissions by 40% in Europe and Canada, despite the implementation of landfill gas capture practices. Despite the fact that separate organic waste at source to produce a compost of higher quality and value, this management option through industrial composting infrastructure increases collection and transport costs, regardless of the disposition method. The separation of organic urban waste at source by via decomposition or aerobic digestion requires selective collection, which increases the costs of transport. Certain cities have dealt with this problem through a weekly collection of these waste, collecting the remaining types of urban waste twice a month. This study concludes that, in 2025, it is predicted that composting practices will reduce costs and gas emissions. greenhouse effect up to 50% compared to maintaining landfill practices. In addition, 3440 hectares of agricultural land in Europe and 330 hectares of agricultural land would be safeguarded annually in Canada [1].

[10] states that efficiency assessment and benchmarking are crucial to managing any organization. However, especially from a regulatory perspective, this efficiency assessment and benchmarking must be impartial with respect to specific issues of the context and must provide a rating absolute rather than relative. This work analyses the approaches used for the evaluation of performance and benchmarking of waste collection services, revealing that most are biased and it is not absolute.

2.4 Home composting decision support tools

The main existing example of a tool to support the decision on home composting in Portugal is the Excel file developed by the Environmental Fund [11]. This file is included in an open program by the Environmental Fund (a financial instrument to support the government's environmental policy) aimed at providing municipalities with funding for the preparation of a diagnosis leading to the definition of an Action and Investment Plan for the operationalization of the selective collection of bio-waste leading to its recovery, either through the implementation of a network of selective collection of bio-waste or through the separation and recycling at source through the implementation of home or community composting, in line with the strategy defined or to be defined by the Management Systems of Municipal Waste.

The methodology related to this project supports the development and comparison of scenarios for selective collection of biowaste and reporting of results [12]. This methodology was elaborated within the scope of a collaboration protocol signed between the Environmental Fund and Universidade Nova, for the “Definition of a methodology for the elaboration of municipal studies for the collection of biowaste”, arising from the “Support program for the elaboration of studies for the development of bio-waste collection systems” (Order No. 7262/2020 of 17 July). This methodology includes the aforementioned Excel file, which combines three inseparable aspects, the technical, economic-financial and environmental indicators that underlie the comparative analysis between alternative scenarios, that is, options for implementing selective collection and recycling at the source of bio-waste. For this comparative analysis, criteria are defined for obtaining data and information and calculating indicators and variables.

The objective of this methodology, and its respective File, is to support municipalities in the construction and comparison of scenarios of diversion systems for landfill biowaste and energy recovery, either by separation and recycling at source or through the selective collection of biowaste in the technical and economic aspects and environmental. Thus, the final objective of this methodology is precisely to provide the concepts and tools for analyzing and simulating alternatives in a reasoned way, and which is desired with the greatest possible realism, so that the best solution for collecting biowaste can be identified.

3 Methodology

For the development of this work, the following steps were followed:

- ✓ Definition of requirements
- ✓ Choice of variables to include in the database
- ✓ Data import and database creation
- ✓ Tool development and validation

3.1 Definition of requirements

The definition of requirements for the tool to be developed was done in collaboration with the non-governmental organization ZERO and with the consulting company in the area of waste ECOGESTUS. To this end, in April 2021, a meeting was held at which the important points to which the final solution should correspond, as well as the conditions under which its implementation would be possible, were defined.

At this meeting, it was defined that the tool should allow a municipal manager to obtain information about the feasibility of implementing home composting in a given municipality, takinginto account a reduced set of data that will be entered by the user about the conditions under which it would be carried out, as well asdata about the municipality itself, which would be obtained, whenever possible, from statistical and other existing information.

3.2 Choice of variables to include in the database

First, the set of relevant variables to be collected and compiled in the database associated with the tool was identified, taking into account the objectives to be achieved, the information currently available and the reliability of this information.

A literature search was carried out on the internet and based on these criteria, data from two sources were selected: (i) Census data,provided by the National Institute of Statistics (INE) and with granularity at the municipality level; and, (ii) data on waste management and the companies responsible for such management,made available by ERSAR (Regulatory Authority for Water and Waste Services), which annually releases the Annual Report on Water and Waste Services in Portugal (RASARP).

In each case, we tried to use the most up-to-date data possible, with the latest available information being the 2011 CENSES [13] [14] andthe RASARP for the year 2019 [15]. The release of the updated results of the 2021 CENSES and the 2020 RASARP is awaited at all times, which until the moment of submission of this dissertationhas not happened yet.

Table 1 shows the variables collected from INE and RASARP.

3.3 Data import and database creation

From the files collected at INE relating to each of the relevant indicators to be collected, the columns were cut in each one,

According to the alphabetical order of the municipalities, in order togather all data in a single file, which in turn was copied to an emptysheet in the tool, which was given the name 'Geo', as it contains mostly geographic data. Regarding the RASARP data, based on a filter, only the codes relating to the variables that were intended to be collected were selected. Through the RASARP indicator relatedto the SGRU, each company already had an associated SGRU. Then, through a search of the relative websites, the corresponding municipality was associated with each SGRU, so that, later on, it would be possible to associate the data of that SGRU to themunicipality selected by the user, and this association was stored inthe 'SGRU-Municipality' table.

3.4 Tool development and validation

Microsoft Power BI was the software initially chosen to develop this tool. However, early on, it was found that this software had some limitations that made it impossible to meet some of the defined requirements. The tool was thus developed using MS Excel software, version 2019.

Table 1 Variables collected from INE and RASARP.

INE	RASARP
Municipality name	Enterprise name
Population	TMB refuses and rejects in 2019 (tons)
Surface Area (km^2)	Waste entered in TM/TMB in 2019 (tons)
Population density (inhabitants/km^2)	Municipal waste directly deposited in landfill (tons/ year)
Number of individuals per family accommodation classic of usual residence	Municipal waste collected indifferently (tons/year)
Number of households from usual residence in buildings with 1 exclusively residential accommodation	CO_2 emissions from undifferentiated collection vehicles (kg/year)
Number of households from usual residence in buildings with 1 partially residential accommodation	Urban Waste Management System
Number of households from usual residence in buildings with 2 accommodations	Amount of undifferentiated municipal waste collected in the municipality in 2019 (tons)
	Rising tariff (Euros/ton)

4 Proposed Solution

The solution was developed using Microsoft Excel software, whosefile has sheets invisible to the end user with the indicators necessary for the analysis (after the respective treatment and import). These sheets include the aforementioned tables, which store geographic data relating to the municipality ('Geo' sheet), RASARP data ('RASARP' sheet) and also the association of each municipality to the respective SGRU ('SGRU-Municipality sheet'). Finally, the 'Calculation' sheet, which contains all the calculations performed on the data imported and entered by the user in order to return the intended output, in the form of a table with data corresponding to the years 2021 and forecasts until 2030, it is also an invisible sheetto the end user.

In addition to these invisible sheets, there are 2 sheets visible to the user. In the data input sheet ('DadosIntrod'), the user must select, for each variable from a given list, the values related to his municipality and the most feasible forecasts of the conditions under which the implementation of home composting in the municipality will take place. In the report sheet, all the values considered relevant will be presented to the user, as well as some graphical representations, resulting from the calculations carried out in the spreadsheet, from values present in the databases or even from the values entered by the user. It is a sheet whose format allows printing on A4 sheets.

4.1 Data input sheet

The first sheet visible to the user is the 'DadosIntrod' sheet with the data that the user must fill in about, not only their municipality and its current waste collection and treatment conditions, but also aboutforecasts for the analysis time interval (2021 to 2030).

To allow the user a more practical and faster way of selecting values for these variables, a Dropdown list with feasible and practicable values was implemented for each one, through the Microsoft Excel Data Validation feature, and confirmed in a meeting with associations representing Civil Society. These lists were stored in a separate sheet, hidden from the end user, from which Data Validation imports the values available for the user's choice.

4.2 Calculation sheet

In addition to the database sheets, there is another sheet equally invisible to the end user, but no less important. It is the spreadsheet,in which data are collected, processed, and used in calculations whose final purpose will be to allow the user to be presented with values and graphs that will allow him to draw precious conclusions.

4.3 Report sheet

The result to be presented to the user is a sheet with data relating tothe characterization of the municipality selected by the user, the potential corresponding to the implementation of home composting by the year 2030 and, finally, 3 graphs representing information on financial and environmental advantages concerningthe implementation of home composting in the municipality.

4.4 Sensitivity analysis

In order to understand which variables have the greatest impact onthe model's results, a sensitivity analysis was carried out for each of those used in the most pertinent calculations of the model (Investment Plan and Environmental Impact). For this, an analysis was made of the graphs resulting from an input variable, in which changes are made for the comparison (between the base value and a value with a certain percentage value), and an output variable (final balance of the period). The input variable will always be oneof the variables whose value is entered by the user, as they are the only ones in the database whose value can be changed. The final analysis will be made on a graph in which the percentage changes on the output variable are presented for a 10% change on the inputvariable, whose value is obtained via a simple rule of 3, since theseare linear values. As the calculations used to obtain the values of the output variables are all linear operations (sum, division, subtraction, multiplication), variations in the results of these corresponding to changes in the values that compose it will also be(and so it was enough to use of a value for comparison in the sensitivity analysis).

To carry out this analysis, a series of values were defined as defaultvalues for the input variables. The county was chosen at random. The values of variables related to municipal waste management processes were chosen under the criterion of being values, in general, common in this area. Finally, values related to predictionsfor the tool's analysis time interval were defined according to the most acceptable and realistic values possible.

4.4.1 Analysis with non-zero funding rate by European Funds

Initially, an analysis was carried out with the value of the non-zero Financing Rate variable by European Funds, in order to assess the sensitivity of each input variable, with the majority of the composter price in 2021 not being the responsibility of the municipality.

4.4.1.1 Results' analysis

Inflation Rate - The input variable with the least sensitivity is the inflation rate, with a negative variation of 0.00075% of the final balance of the period for each 10% variation on this rate. These values can be explained due to the fact that the inflation rate is a value only used to calculate annual marginal increases in the price of each composter, over the 10 years, having, thus, a weak effect on the final balance. The negative value of the effect on the output variable represents an inverse proportion between the variables, meaning that an increase in the inflation rate will always represent a decrease in the value of the final balance.

Percentage of composters to be replaced per year - Another variable with low sensitivity is the percentage of composters to be replaced annually, with a negative change on the final balance of 0.36% for every 10% change in this percentage. These values can be explained by the fact that, with the 80% base financing, the amount paid by the municipality for each composter is much lower, making the need to purchase new composters much less expensive to replace the lost/damaged ones. The negative value of the effect on the final balance represents an inverse proportion between the variables, meaning that an increase in the percentage of composters to replace by year will always represent a decrease in the value of the final balance.

Unit cost per composter in 2021 - This input variable is the first to vary by 10% implies a change of more than 1% in the value of the final balance, in this case a negative value of 1.8%. Despite being a more significant value than those mentioned above, it does not represent a significant change in the final balance, so its sensitivity is considered as average. This it is mainly due to the fact that the value of this variable loses importance with high values percentages of the financing rate. The higher this rate, the lower the cost per composter for the municipality, and, consequently, the sensitivity of the variable turns out to be smaller (in this case, the value default this rate is 80%). The negative value of the effect on the final balance represents an inverse proportion between the variables, meaning that an increase in the unit cost per composter in 2021 it will always represent a decrease in the value of the final balance.

Percentage of adhesion to home composting of residents in buildings with 1 or 2 dwellings in the 1st year/10th year – For the variable relating to the 1st year, a 10% change in its value implies a variation of 2.5% in the final balance of the period, while for the 10th year, a change of 10% means a 7.5% change in the final balance. This is due to the fact that a value being higher in the 10th year, allows a greater growth in the set of 10 years, while for the 1st year, the variable of input only changes the value for the first of these 10 years, thus having less sensitivity and impact on the final balance than the input variable for the 10th year, which influences the values of the remaining 9. Both variables have positive values for the effect on the final balance, which represents a direct proportion between these and the output variable. This means that an increase in percentage of adherence to home composting, both in the 1st and 10th year, will always represent an increase in the value of the final balance.

Cost of training and monitoring and awareness of home composting in the 1st year from the 2nd year - For the variable relating to the 1st year, a 10% change in its value implies a negative variation of 2.7% in the final balance of the period, while for the variable related to values from the 2nd year onwards, a 10% change in its value implies a negative variation of 4.5%. This is due to the fact that, while for the 1st year, the input variable only changes the value for the first of those 10 years, thus having less sensitivity and impact on the final balance than the variable of entry for the 2nd year, which influences the values of the remaining 9. Both variables have negative values for the effect on the final balance, which represents an inverse proportion between these and the output variable. This means that an increase in the cost of training and monitoring and awareness of home composting, both in the 1st and from the 2nd year, will always represent a decrease in the value of the final balance.

Financing rate - For this input variable, a 10% variation implies a change of 7.2% on the value of the final balance. Despite being an even more significant amount than those mentioned previously, it also does not represent a significant change in the final balance, thus its sensitivity also considered as average. This is mainly due to the fact that the value of this variable only has a direct effect on the total value of the unit price per composter in 2021, although this effect can be very significant (up to 100%). This balance of influences makes its sensitivity turn out to be, at the same time, average. The positive value of the effect of this variable on the balance sheet end represents a direct proportion between the variables, meaning that an increase in the rate of financing will always represent an increase in the final balance sheet value.

Average cost of collecting biowaste/undifferentiated - It is the first value that is considered as having high sensitivity, because it considerably approaches or exceeds the 10% variation in the final balance for every 10% change. In this case, the variation on the output variable in these circumstances is 9.6%, which is already a considerable effect of the input variable on it, which means that the final balance will practically vary in equal measure with the average cost with the collection of biowaste/undifferentiated. This value is mainly due to the fact that the value of this variable be preponderant in determining the costs that will be avoided for the municipality with the implementation of home composting, which in turn have a large weight in the final calculation of the return on investment and the final balance. The positive value of the effect of this variable on the final balance represents a direct proportion between the variables, meaning that an increase in the average cost with the collection of biowaste/undifferentiated will always represent an increase in the balance sheet value.

Percentage of biowaste in municipal waste – Finally, the variable to which the model is the most sensitive and which consequently has the greatest influence on the final balance is the percentage of biowaste in municipal waste. A 10% increase in the content of biowaste in municipal waste causes a change in the final balance of 19.0%. The amount of urban waste in a given municipality being always significant (approximately 46%, according to national averages – reference), each percentage variation (corresponding to the 'slice' of biowaste) over this large amount will be it is also significant, having a large impact on the universe on which composting home can work and return dividends. The more biowaste there are in the municipality, the greater will be the positive impact of implementing home composting on it and, consequently, the greater the final balance. As it is visible in the results in which, being positive the value of the effect of this variable on the final balance, a direct proportion between the variables, meaning that an increase in the percentage of bio-waste in municipal waste it will always represent an increase in the value of the final balance.

4.4.2 Analysis with zero Financing Rate by European Funds

In order to analyze the sensitivity values of each input variable without the extreme influence of high values of the Financing Rateby European Funds on one of the most important values for the finalcalculation of the balance, the unit price per composter in 2021, thisanalysis was repeated, this time with a 0% value for this rate.

4.4.2.1 Results' analysis

Inflation Rate - The input variable with the least sensitivity is the inflation rate, with a negative variation of 0.02% of the final balance of the period for each 10% variation on this rate. Despite the change in the financing rate, from 80% to 0%, the sensitivity value related to this input variable remains very low, still close to 0%. The negative value of the effect on the output variable represents an inverse proportion between the variables, meaning that an increase in the inflation rate will always represent a decrease in the final balance sheet value.

Percentage of adhesion to home composting of residents in buildings with 1 or 2 dwellings in the 1st year/10th year - For the variable relating to the 1st year, a 10% change in its value implies a variation of 5.46% in the final balance of the period, while for the 10th year, a change of 10% means a variation of 4.54% in the final balance. The difference between these values and those collected with the non-zero funding rate is mainly due to the fact that, under these conditions, the price per composter supported by the municipality is significantly higher, causing the adhesion in the first year (in which the number of composters to be acquired is the greatest) has a greater impact, and the 10th year has a lower impact (less composters to be acquired from the 2nd year onwards). Both variables have positive values for the effect on the final balance, which represents a direct proportion between these and the output variable. This means that an increase in the percentage of adherence to home composting, both in the 1st and 10th year, will always represent an increase in the balance sheet value.

Percentage of composters to be replaced per year - Another variable with relatively low sensitivity is the percentage of composters to be replaced annually, with a negative change on the final balance 8.86% for every 10% change in this percentage. Despite this, regarding the values collected with a non-zero funding rate, there is a significant increase in sensitivity, since, with a zero financing rate, the value of the price per composter supported by the municipality is higher, making the costs to replace composters higher. The negative value of effect on the final balance represents an inverse proportion between the variables, meaning that an increase in the percentage of composters to be replaced per year will always represent a decrease in the balance sheet value.

Cost of training and monitoring and awareness of home composting in the 1st year from the 2nd year - For the variable relating to the 1st year, a 10% change in its value implies a negative variation of 15.18% in the final balance of the period, while for the variable related to values from the 2nd year onwards, a 10% change in its value implies a negative variation of 22.2%. As in the case where the funding rate is non-zero, the difference between these two is explained, in the same, by the fact that, while for the 1st year, the input variable only changes the value for the first of these 10 years, thus having less sensitivity and impact on the final balance sheet than the input variable for the 2nd year onwards, which influences the values of the remaining 9. Both variables have negative values for the effect on the final balance, which represents an inverse proportion between these and the output variable. This means that an increase in the cost of training and monitoring and awareness of home composting, both in the 1st and from the 2nd year, will always represent a decrease in the value of the final balance.

Average cost of collecting biowaste/undifferentiated - This input variable presents values considerable variation on the output variable for each 10% change, in this case, 43.26%. As in the case where the financing rate is non-zero, this high sensitivity value is mainly due to the fact that the value of this variable is preponderant in determining the costs that will be avoided for the municipality with the implementation of home composting, which in turn have a great weight in the final calculation of the return on investment and the final balance. The positive value of the effect of this variable on the final balance represents a direct proportion between the variables, meaning that an increase in the average cost of collecting biowaste/undifferentiated will always represent a increase in the value of the final balance.

Unit cost per composter in 2021 - This is the highest sensitivity value with a negative effect on the final balance of the period. As the financing rate, in this scenario, is zero (instead of 80%), the cost value per composter to be borne by the municipality is significantly higher, thus representing significant sensitivity values on the output variable. Most specifically, every 10% change in this input variable causes a negative change of 49.37% on the output variable. The negative value of the effect on the final balance represents an inverse proportion between the variables, meaning that an increase in the unit cost per composter in 2021 will always represent a decrease in the final balance sheet value.

Percentage of biowaste in urban waste - Finally, as in the context of non-zero funding, and for the same reasons, the input variable with the greatest sensitivity in this scenario is the percentage of bio-waste in municipal waste. However, this sensitivity is even more pronounced with a zero funding rate. With a higher cost per composter, it is very important, for the final balance, that this high cost is matched by a quantity of biowaste to be potentially composted in the municipality. This importance is reflected in the high values of variation on the output variable (96.66%) that a 10% change about the input variable causes. As it is visible in the results in which, being positive the value of the effect of this variable on the final balance, a direct proportion between the variables is represented, meaning that an increase in the percentage of biowaste in municipal waste will represent always an increase in the value of the final balance.

4.5 Validation

On October 8, 2021, through a Zoom meeting, the final state of the tool was presented to ZERO and ECOGESTUS entities, initially interested in its development, and responsible for its subsequent dissemination and implementation in the future. During the meeting, the functioning of the tool was demonstrated as if it were a municipal manager using it. During this process, feedback was collected on corrections to be made to improve it. At the end of the meeting, there was unanimous satisfaction among all representatives of these two entities about the relevance, detail and functioning of the tool.

4.6 Limitations

Although user-friendly, and with remarkably consistent results, the tool naturally has its limitations. One of them is the lack of data for some municipalities. The lack of one or both variables end up considerably conditioning the quantity and quality of information available to be presented to the user, as there are several calculations necessary for the construction and presentation of the report that use the values of these variables. In these circumstances, using the conditional IF function of Microsoft Excel, conditions areapplied to each of these variables that check whether the values in question are missing in the respective database or in the spreadsheet. If so, these conditional functions return the text “S/dados” in the missing data cell, so that the user understands the existence of this lack of data in the final report. In addition, and also via the IF conditional function (which checks in each of the cells relative to the values that may be missing if they have the string "S/ dados"), if there is missing data, it appears in the report, immediately before the graphics, a text message stating that “Due to lack of data, the following graphics may be incomplete”.

In addition to these limitations, it should also be noted to the user that the results of the tool may not be completely reliable, and therefore investments should not be made rashly and blindly based on them. At the time where the tool was developed, the 2021 Census' data wasn't yet available. Therefore, the data from 2011 had to be used. Therefore, the current data related to municipalities may vary from those used in the final tool. Despite of this, the tool will always have great flexibility to import more up to date data atany time.

Due to an exponential increase in the complexity of the tool, if theywere included, there are no variables in the tool that could have influenced the final values and conclusions drawn by the user, suchas, for example, the methane emissions related to the composting process itself, or even variations in the prices of composters depending on the quantity purchased by the municipality.

Variables representing the value created by the compost for agriculture were not included in the predictive calculations. It is known that home compost results in a compost that can be usedin an agricultural context as a fertilizer. In other words, in addition to the economic advantages associated with home composting discussed in this work, these advantages can be extended after the composting process itself, in the cost savings of fertilizers whose purchase is no longer necessary thanks to the incorporation of this compost. Of course, these values of additional savings would always vary greatly according to the characteristics of the municipality, which may have more or less agricultural land.

It is also worth noting the impossibility for the user to somehow change the layout of the report and the graphs presented in it, and to be able to only introduce limited values for the variables in the data entry sheet (limiting values with lists was an option assumed Dropdown, but increasing the practical and accessible component of the tool). Finally, another limitation to mention is that it is only possible to analyze data with the granularity of the municipality, and it is not possible to view results on more general parishes or regions.

5 Conclusion

This master's thesis aimed to develop a tool to support civil society. In order to allow a more informed decision-making when implementing home composting at the municipal level, through a forecast of a 10-year period of the return on the investment made and the corresponding environmental impact, with the flexibility regarding the possibility of the user to introduce the values related to the implementation conditions that will be used later in the calculations.

In order to carry out this project, several stages of preparation were passed through. Initially, a meeting was held with the associations interested in the development of the tool in order to define the termsin which it would have to be developed.

Then, the data that would need to be collected were defined, as well as their sources. After collecting, processing and loading them intothe tool, the equations and calculations necessary for the final analysis were developed.

Finally, aesthetic, and functional adjustments were made to the tool sheets, so that it was as easy as possible for the end user to understand.

In future works of the same kind as this dissertation, the possibilityof developing a tool with the possibility of analysis at the parish level would be relevant above all, with more current data than thosecollected for this one.

It would also be important to include in the analysis other variables and calculations that were not included in this work and that can also influence the results, making them even more consistent and reliable, through the inclusion of, for example, variables related to emissions of Methane from the home composting process, price fluctuations related to larger quantities of purchased composters or even avoided costs associated with agricultural fertilizers.

At a technological level, it would be interesting to include the possibility for the user to easily transform the final report to their liking, being able, in real time, to change the type of graph, the variables used, and the calculations performed, in order to further increase flexibility of the solution.

It would also be very relevant to develop a similar tool to this one, focusing on the topic of community composting instead. This could be achieved by replacing some of the variables used in this work. For example, by replacing the variable representing the number of residents in buildings with 1 or 2 dwellings, applicable to home composting, with the number of residents in buildings with more than 2 dwellings, applicable to community composting.

ACKNOWLEDGMENTS

I would like to thank my advisors (Célia Dias Ferreira and Verónica Oliveira) for their priceless help throughout the process of developing this Master Thesis. Without all their support this work could never have been completed. I would also like to thank the NGO ZERO and consulting company ECOGESTUS for their precious feedback during the initial development and closing phases and for making possible the implementation and disclosure of the tool to the Portuguese Civil Society.

REFERENCES

[1] B. K. Adhikari, A. Trémier, J. Martinez e S. Barrington, "Home and community composting for on-site treatment of urban organic waste: perspective for Europe and Canada," Waste Management & Research, vol. 28[7], pp. 1039-1053, 2010. DOI: 10.1177/0734242X10373801.

[2] A. V. A. Sabino Charrua, "Recolha seletiva de biorresíduos – medidas para a sua implementação," 2018. Master Thesis for Faculdade de Ciências e Tecnologias, Universidade Nova de Lisboa.

[3] Agência Portuguesa do Ambiente, "Estudo prévio sobre a implementação da recolha seletiva em Portugal Continental incidindo em especial sobre o fluxo de biorresíduos," EY, 2019.

[4] Decreto de Lei 102 D/2020. Diário da República n.º 239/2020, 1º Suplemento, Série I), 10-12-2020, pp. 1-2, Regime Geral de Gestão de Resíduos.

[5] I Diretiva 2018/851 do Parlamento Europeu. Jornal Oficial da União Europeia, pp. 1-32.

[6] SAPO MAGG, "Lidl lança compostor doméstico e só custa 24.99€," [Online]. Available: https://magg.sapo.pt/sustentabilidade/artigos/lidl-lanca-compostor-domestico-e-so-custa-24-99e. [Acedido em julho 2021].

[7] R. P. González-Sierra, J. S. Arizmendiarrieta, B. P. Sánchez, I. I. iriarte e G. N. Duarte, "Community Composting: A Practical Guide for Local Management of Biowaste," Zero Waste Europe Guides, vol. 01, 2019.

[8] V. Sousa, C. Dias-Ferreira, J. M. Vaz e I. Meireles, "Life-cycle cost as basis

to optimize waste collection in space and time: A methodology for obtaining a detailed cost breakdown structure," Waste Management & Research, vol. 36 (9), pp. 788-799, 2018. DOI: 10.1177/0734242X18774618.

[9] A. Gomes, M. Matos e I. Carvalho, "Separate collection of the biodegradable fraction of MSW: An economic assessment," Waste Management, vol. 28 (10), pp. 1711-1719, 2007. DOI: 10.1016/j.wasman.2007.08.017.

[10] V. Sousa, C. Dias-Ferreira, A. Fernández-Braña e I. Meireles, "Benchmarking operational efficiency in waste collection: Discussion of current approaches and possible alternatives," Waste Management & Research, vol. 37 (8), pp. 803-814, 2019. DOI: 10.1177/0734242X19854119.

[11] "Fundo Ambiental," 2021. [Online]. Available: https://www.fundoambiental.pt/avisos-2021/residuos-e-economia-circular/2-fase-do-programa-de-apoio-a-elaboracao-de-estudos-de-sistemas-de-recolha-de-biorresiduos.aspx. [Accessed in 27 October 2021]. DOI:https://doi.org/10.1007/3-540-09237-4.

[12] A. Silveira, J. Pina e J. B. Ana, "Metodologia para o planeamento de sistemas de recolha de biorresíduos," 2020. Faculdade de Ciências e Tecnologias da Universidade Nova de Lisboa, MARE and Fundo Ambiental.

[13] Instituto Nacional de Estatística, "INE - População, Alojamentos," 2011. [Online]. Available: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorr Cod=0006272&selTab=tab0. [Accessed in April 2021]. Conference Name:ACM Woodstock conference

[14] Instituto Nacional de Estatística, "INE - Superfície Territorial," 2011. [Online]. Available: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorr Cod=0007822&contexto=bd&selTab=tab2. [Accessed in April 2021].

[15] ERSAR, "Relatório Anual dos Serviços de Águas e Resíduos em Portugal Volume 1," 2020. [Online]. Available: http://www.ersar.pt/pt/site-publicacoes/Paginas/edicoes-anuais-do-RASARP.aspx. [Accessed in April 2021].