Life Cycle Assessment of Cemetery Waste of Oporto Region, Portugal

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Abstract

The valorization process of cemetery wastes of LIPOR was studied using the Life Cycle Assessment methodology. This process includes sorting of the wastes and sending the different fractions to the most technically suitable solution: green wastes are sent to composting; metals, paper and plastics are sent to recycling processes; some materials are sent to incineration and a residual amount of waste goes to landfill. The environmental impacts of the existing process and of the waste collection system were determined, using IMPACT 2002+. The conclusion of this phase was that globally this process has a very positive effect on the environment. However, negative impacts can be further reduced by optimizing internal routes. The waste collection system has a significant negative impact on environment and in global warming category. Afterwards the environmental impacts of different scenarios (incineration and landfill) were determined and it was possible to conclude that the solution with better environmental performance was the existing process, followed by the incineration both with benefic environmental impact, but the incineration alternative increases global warming. The worst scenario is landfill that has a negative environmental impact and contributes to increase global warming.

Keywords: LCA, Cemetery wastes, composting, incineration, landfill.

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Avaliação do Ciclo de Vida dos resíduos de cemitério da região do Porto, Portugal

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Resumo

O processo de valorização de resíduos de cemitério da LIPOR foi estudado recorrendo à metodologia Avaliação de Ciclo de Vida. Este processo inclui uma operação de triagem e o envio das diferentes frações para o destino mais adequado: resíduos verdes para compostagem; metais, papel e plásticos para reciclagem; alguns materiais para incineração e uma quantidade residual para aterro. Os impactos ambientais do processo existente e do sistema de recolha de resíduos foram determinados usando o IMPACT2002+. A conclusão desta fase foi que globalmente o processo tem um impacto positivo no ambiente. Contudo os impactos negativos podem ser reduzidos ainda mais otimizando as rotas internas. O sistema de recolha de resíduos tem um impacto negativo significativo no ambiente e na categoria aquecimento global. De seguida foram determinados os impactos ambientais de diferentes cenários (incineração com produção de energia e aterro), tendo sido possível concluir que a solução com melhor desempenho ambiental é o processo existente, seguido da incineração, ambos com um impacto benéfico no ambiente, embora a incineração aumente o valor relativo ao aquecimento global. O pior cenário é o aterro com um impacto ambiental global negativo, apresentando também um impacto negativo superior para o aquecimento global relativamente às outras alternativas.

Palavras-chave: ACV, resíduos de cemitério, compostagem, incineração, aterro.

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1 Introduction

The increase of population and the industrial revolution contributed to the increase of the generation of wastes. The migration of population to urban centers and modern society life style are other factors that aggravate the problem of solid wastes, increasing their generation and diversity. In 2012 cities generated about 1.3 billion tonnes of solid waste per year and the volume of wastes is going to increase to 2.2 billion tones by 2025 (World Bank 2012). By 2050, 66% of the world population will live in urban areas and municipal waste management will become a challenge since the choice of a given management system affects the environment and the quality of life of inhabitants, what makes this an important issue for local and national governments (Chifari et al. 2016). Waste can cause several environmental impacts such as pollution, water contamination, soil contamination and public health problems. The search for municipal waste management systems, which can decrease environmental and social impacts and are economically feasible, is being carried out in several countries and regions of the World since it can contribute to enhance sustainability (Simões & Marques 2012, Aparcana 2016, Havukainen et al. 2017, Sarra et al. 2017).

The European Union (EU) has introduced many policy instruments and targets since the 1990s. The waste hierarchy presented in the Directive 2008/98/EC (EU 2008) defines priorities for waste prevention and management. However, this hierarchy can be changed if supported by a life-cycle thinking study or if a global approach is used to design the integrated waste management (Herva et al. 2014). Also legislation on specific waste streams, such as packaging, vehicles, electrical and electronic equipment and waste treatment options, such as landfill and others were introduced (EU 1994, 1999, 2000, 2012). Due to the scarcity of resources, waste prevention and management are very important to create a circular economy, which is currently one of the European Union strategies (EEA 2016). However, there is still a long way to achieve sustainable solutions and improve existing systems because in 2011 statistics showed that the EU continued to burn and bury between 60% and 100% of municipal solid waste (MSW) (Hornsby et al. 2017). Waste management is a complex task and it is constituted by several operations such as storage, collection, transport, transfer, sorting, composting, incineration, etc., and several MSW forecasting methods, technologies and decision support systems were studied and developed (UNEP 2005, UNEP 2009, Ghiani et al. 2014, Abbasi & Hanandeh 2016, Melaré et al. 2017).

Life cycle thinking is nowadays a strategy applied in several sectors and the solid waste sector is no exception and it can be an important tool in the decision-making process. Life Cycle Assessment (LCA) is used to determine the environmental impacts (Guinée 2002, Varanda et al. 2011). In solid waste sector, LCA has been used to compare different waste management routes and assess environmental performance (Tarantini et al. 2009, Van Haaren et al. 2010, Beylot & Villeneuve 2013, Boesch et al. 2014, Ferreira et al. 2014, Parkes et al. 2015, Rigamonti et al. 2016, Ripa et al. 2017).

LIPOR – Intermunicipal Waste Management of Greater Porto is responsible for the management, recovery and treatment of the Municipal Waste produced in eight Portuguese' municipalities. Its intervention area represents 1% of the geographical area of Portugal, 10% of the population and 12% of the municipal waste national production.

Adopting an integrated waste management strategy, based on multimaterial, organic and energy recovery, complemented by a landfill and clearly assuming that this approach is carried out from the point of view of resource management, LIPOR concentrates all efforts on the most appropriate valuation of its waste in order to promote sustainability (LIPOR 2013a).

In 2004, it starts the sorting of green waste from cemeteries produced in the LIPOR's municipalities, having been created a platform for reception and separation of those materials. This was a pioneer and innovative process in Portugal.

Currently, LIPOR receives waste from more than 100 cemeteries of those 8 municipalities, resulting in a wide variety of materials with valorization potential, for which LIPOR has a valorization process. In this work LCA methodology was used to determine the environmental impacts and the contribution to climate change of LIPOR's valorization process of cemetery wastes. LCA was also used to compare the environmental impacts of different scenarios (incineration and landfill) with the results for the existing process.

2 Methods

In this section Life Cycle Assessment will be addressed. LCA was performed in four steps, namely goal and scope definition, inventory, impact assessment and interpretation (ISO 2006).

Goal and scope definition. The purpose of this work was to perform a life cycle assessment of the LIPOR's valorization process of cemetery wastes and to compare its environmental impacts with the environmental impacts of other scenarios to manage cemetery wastes. The LCA was performed with a "gate to grave" approach: thus, the system boundary begins at the collection of cemetery wastes. The life cycle of cemetery wastes is presented in Figure 1 and the stages considered for the existing valorization process are inside the line, which establishes the system's boundary.

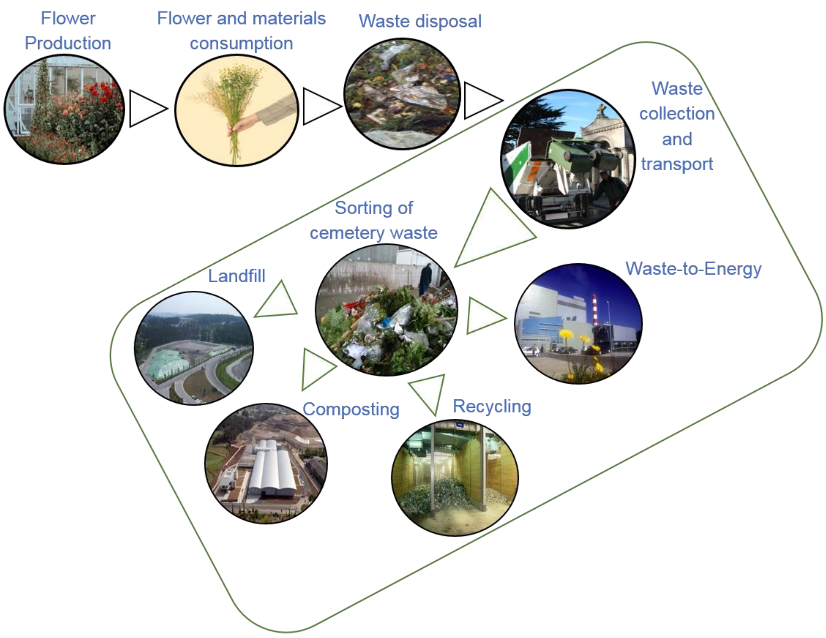

Figure 1. Life cycle of cemetery wastes

Functional unit. The functional unit defined to this study is 1 kg of cemetery waste. In 2013 the production of cemetery solid wastes for the 8 municipalities of LIPOR was 3 270 880 kg.

Figure 2 presents the existing valorization process and the other two scenarios considered (energetic valorization and landfill). In the existing process the landfill disposal is not represent because it corresponds to 0.3% of the total cemetery wastes although its environmental impacts were calculated.

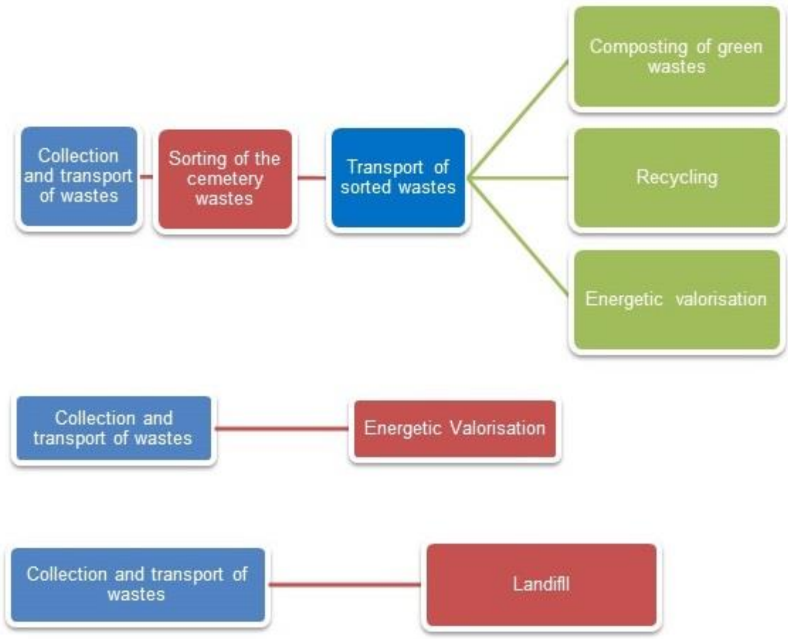

Figure 2. Existing valorization process and other scenarios

In the existing solution 77.2 % of the cemetery wastes are sent to composting, 16.4 % to energetic valorization and the remaining to recycling. In the landfill scenario, the total quantity of cemetery wastes is sent to landfill, and in the energetic valorization the total quantity of cemetery wastes is sent to incineration with energy recovery.

Inventory. In this study 110 cemeteries located in the 8 municipalities of LIPOR were considered. The average distances between the cemeteries of each municipality and LIPOR was estimated and is presented in Table 1. The collection and transportation of wastes are carried out by local authorities and data were gathered for the year 2013. All trucks used in the transport were identified and classified according to the European emission standards (EURO classification). This study was based on primary data given by the operator or available in bibliography and on secondary data given by proper LCI (Life Cycle Inventory) data sets available on SimaPro 8.3.0.0. Operator information was used to determine the environment impacts of the valorization process of cemetery wastes, composting and energetic valorization (LIPOR 2013a, b). Bibliography data (Ntziachristos & Samaras 2012) was important to determine environmental impacts of transport, and data sets of SimaPro were used to determine environmental impacts for transport and all other processes not mentioned before.

Table 2 presents the inputs to the valorization process and Table 3 the outputs of the sorting phase and final disposal of wastes in 2013.

Allocation. In LCA studies the allocation procedure is very important. The system expansion or substitution option is the preferred option in LCA studies about waste management systems. For this method to be applied the system should also deliver co-products besides doing the waste treatment. This was the method applied in this work. The Portuguese electricity production was chosen as the avoided process for the electricity produced in energetic valorization and the fertilizer ammonium nitrate was chosen as the avoided process for the compost produced in composting. For these products the replacement ratio is equal to one as well as for the other recycled materials such as metals, paper and plastics. For glass, the ratio considered was about 1:0.2. All processes considered are for the RER region (Europe) and the avoided processes can be subtracted from the waste treatment process (Zhao et al. 2009).

Table 1. Average distances, number of cemeteries and waste mass collected from each municipality in 2013

Municipalities	Number of cemeteries	Average distance (km)	Number of discharges	Waste mass (kg)	Percentage
Póvoa do Varzim	5	38.4	53	182 740	**5.6**
Vila do Conde	31	30.8	69	391 660	**12.0**
Valongo	8	6.9	106	290 880	**8.9**
Maia	20	14.6	116	548 920	**16.8**
Porto	8	12.7	379	604 940	**18.5**
Gondomar	19	17.2	179	604 280	**18.5**
Matosinhos	14	12.7	152	494 700	**15.1**
Espinho	5	33.5	53	152 760	**4.7**
Total	110	-	**1107**	**3 270 880**	**100.0**

Table 2. Inputs of the valorization process in 2013

Waste mass (kg)	Electric energy consumption (kwh)	Diesel consumption (kg)	Water consumption (m^3)
3 270 880	20.8	2 492.6	10

Table 3. Outputs of the sorting platform in 2013

Type of material	Number of discharges	Waste mass (kg)	Percentage	Final disposal
Metals	13	50 040	1.6	Recycling
Candle supports	112	96 780	3.1	Recycling
Packages	21	8 040	0.3	Recycling
Glass	1	7 020	0.2	Recycling
Paper/Cardboard	13	7 700	0.2	Recycling
Plastics	1	22 960	0.7	Recycling
Rejected materials	247	511 740	16.4	Energetic Valorisation
Green wastes	672	2 404 240	77.1	Composting
Others	23	8 920	0.3	Landfill
TOTAL	**1 176**	**3 117 440**	**100.0**	

Impact assessment. The methodology applied was the "IMPACT 2002+" that proposes a feasible implementation of a midpoint in a combined approach to damage. The level categories considered are aggregated in four damage categories: climate change, ecosystem quality (aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification and nitrification, land occupation), human health (ionising radiation, respiratory effects (inorganics), photochemical oxidation, ozone layer depletion, human toxicity) and resources (non-renewable energy and mineral extraction). In this methodology the results are expressed in points due to the normalization which facilitates calculations. A default weighting of 1 was considered, meaning that all categories have the same weight. Figure 3 presents the results of the impact assessment for transport. The overall impact for this process (transport) is 11.2 points and the emissions of CO_{2eq} are 29.6 t for 2013. The damage categories human health and climate change are the ones that presented the highest values which are in accordance with the main inputs and outputs of this process: fuel consumption and air emissions.

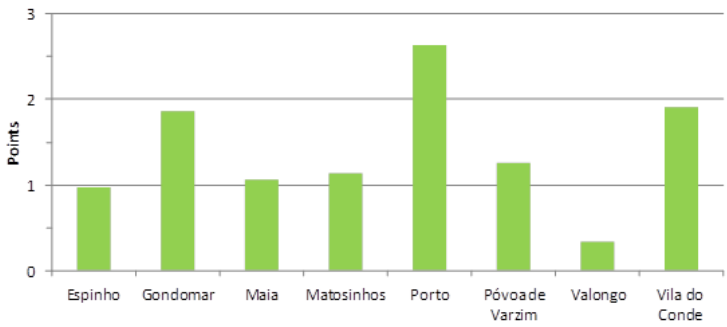

Figure 3. Environmental impacts for waste transport in 2013

Table 4 presents the environmental impacts of the valorization process. The operations that contribute most to the negative environmental impacts are the internal transport (truck), the electricity (sorting line) and the diesel consumption (machine). The composting process, the recycling processes and the energetic valorization have a positive environmental impact, but energetic valorization contributes negatively to climate change category. Overall, the existing valorization process is environmentally beneficial with -631,5 points. The scenario energetic valorization is also environmentally beneficial with -39.8 points but the landfill option is environmentally damaging with 66.6 points.

Table 4. Environmental impacts for the existing process and scenarios

		Total (µPt/kg waste)	Climate Change (kg CO_{2eq}/kg waste)
Valorization process	Collection and transport	3.4150	0.0090
	Water consumption	0.0002	9.38x10-7
	Electricity consumption	1.0572	0.0044
	Diesel Consumption	0.7312	0.0019
	Composting	-176.02	-0.9356
	Energetic valorization	-2.4401	0.0137
	Internal transport	0.2798	0.0010
	Recycling Processes	-21.8890	-0.09208
	Landfill	0.0106	3.22x10-5
	External transport	1.7891	0.0077
	Total	**-193.066**	**-0.990**
Scenario landfill	Collection and transport	3.4150	0.0090
	Landfill	16.9601	0.1300
	Total	**20.3751**	**0.1390**
Scenario energetic valorization	Collection and transport	3.4150	0.0090
	Energetic valorization	-15.5964	0.0876
	Total	**-12.1814**	**0.0966**

Note: µPt = micropoints

Interpretation and sensitivity analysis. From the analysis of Table 4 it is possible to conclude that the municipality that presents a higher environmental impact for transport is Porto, followed by Vila do Conde and Gondomar, and the same result was obtained for the damage category climate change. But the environmental impacts observed for each municipality are a function of several variables such as distance between the cemeteries and LIPOR, the amount of wastes transported by voyage and the characteristics of the vehicles. It is possible to conclude that there is not always proportionality between the amount of wastes transported and the environmental impacts calculated. Porto generates the highest amount of wastes and presents a medium distance. Gondomar generates almost the same amount of wastes and presents a higher distance, which, conjugated with the calculated indicator, shows a good efficiency in the use of vehicles (more modern and use of full capacity). Vila do Conde, Póvoa de Varzim and Espinho are municipalities that are located far from LIPOR when compared with the other municipalities, and this greater distance affects greatly the environmental impact due to transport. However, both Póvoa de Varzim and Espinho present a low waste generation.

The existing valorization process is a good option from an environmental point of view, presenting a strong benefic impact on environment. Climate change is very important nowadays and is one of the challenges that should be addressed by all sectors and stakeholders. Considering the category of damage, climate change, the existing solution is also beneficial since it contributes to the mitigation of greenhouse gas emissions. The different scenarios considered are a sensitivity analysis to the different options to manage cemeteries wastes. From the analysis of Table 5 it is possible to conclude that from an environmental point of view the existing valorization process is the best option. The overall indicator for this solution is 16 times better than for energetic valorization. Disposal in a landfill is the worst solution of all, presenting an overall positive indicator, which means that it has damaging environmental impacts. Considering the category of damage climate change, it is possible to conclude that the existing process is by far the best solution because it presents a negative value for the indicator while the other two scenarios present a positive value for this category, although energetic valorization presents an indicator 30% lower than the landfill scenario. In almost all operations of the valorization process the categories of damage that present the highest environmental impacts (positive or negative) are human health and climate change. The same happens for the two scenarios studied.

In LIPOR's existing process the environmental impacts are relatively small. The opportunities found for improving the existing solution were mainly related to the transport of the wastes (load optimization, use of more efficient vehicles, etc.).

The goal of the present work was to carry out a LCA of cemetery wastes. An economic analysis as well as the study of other dimensions such as social and sustainability issues are out of the scope of the present work. However, those other dimensions maybe explored in future works.

3 Conclusions

The results of this study demonstrated that LIPOR's decision concerning the implementation of this innovative process for cemetery wastes in 2004 was the best option from an environmental point of view, presenting environmental benefits and contributing to the reduction of greenhouse gas emissions. In addition, it is a source of raw materials for the composting central (green wastes) and sorting plant (recycling materials).

The operation exclusively managed by LIPOR, the sorting process, does not present many opportunities of improvement since the negative environmental impacts are already low, but the internal routes can be optimized to further reduce the fuel consumption and consequently the negative environmental impacts.

The waste collection system has a significant negative environmental impact, namely in climate change category. Considering this process, it was possible to conclude that the environmental impacts could be reduced, e.g. by using full capacity of vehicles, vehicles of higher EURO classes, vehicles that use fuels with lower environmental impact, etc., opportunities that should be further explored by the local authorities responsible for this process.

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