**Environmental Engineering and Management Journal** *March 2018, Vol.17, No. 3, 611-619*
*http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu*

***"Gheorghe Asachi" Technical University of Iasi, Romania***

# EVALUATION OF MUNICIPAL SOLID WASTE BY MEANS OF LIFE CYCLE ASSESSMENT: CASE STUDY IN THE SOUTH-WESTERN REGION OF THE DEPARTMENT OF NORTE DE SANTANDER, COLOMBIA

**Oscar Orlando Ortiz-Rodriguez[1]*, Héctor Uriel Rivera-Alarcón[2], Raquel Amanda Villamizar-Gallardo[3]**

[1]*University of Pamplona, Department of Industrial Engineering, Pamplona, Norte de Santander, Colombia*
[2]*University of Pamplona, Department of Environmental Engineering, Pamplona, Norte de Santander. Colombia*
[3]*University of Pamplona, Department of Microbiology, Pamplona, Norte de Santander, Colombia*

## Abstract

The main objective of this research was to evaluate the environmental impact generated by municipal solid waste during its collection, transportation, treatment and processing in the south-west region of the department of Norte de Santander, Colombia, by means of Life Cycle Assessment (LCA). Three strategies for waste management were considered: the current baseline situation, wherein 100% solid waste was taken to the landfill; plus, an optimistic and a pessimistic scenario in which solid waste is properly and moderately recycled, respectively.

The results show that approximately 72% was organic waste, out of which 40% corresponded to organic material. Twenty seven percent corresponded to inorganic materials such as plastics, metal, glass, rubber and leather. In comparing waste management in the three proposed scenarios in terms of global warming, the optimistic scenario was the greenest one due to better Municipal Solid Waste (MSW) recycling and usage, since it prevents the emission of 460 kg $CO_2$Eq inhab$^{-1}$ year$^{-1}$. Finally, to achieve the reuse and recycling of waste, we propose the creation of small businesses which can improve people's socio-economic conditions. This will undoubtedly become a source of employment for many families in the community. Acceptance of composting is still low in the region because most farmers in rural areas show psychological resistance to products derived from waste, thus being more responsive to fertilizers. Finally, there is no doubt that LCA is definitely a methodology that helps decision making towards finding more sustainable solutions and hence is a good tool for improving environmental sustainability performance within the Municipal Solid Waste of the rural areas.

*Key words:* environmental impact, life cycle assessment, municipal solid waste, recycling

*Received: May, 2013; Revised final: June, 2014; Accepted: July, 2014; Published in final edited form: March 2018*

## 1. Introduction

The rapidly growing populations as well as economies brings as a consequence an increase in waste generation, which becomes a challenge for health authorities and the environment of any city or country. Inappropriate management of municipal solid waste (MSW) can lead to the contamination of water sources due to leakage percolation which, consequently, causes public health issues (Henry et al., 2006; Mor et al., 2006; Rusu et al., 2017).

Solid waste has been associated to diseases such as viral hepatitis, acute diarrhea, intestinal parasitosis, skin illnesses, allergies, breathing diseases

* Author to whom all correspondence should be addressed: e-mail: oscarortiz@unipamplona.edu.co; Phone: +573132613340; Fax: +575685303 ext. 154

and conjunctivitis, among others. The transmission of infections can take place directly through contact with waste or indirectly through the vectors that live in landfills. This is so because waste is an adequate environment for the proliferation of flies, mice, birds, cats and dogs among others (WRI, 1996).

Inadequate waste management is more frequent in developing countries, where consumption patterns are constantly changing due to the introduction of new products into the market and to the lack of strategic policies for improving production and sustainable consumption. In Colombian cities and municipalities, this situation is enhanced by additional factors such as the displacement of people from the countryside to the city, inadequate management of public resources, and the lack of adequately qualified human talent to effectively apply environmental policies. All this undoubtedly renders ineffective solid waste management systems which, in turn, determine very precarious public health and environmental perspectives. Most of the researchers who have conducted studies this topic (Al-Khatib et al., 2007; Bel and Mur, 2009; Bovea et al., 2010; Del-Moral-Avila et al., 2016; Kanat, 2010; Kumar and Goel, 2009; Li et al., 2011; Moy et al., 2008; Magrinho et al., 2006; Okot-Okumu and Nyenje, 2011; Zarate et al., 2008) considered that the main factors determining total waste generation are urbanization, demographic growth and industrialization.

Due to the inherent difficulties in controlling economic and demographic growth and, consequently, waste production, it is necessary to improve processes such as recovery, recycling and MSW elimination, the aim of attaining their sustainable management (Al-Salem et al., 2009; Turan et al., 2016; Zhanga et al., 2010).

At the international level, resources like the MSWM (2010) have been developed. This document constitutes a response to the Rio Declaration and the recommendations of Agenda 21, looking forward to promote the transfer and application of ecologically rational technologies and finally improve MSW. At the national level, Resolution 1045 of 2003 and Decree 1713 of 2002 establish and regulate policies intended to adequately reach an integral solid waste management.

Local data indicate that in 2010 Colombia produced 27,500 tons of solid waste a day (1,056 municipalities and 32 departments) composed of 81% organic solid waste, 13% plastic, 3% paper, 1% glass and 2% metal (Marmolejo et al., 2012). As stated by Barton et al. (2008), different countries and cities require different waste management systems. Furthermore, there is need to generate alternatives that minimize the environmental impact of these residues, which reveals the importance of either implementing reutilization or recycling strategies when possible, or of providing efficient gathering and transportation to safe final disposal sites.

Life cycle assessment (LCA) is an environmental management methodology that has been applied to the case of solid waste with the aim of evaluating the environmental sustainability of these systems from an ecological perspective (Francesco-C et al., 2009; Ghinea et al., 2014; Regina-Mendes et al., 2010; Wittmaier-M et al., 2009; Zeng et al., 2005). These studies leave no doubt about the importance of applying LCA when it comes to minimizing the environmental impact of these residues in order to improve the sustainability indicators in our region.

Hence, the main objective of the current paper has been to evaluate the environmental impact generated by municipal solid waste during the collection, transportation, treatment and processing in the south-west region of the department of Norte de Santander, Colombia. Thus, this is the first study to apply LCA in this department and to promote MSW reutilization and recycling as an option to mitigate its environmental impact, especially global warming, acidification and human toxicity. In this way, the current study could be used as a MSW integrated management system in the municipalities of the most important rural areas of this region, thus facilitating environmental impact minimization and the sustainability of the process over time.

## 2. Methodology

### *2.1. Selection of study area*

The department of Norte de Santander is made up of 40 municipalities grouped into six sub regions, namely North, West, East, Center, Southwestern and South East. The current study focused on the Southwest region of the department, which includes the municipalities of Cacota, Chitagá, Cucutilla, Mutiscua, La bateca, Pamplona, Silos and Toledo. The choice of this subregion results from the fact that it is the second most important one in the department due to its location, urbanization process and economic and demographic growth during the last five years. Additionally, *La Cortada* landfill, located in the municipality of Pamplona, receives the MSW of the mentioned municipalities, which facilitates data collection.

### *2.2. Description of MSW collection*

The solid waste collection system in the different municipalities mentioned in section 2.1 follows the scheme. This figure shows how MSW collection starts by sending the collecting trucks (1) along the macro routes defined in each municipality. The gathering is done once or twice a week in all neighborhoods. The method employed is door to door collection of the waste people pack in polyethylene bags, cardboard boxes or plastic containers (2a); or simple collection from the metallic containers set in each municipality (2b). Later on, the truck takes the collected waste directly to the landfill, where it is covered and compacted with clayey soil (3) (Fig. 1).

*La Cortada* landfill receives the MSW of the different municipalities of the South Western region of the department of Norte de Santander. Covering an area of 28 ha, the landfill is located in the municipality of Pamplona, at kilometer 4 on the north east side of the road that leads to the municipality of Chitagá. With only 3 ha currently in use as waste cells, it has been in operation for two years and a half. Table 1 shows the number of collecting trucks per municipality, their capacity and number of discharges to the landfill per week, as well as the distance they cover, including the gathering process.

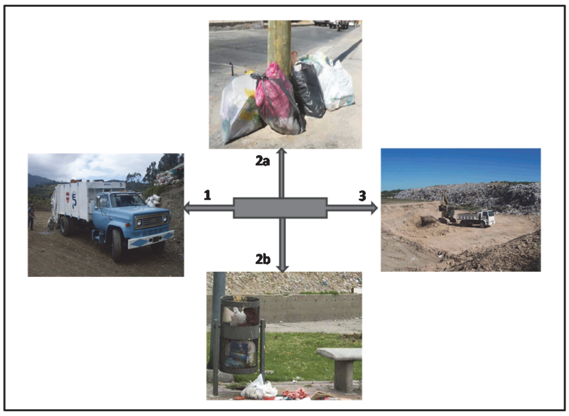


**Fig. 1**. Typical garbage collection system in the Southwest subregion of the department of Norte de Santander.

### *2.3. MSW characterization*

MSW characterization was carried out during September of 2011, applying the Official Mexican standard NMX-AA-015 (1985). The analyses were carried out during November of that year, on the total MSW produced by the different municipalities under study. Each collecting truck discharged its load on the corresponding site, where residue sampling covered an area of 4 x 4 m.

Sample extraction itself was done by 4 different work teams, each of them made up of 4 people. In the first place, the solid residues were removed with shovel until homogenization. Then, they were divided in equal quadrants named A, B, C and D, which were assigned clockwise to the sampled waste plot. Out of these quadrants, two opposed ones (for example A and C or B and D) were eliminated. This process was repeated until reaching maximum and minimum sample weights of 200 kg and 50 - 60 kg, respectively. Later on, the subproducts were selected according to section F of the sector's Rules and Regulations by the Mexican standard NMX-AA-015 as follows: 1. Food and garden residues, 2. Paper products, 3. Cardboard products, 4. Plastics, 5. Rubber and leather, 6. Textiles, 7. Wood, 8. Metal products, 9. Glass, 10. Ceramic products, ashes, rocks and debris, 11. Bones, 12. Others.

From the waste eliminated before the actual sampling, 1 to 3 kg of solid waste were taken to the laboratory for physical, chemical and microbiological analyses. The samples thus obtained were transported in plastic bags correspondingly labeled, and refrigerated in boxes. The remaining waste was used to calculate the volumetric weight of residues in that site. Upon completion of the quartering and having sectioned the entire sample, we proceeded to segregate the 12 lines of products specified in the Mexican standard NMX-AA-015.

The volumetric weight determination was carried out according to Mexican standard NMX-AA-19 (1985) through the following Eq. (1):

$$P_V = P / V \quad (1)$$

where: $P_V$ = is the volumetric weight in kg m$^{-3}$, $P$ is the weight of solid waste (less gross tare weight) in kg and $V$ is the container volume in m$^3$.

### *2.4. Life cycle assessment (LCA) methodology*

Life Cycle Assessment (LCA) is an environmental management methodology that evaluates the environmental impacts of a product or service, starting from extraction of raw materials, manufacturing, production, use and finishing with the final disposal, that is, from cradle to grave (Ortiz-R et al., 2009). Following ISO 14040 International Standards, the LCA methodology is based on four essential phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. *2.4.1. Goal and scope definition*

The overall scope of this paper involves the environmental loads generated by municipal solid waste during the collection, transportation, treatment and processing. In this research, the functional unit is defined as the amount of waste produced in the year 2011 by the rural areas with a density of 20 inhabitant's km$^{-2}$ generated per capita. Table 2 details some relevant aspects of the definition and scope of the case study:

**Table 1**. MSW collection data in the different municipalities of the Southwestern region of the department of Norte de Santander

| *Municipality* | *No. Trucks* | *Capacity (t)* | *No. of loads per week* | *Travel distance to landfill (Km)* | *Solid waste per capita (kg day$^{-1}$)* |
|---|---|---|---|---|---|
| Cacota | 1 | 10 | 1 | 43 | 0.96 |
| Chitagá | 1 | 10 | 2 | 58 | 0.70 |
| Cucutilla | 1 | 10 | 1 | 54.5 | 0.90 |
| Mutiscua | 1 | 10 | 1 | 35 | 1.20 |
| La bateca | 1 | 10 | 1 | 37 | 0.84 |
| Pamplona | 2 | 10 | 2 | 12 | 0.84 |
| Silos | 1 | 10 | 1 | 49 | 0.92 |
| Toledo | 1 | 10 | 2 | 51 | 0.39 |

**Table 2.** Processes defined to establish LCA definition and scope

| *Definition* | *Concept* | *Description of impact* |
|---|---|---|
| Collection – transport | It considers the impact of residue collection and transport to the landfill. | Environmental evaluation of fuel consumption in the different macro routes leading to the landfill. |
| Final disposal of solid waste in the landfill. | Evaluation of residue and/or product processing strategies. | Evaluation of the impact produced by inputs such as fuel and electric power used in the process (tractor employed for soil removal, compactors), as well as the environmental impact of residues once they are in the landfill. |

The different final disposal scenarios for the management of the wastes generated are described as follows:

*Landfilling*: all the wastes are disposed to landfill. This scenario includes the dump infrastructure, the use of land and the effect of the landfilled waste (leachate). Wastes that are to be landfilled are special wastes disposed of in underground deposits or controlled landfills, inert wastes are disposed of in inert material landfills and non-special wastes are disposed of in landfills or sanitary landfills.

*Recycling:* Two recycling scenarios are considered, see Table 4 for each description. In both scenarios, recyclable wastes are sent to a local recycling plant located in the city of Pamplona which is located 8km from the sanitary landfill; non-recyclable wastes are sent to landfill. This scenario takes into account the plant infrastructure, recycling process, products obtained and wastes generated.

*2.4.2. Life cycle inventory analysis*

Life cycle inventory analysis involves data collection and calculation in order to quantify the inputs and outputs of a product or service. At each of these stages of the process, inputs (materials, resources and energy) and outputs (emissions to the air and water, as well as solid waste) were calculated. Fig. 2 shows a schematic diagram of the inputs and outputs of the process.

Finally, the following assumptions have been considered in the present study:

-LCA calculation regarding electric generation was used for the year 2011 corresponding to 56,887 GWh. This involves an energetic mix made up of hydroelectric power 80%, cycle combined 12%, coal 7% (adapted from Ortiz et al., 2010).

- population mixes all their waste in unclassified polythene bags. Bag manufacturing was not counted in the environmental impact study.

- emission factors: 3% Sulphur is annually released into the atmosphere as $H_2S$.

- emission factors of biogas combustion: CO (800), $NO_2$ (100), HCl (12), HF (0.02 mg $m^{-3}$).

- gas emissions of the leachate as affected by waste treatment were measured in terms of $CH_4$ (55%) and $CO_2$ (45%). $CO_2$ emitted in the landfill is of the biogenic type; therefore, it was not taken into account in the calculation of global warming.

- heavy metals released into the atmosphere: Mercury (Hg) and Cadmium (Cd) mainly due to discarded batteries

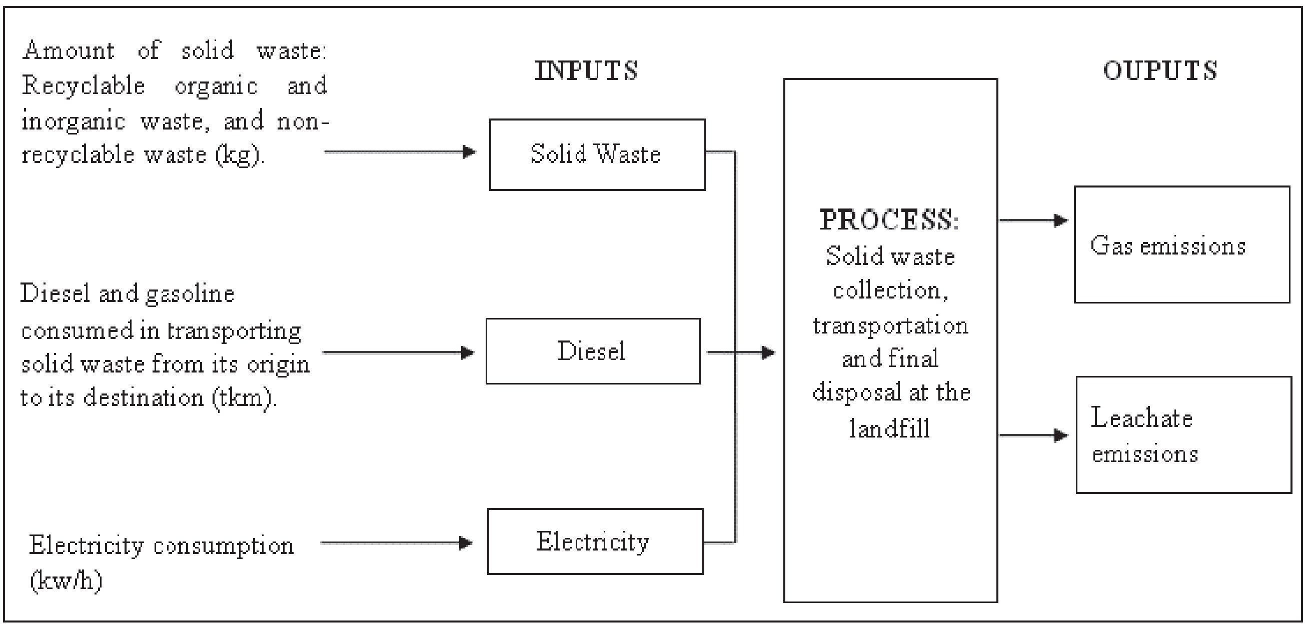


**Fig. 2.** Diagram of the current landfill operation as evaluated by LCA.

*2.4.3. Life cycle impact assessment*

The Ecoinvent V2.01 database was used to obtain the inventory data of the processes involved in the study. The actual impact assessment is based upon the CML 2 method (CML, 2001) developed by Leiden University's Centre for Environmental Science (CML, 2001). In the present case study, we categorized Global Warming (GWP) (kg$CO_2$-Eq), Acidification (AP) (kg $SO_2$-Eq) and Human toxicity HT (kg 1.4-DCB-Eq). Finally, the last phase of LCA is interpretation, corresponding to result analysis and discussion.

## 3. Results and discussion

*3.1. SMW characterization results*

Solid waste collected in different municipalities of the southwestern subregion were mainly generated by households and commercial establishments, which is consistent with previous research reported by Marmolejo et al., (2012), in the sense that urbanization and population growth are some of the most influential factors affecting total waste generation.

The residues were grouped in twelve categories of practical management according to their (organic or inorganic) nature and to their treatment vocation. Recyclable material averaged 27%, while rubber, leather and metal products showed a relatively low participation. This is partly due to the increasing substitution of these metals in the packaging and presentation of consumer home products. This allows stating that household waste is not a major source for the recycling of these materials. In the case of glass and plastic we can see a greater representation. In most significant waste fractions organic material were found which include Kitchen garbage and yard waste and other types of biodegradable material and other plastics waste made from PVC and polyethylene bags. In addition, residues of cardboard, paper, textiles including rubber and leather, wood and ferrous and nonferrous metals and ceramic products waste were also found. Table 3 shows the composition of these samples

Determining the volume and type of recyclable materials involves selecting those that are to be collected, since not all materials generated in a municipality can be selected. Some may be discarded due to low available volumes resulting in economic unfeasibility, or to lack of destination markets in the area. It is important to remember that the market situation is constantly changing, so a non-viable product at a given time may become feasible later on, and vice versa.

The percentage of treatable organic materials is comparatively more representative (66%), which allows the possibility to introduce some kind of utilization at the source. When comparing the results to the literature (Marmolejo et al., 2012), in most cases the organic material ranges from 25% to 65% of residential MSW, while paper values are constant, ranging between 20% and 40% weight in most cases.

For their part, textiles (typically in the range of 2 - 5% by weight), together with paper and organic matter explain most of solid waste flow. Finally, untreatable hazardous waste such as batteries and disposable diapers represent 1 - 4% of household waste by weight. Fig. 3 shows the total MSW composition data employed for the current LCA of the south-western region of the department of Norte de Santander.

Within the characterization of the studied waste, Pamplona is outstandingly important as the second municipality of the department due to its great demographic and urban growth during the last 10 years. This condition has mainly resulted from the student population increase, which, through the University of Pamplona, is the base of the city's economy. This information is essential not only to design an appropriate system of integrated waste management, but to provide support for rural development planning in the province since the landfill is located on the perimeter of the city.

**Table 3**. Classification of MSW from different municipalities in the south-western region of the department of Norte de Santander, Colombia.

| *Residue category* | *Cacota* | *Chitaga* | *Cucutilla* | *La Bateca* | *Toledo* | *Mutiscua* | *Pamplona* | *Silos* |
|---|---|---|---|---|---|---|---|---|
| Domestic MSW arising (kg capita$^{-1}$ day) | 0.96 | 0.70 | 0.90 | 0.84 | 0.39 | 1.20 | 0.84 | 0.92 |
| Organic material (%) | 53 | 34 | 33 | 40 | 31 | 41 | 41 | 40 |
| Paper (%) | 4 | 6 | 9 | 5 | 6 | 7 | 5 | 6 |
| Cardboard (%) | 6 | 10 | 11 | 7 | 11 | 6 | 9 | 9 |
| Plastic (%) | 6 | 8 | 10 | 6 | 16 | 7 | 7 | 6 |
| Rubber and leather (%) | 4 | 0 | 4 | 2 | 3 | 5 | 1 | 7 |
| Textiles (%) | 5 | 13 | 6 | 4 | 9 | 7 | 6 | 4 |
| Wood (%) | 0 | 0 | 0 | 5 | 2 | 3 | 2 | 0 |
| Metallic products (%) | 5 | 5 | 6 | 5 | 4 | 2 | 6 | 6 |
| Glass (%) | 7 | 9 | 15 | 12 | 9 | 10 | 12 | 14 |
| Ceramic products (%) | 0 | 0 | 0 | 3 | 0 | 0 | 4 | 1 |
| Bones (%) | 2 | 6 | 3 | 7 | 3 | 3 | 2 | 0 |
| Others (%) | 8 | 9 | 3 | 3 | 5 | 9 | 6 | 8 |

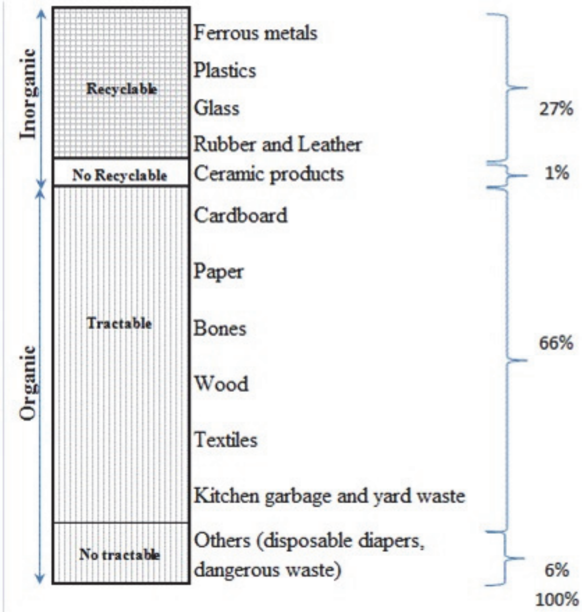


**Fig. 3.** Domestic solid waste percent composition in the south western region of the department of Norte de Santander.

*3.2. LCA Results*

Although the landfill is not classified as a treatment, it is, indeed, a component of solid waste final disposal, and a baseline scenario for calculating the environmental impact of MSW at *La Cortada* landfill. This implies the temporary persistence of the current practice of disposal without recovery of recyclable materials, nor any processing, composting, worm composting, incineration, pyrolysis, thermolysis, gasification, or other waste treatment.

From the figure above, it can be seen that the main environmental impact in the global warming category corresponds to final disposal in the landfill (95%), followed by electricity (4%) and transportation (less than 1%). The biggest impact in this stage of the process is due to air emission of methane (83%) and nitrogen oxide (10%), resulting from the biodegradation of MSW. With respect to the process, the main source of emissions is organic waste (44%), cardboard (34%), paper (19%), plastic (1%) and other residues (2%).

According to the environmental impact of human toxicity, the process represents 98%. The remaining 2% corresponds to electricity. Finally, 77% of adverse environmental impact of acidification belongs to the process. The contribution to acidification is due to air emission contributing compounds such as $SO_2$ by 53% and 47% $NO_2$, from the process of biodegradation of the waste. Fig. 4 shows the total environmental impacts of the studied MSW.

According to the environmental impact of human toxicity, the process represents 98%. The remaining 2% corresponds to electricity. Finally, 77% of adverse environmental impact of acidification belongs to the process. The contribution to acidification is due to air emission contributing compounds such as $SO_2$ by 53% and 47% $NO_2$, from the process of biodegradation of the waste (Fig. 5).

Finally, in the studied municipalities there are no companies that are using byproducts of solid waste development, so that the description of the environmental impacts is focused on the collection and transportation, sweeping and cleaning of public areas and final disposal of waste. Regarding the collection and transportation of solid particulate material generated, and $CO_2$ emissions produced from internal combustion engines. Vehicles transporting waste were the major sources of particulate pollution as the compactors produced little pollution.

Particulate material generated by sweeping and cleaning public areas has a short-term impact, and goes to the Cortada landfill, which has an environmental license. In addition, some waste is spilled onto public roads but also generated by people who go through other peoples' garbage looking for recyclable material along waste collection routes. Sometimes compacter trucks leak solid waste during the compacting process.

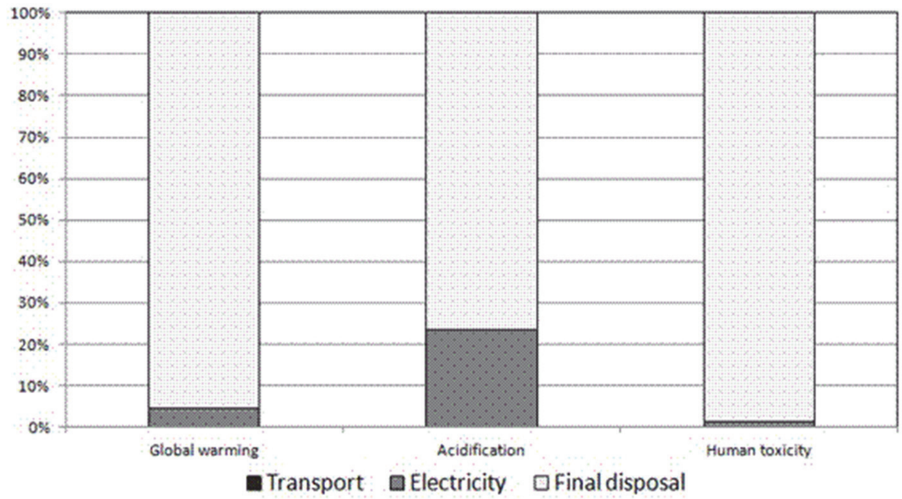


**Fig. 4.** MSW Environmental impact results

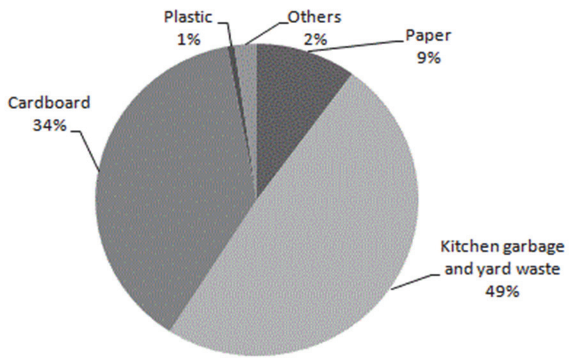


**Fig. 5.** Environmental impact of *La Cortada* landfill's (Pamplona, Colombia) process on global warming in Kg $CO_2$Eq.

It is recommended to focus attention on the management of waste final disposal, as it is the largest emitter of environmental impacts. Therefore, two additional scenarios are proposed for proper waste disposal: the possible involvement of separation and the use of composting. Both options present different disposal processes for treatable MSW. The materials that can be reused and recycled are used as raw material for other sub-products, which could prevent the process of production, transport, and energy consumption. The proposed scenarios are detailed in Table 4.In comparing waste management in the three proposed scenarios in terms of global warming, we can observe that the optimistic scenario is the greenest one, wherein MSW is better recycled and used, as it prevents the emission of 460 Kg $CO_2$ Eq $inhab^{-1}$ $year^{-1}$ (equivalent to 57%) (Fig. 6.)

However, to achieve the reuse and recycling of waste, we propose the creation of small businesses which can improve people's socio-economic conditions. This will undoubtedly become a source of employment for many families in the community. Acceptance of composting is still low in our area because most farmers in rural areas show certain psychological resistance to products derived from waste, thus being more responsive to fertilizers.

It is further suggested to introduce strategies for collecting the batteries used in cell phones and other appliances, which are starting to become increasingly more frequent, and for which there are no recycling strategies. Finally, with regard to waste resulting from housing and demolition, we recommend reusing it for street patching.

## 4. Conclusions

The environmental impacts generated by the handling and disposal of solid waste depend on the socio-economic characteristics of the particular geographical area where they are analyzed. This undoubtedly does not mean that controlled solid waste management processes do not generate positive and negative environmental impacts; in these cases, however, the tools and mechanisms needed to prevent, mitigate, correct or offset any negative impacts or to potentiate positive ones are certainly available.

**Table 4.** Description and details of MSW proposed scenarios.

| ***Scenarios*** | ***Description of MSW*** |
|---|---|
| Current baseline scenario | The use of solid waste and composting as a strategy is not implemented to mitigate the environmental impact generated waste. |
| Scenario 1 “optimistic” (adequate recycling) | Recycling 80% of paper, cardboard and plastic; 50% of glass and materials containing iron, aluminum, copper, brass or steel. Application of the separation and composting processes to 50% of the waste reaching the landfill. What is not recycled, recovered or used for composting is disposed in the landfill. |
| Scenario 2 “pessimistic” (moderate recycling) | Recycling 50% of paper and cardboard; and 25% of glass and materials containing iron or steel. Application of the separation and composting processes to 25% of the waste reaching the landfill. What is not recycled, recovered or used for composting is disposed in the landfill. |

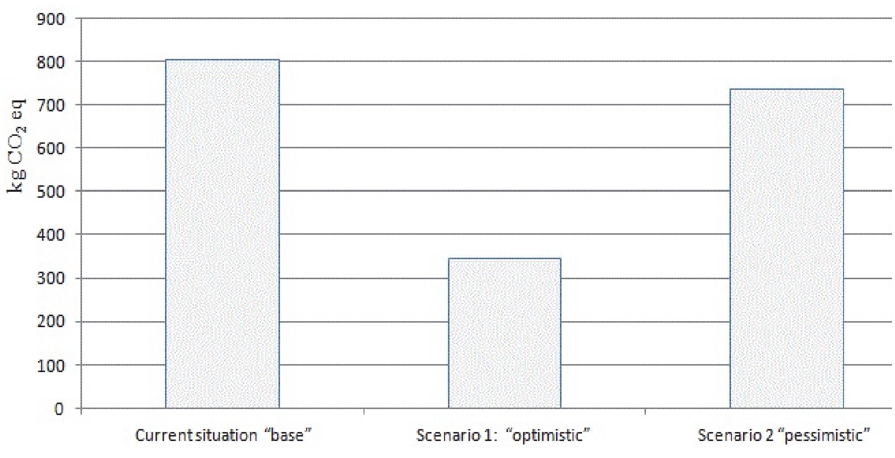


**Fig. 6.** Results of MSW alternative management scenarios

Alternatives such as cardboard, paper, plastic, glass and metal product recycling, as well as composting of organic materials can generate employment and recover materials, all of which is essential for improving the sustainable development of our region.

**Acknowledgments**
The authors are grateful to Empo-pamplona - Water and Sewerage Company of Pamplona - and CORPONOR - Regional Autonomous Corporation of Norte de Santander, for providing data and process information. Part of this study was funded by the University of Pamplona, Norte de Santander, through the "2010 - 50 years" open call.

## References

Al-Khatib I.A., Arafat H.A., Basheer T., Shawahneh H., Salahat A., Eid J., Ali W., (2007), Trends and problems of solid waste management in developing countries: a case study for seven Palestinian districts, *Waste Management*, **27**, 1910-1919.

Al-Salem S.M., Lettieria P., Baeyensa J., (2009), Recycling and recovery routes of plastic solid waste (PSW): A review, *Waste Management*, **29**, 2625-2643.

Barton J.R., Issaias I., Stentiford E.I., (2008), Carbon – Making the right choice for waste management in developing countries, *Waste Management*, **28**, 690-698.

Bel G., Mur M., (2009), Intermunicipal cooperation, privatization and waste management costs: Evidence from rural municipalities, *Waste Management*, **29**, 2772-2778.

Bovea M.D., Ibáñez-Forés V., Gallardo A., Colomer-Mendoza F.J., (2010), Environmental assessment of alternative municipal solid waste management strategies: A Spanish case study, *Waste Management*, **30**, 2383-2395.

CML, (2001), CML's impact assessment methods and characterization factors, Leiden University, Institute of Environmental Science (CML), Centre for Environmental Studies, University of Leiden, CML 2 baseline method; On line at: http://www.leidenuniv.nl/cml/index.html

Del-Moral-Avila M.J., Huete-Morales M.D., Navarrete-Alvarez E., Quesada-Rubio J.M., Rosales-Moreno M.J., (2016), Study of an annual waste recycling index in Spain, *Environmental Engineering and Management Journal*, **15**, 1465-1472.

Heijungs R., Guinée J.B., Huppes G., Lamkreijer R.M., Udo de Haes H.A., Wegener Sleeswijk A., Ansems A.M.M., Eggels P.G., van Duin R., de Goede H.P., (1992), Environmental Life Cycle Assessment of Products: Guide (Part 1) and Background (Part 2); CML Leiden University, On line at: http://hdl.handle.net/1887/8061

Francesco C., Silvia B., Sergio U., (2009), Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration, *Energy*, **34**, 2116-2123.

GD, (2003), Governmental Decision no. 1045/2003, surnamed SEA Governmental Decision, Methodology for the preparation of plans integrated management of solid waste PGIRS, *Colombian Official Monitor*, from 26th of September, 2003, Bogota, Colombia.

GD, (2002), Governmental Decision no. 1713/2002, surnamed SEA Governmental Decision, Provision of public services, *Colombian Official Monitor*, from 6th of August, Bogota, Colombia,

Ghinea C., Petraru M., Simion I.M., Sobariu D., Bressers H.T.A., Gavrilescu M., (2014), Life cycle assessment of waste management and recycled paper systems, *Environmental Engineering and Management Journal*, **13**, 2073-2085.

Henry R.K., Yongsheng Z., Jun D., (2006), Municipal solid waste management challenges in developing countries – Kenyan case study, *Waste Management*, **26**, 92-100.

MSWM, (2010), International Source Book on Environmentally Sound Technologies (ESTs) for Municipal Solid Waste Management, Report of the United Nations Environment Program, Division of Technology, Industry and Economics, On line at: http://www.unep.or.jp/ietc/ESTdir/Pub/MSW/index.asp.

ISO, (2006), International Standard ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework, On line at: https://www.iso.org/standard/37456.html.

Kanat G., (2010), Municipal solid-waste management in Istanbul, *Waste Management*, **30**, 1737-1745.

Kumar K.N., Goel S., (2009), Characterization of Municipal Solid Waste (MSW) and a proposed management plan for Kharagpur, West Bengal, India. *Resources, Conservation and Recycling*, **53**, 166-174.

Li W.B., Yao J., Tao P.P., Hu H., Fang C.R., Shen D.S., (2011), An innovative combined on-site process for the remote rural solid waste treatment – A pilot scale case study in China, *Bioresource Technology*, **102**, 4117-4123.

Marmolejo L., Díaz L., Torres P., García M., (2012), *Perspectives for Sustainable Resource Recovery from Municipal Solid Waste in Development Countries: Applications and Alternatives*, In: *Waste Management - An Integrated Vision*, Marmolejo L., (Eds.), In Tech, Rijeka, Croatia, 153-166.

Magrinho A., Didelet F., Semiao V., (2006), Municipal solid waste disposal in Portugal, *Waste Management*, **26**, 1477-1489.

Mor S., Ravindra K., Dahiya R.P., Chandra A., (2006), Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site, *Environmental Monitoring Assessment*, **118**, 435-456.

Moy P., Krishnan N., Ulloa P., Cohen S., Brandt-Rauf P.W., (2008), Options for management of municipal solid waste in New York City: A preliminary comparison of health risks and policy implications, *Journal of Environmental Management*, **87**, 73-79.

Mexican standard, (1985), Protecting the environment-soil contamination- municipal solid waste-sampling-quartering, NMX-AA-015, On line at: http://legismex.mty.itesm.mx/normas/aa/aa015.pdf

Mexican standard, (1985), Protecting the environment - soil contamination - Municipal Solid Waste-volumetric weight in situ, NMX-AA-19, On line at: http://www.publicaciones.ujat.mx/publicaciones/uciencia/agosto2008/1.pdf

Okot-Okumu J., Nyenje R., (2011), Municipal solid waste management under decentralization in Uganda, *Habitat International*, **35**, 537-543.

Ortiz-O O., Castells F., Sonnemann G., (2009), Sustainability in the construction industry: A review of recent developments based on LCA, *Construction and Building Materials*, **23**, 28–39.

Ortiz-O O., Castells F., Sonnemann G., (2010), Operational energy in the life cycle of residential dwellings: The experience of Spain and Colombia, *Applied Energy*, **87**, 673–680.

SIMPPLE SL. LCAManager – environmental management tool, On line at: www.simpple.com

Regina M.M., Toshiya A., Keisuke H., (2004), Comparison of the environmental impact of incineration and landfilling in São Paulo City as determined by LCA, *Resources, Conservation and Recycling*, **41**, 47-63.

Rusu L., Suceveanu M., Suteu D., Favier L., Harja M., (2017), Assessment of groundwater and surface water contamination by landfill leachate: a case study in Neamt County, Romania, *Environmental Engineering and Management Journal*, **16**, 633-641.

Turan N.G, Baki O.G., Ergun O.N., (2016), Municipal solid waste characteristics and management in Sinop, Turkey, *Environmental Engineering and Management Journal*, **15**, 13-18.

Wittmaier M., Langer S., Sawilla B., (2009), Possibilities and limitations of life cycle assessment (LCA) in the development of waste utilization systems – Applied examples for a region in Northern Germany, *Waste Management*, **29**, 1732-1738.

WRS, (1996), World Resources Institute United Nations Environment Programme, United Nations Development Programme, and the World Bank, On line at: http://www.wri.org/publication/world-resources-1996-97-urban-environment.

Zarate M.A., Slotnick J., Ramos M., (2008), Capacity building in rural Guatemala by implementing a solid waste management program, *Waste Management*, **28**, 2542-2551.

Zeng Y., Trauth K.M., Peyton R.L., Banerji S., (2005), Characterization of solid waste disposed at Columbia Sanitary Landfill in Missouri, *Waste Management and Research*, **23**, 62–71.

Zhang D.Q., Tan S.Q., Gersberg R.M., (2010), A comparison of municipal solid waste management in Berlin and Singapore, *Waste Management*, **30**, 921-933.