Environmental assessment of ozone layer depletion due to the manufacture of plastic bags

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Abstract

The results of a quantitative study about the potential environmental impact of ozone layer depletion due to the manufacture of plastic bags in a plant located in northern Colombia are presented in this article. The identification of the emitted gases is essential to determine their contribution to the depletion of the ozone layer and is measured in Kg. Eq. CFC-11 with LCA software, SimaPro. The criterion used in this evaluation are based on a life cycle analysis methodology and the objectives, scope and limitations of the productive system were defined based on this. From this information an inventory was made, taking as the main element the quantitative measurement of matter and energy flows for all inputs and outputs of the production process. The information about the process enabled the identification, characterization and assessment of the environmental impact of global warming related to the production of plastic bags, leading to the conclusion that the most polluting process is that of extrusion followed by the printing of plastic bags.

Keyword: Environmental science
1. Introduction

The ozone layer is a band of natural gas called “ozone”. It is found between 9.3 and 18.6 miles (15–30 kilometers) above the Earth in what is known as the stratosphere, and it functions as a shield against harmful ultraviolet B (UVB) radiation emitted by the sun. At present there is a general concern that the ozone layer is being depleted by the release of pollutants contained in chemical products. The release of these contaminants upsets the delicate balance in the natural production and decomposition of ozone molecules by eliminating the molecules faster than they can be replenished [1].

The most detrimental compounds to the ozone layer are chlorofluorocarbons, carbon tetrachloride, methyl chloroform, halons, hydrochlorofluorocarbons (HCFC), hydrobromofluorocarbons (HBFC) and methyl bromide [2]. The degree of damage caused by any one of these substances to the ozone layer depends on the chemical properties of the compound. Other factors that affect the ozone layer include climate change and greenhouse gasses such as methane and nitrous oxide.

Plastic bags are produced from one of three basic polymers: polyethylene, high density polyethylene (HDPE), low density polyethylene (LDPE), or linear low density polyethylene (LLDPE). Supermarket plastic bags are usually made from HDPE. Plastics are not in and of themselves toxic or harmful. However, plastic bags are manufactured using organic and inorganic additives such as colorants and pigments, plasticizers, antioxidants, stabilizers and metals [3].

The heavy metals of cadmium and lead contained in the pigments used in the manufacture of plastic bags, and the antioxidants and stabilizers, are inorganic and organic chemicals that serve to protect the plastic against thermal decomposition during the manufacturing process. These industrial chemicals are thought to be a great source of atmospheric pollution since they are able to bond with other elements and form compounds such as chlorides, oxides, and sulfides [4], all of which contribute to a considerable degree towards ozone destruction based on their varying proportions and depending on a range of factors [5].

In addition, the authors of a study carried out by the University of Hawaii [6] recently reported that as plastics decompose they emit methane and ethylene. Polyethylene is the most widely produced and discarded synthetic polymer at a global level (it is used in shopping bags). It is also the one that most prolifically emits methane and ethylene.

Although the major effects of plastic bag manufacture points towards global warming, “The damage goes both ways: global warming alters the ozone layer and the depletion of the ozone layer feeds global warming” according to the Ozone Secretary of the Environmental Program of the United Nations [7]. A study published in the journal Nature Geoscience [8] shows that the warming of the Earth affects the
flow of existing ozone between the stratosphere and the troposphere. The accumulation of greenhouse gasses causes the stratospheric ozone to travel from the stratosphere to the troposphere thus leading to the destruction of the ozone layer and greater air pollution. When stratospheric ozone (O$_3$) is found lower than 15 kilometers it is considered to be a pollutant. By the same token, some of the compounds that destroy ozone are also potent greenhouse gasses [9].

The objective of this study is to evaluate the potential environmental impacts of the manufacture of plastic shopping bags for mass consumption in a supermarket chain and locate them in the category of ozone layer depletion. Depletion is evaluated in the “environmental impact” category “ozone layer depletion”. This evaluation is based on life cycle analysis methodology (LCA), which starts by defining the inputs and outputs of each stage of the process, using each of the production records of the company for the years 2014 and 2015. Mass and energy levels were determined to establish the production flows. Based on this information, the scope and objectives of this study were defined including the inventory analysis and the environmental impact assessment for the manufacturing process of plastic bags. The inventory analysis allowed for identifying, selecting and characterizing the environmental loads of production processes. Based on the aforementioned steps, it was determined which stages of the manufacturing process generate the greatest environmental impact.

2. Methodology

Our aim was to use a methodology that can be easily understood by industry while also fulfilling university research standards. As such, Life Cycle Analysis (LCA) in line with the ISO 14040 (2007) [10] standards was used for the research. Four general steps were followed: defining the objectives and scope, inventory analysis, environmental impact analysis of the product, and interpretation [12].

2.1. Phase 1: Definition of the scope and objectives

As mentioned above, this research describes the comparative analysis of the ozone layer depletion due to a massive consumption of plastics bags in a chain of stores serving an area of one and a half million inhabitants. The unit of analysis is the production process of 14-inch plastic bags. Each of the production logs kept by the manufacturer during 2014 and 2015 were examined. The system boundaries covered printing, extrusion, sealing and recovery, and these were used to define door-to-door life cycle analysis encompassing the entry of raw materials up until arriving at a final product.

The analysis of emissions and environmental loads was excluded for the following stages: extraction of raw materials, transport, plastic bag use by the clients and final disposal.
2.2. Phase 2: Life cycle inventory analysis

The Life Cycle Inventory phase was developed by analyzing the collected data and performing data calculation of both a qualitative and quantitative nature.

Primary data related to the production of plastic bags was gleaned from a manufacturing company located in the city of Bucaramanga, Colombia. Data collection tables were drawn up with the purpose of collecting the information requested in an orderly and systematic fashion. The secondary data was acquired through the EcoInvent database [11].

The following considerations and suppositions were taken into account while taking the inventory:

The total energy of the process was calculated by summing the potential energy that leaves the system through each motor used in the machinery. Other aspects that were considered include voltage, amperage and the efficiency of each motor.

Water consumption during the extrusion phase was not considered since it does not influence the product in any physical way. It is only used to cool the extrusion machinery. Water leaves and enters the system in a continuous cycle from the water store to the machine and back again, thus maintaining the same amount of water constantly.

The software Sima Pro (version 7.1) [12] was used for the calculations. In this way, the most important environmental loads associated with the main product (plastic bags, in this case) and their contributions to the process during its life cycle were identified.

2.3. Phase 3. Environmental impact assessment

The relationship between the manufacturing process and its impact on the environment was determined through the environmental impact assessment of the life cycle. The profile of the “environmental impact” category for the plastic bag was defined, viz. ozone layer depletion.

The following stages were carried out in this phase:

- Identification and characterization of environmental loads.

The environmental loads of processes were identified. The impacts associated with the depletion of the ozone layer were analyzed for each one of the processes by looking at mass and energy balances of the manufacturing process of the plastic bag. In this characterization, environmental [13] loads were quantitatively and qualitatively determined based on those identified in the inventory.

- Impact category selection
The EPD 2007 modeling method was chosen to determine the environmental impact category that causes the depletion of the ozone layer precipitated by the manufacturing process of plastic bags. The method was chosen since it is used to create “Environmental Product Declarations” [14, 15] applicable to all sectors and offers a neutral and scientific way of evaluating a product from and environmental perspective. The "single score" property was used to generate SANKEY lines, which highlighted the influence of those routes offering the greatest environmental impact in the product.

3. Results and discussion

3.1. Scope and objectives

The environmental impacts associated with the manufacture of plastic bags [16] and the repercussions in ecosystems, and in this case the destruction and exhaustion of the ozone layer [17], are reasons to evaluate the life cycle of the process. By having pertinent information, it becomes possible to establish technologies and strategies that allow for mitigating the impact of the sector as well as achieving cleaner production.

3.2. Inventory analysis

Company records from January 2014 to June 2015 were used for the development of mass and energy levels necessary for the inventory analysis and the assessment of the potential environmental impact.

As shown in Fig. 1, in the production of High Density PolyEthylene (HDPE) plastic bags [17], three main processes are carried out: extrusion, printing and sealing, and a recovery process of plastic waste. In the printing process of bags, solid waste is generated that goes through a recovery subprocess (agglutinated) consisting of two stages: bonding and pelleted.

In order to protect the confidentiality of the manufacturer’s process, the information does not show the quantitative data analysis for the mass and energy flows inventory related to the production of 14-inch plastic bags.

- Qualitative and quantitative description

The stages of the manufacturing process in which the transformation and adaptation of the material is achieved are described as background for the interpretation of the results. The descriptions aid in understanding how and why each stage impacts ozone depletion. Additionally, some characteristics and properties are included that lead to HDPE plastic bags as a final product [18].
The first stage is the extrusion process in which high-density polyethylene is transformed into rolls from which the plastic bags are made. Color is added to the material at this stage, as well as the desirable characteristics and properties such as the size of the roll, texture and nature (bio or non-biodegradable) of the bag, among others.

The second process, called imprinting, only applies to plastic bags that require it. At this stage a flexographic machine is used allowing for printing directly from the extrusion stage. While the process may seem simple at first glance, it is very complicated since it requires more precision and monitoring by the operator. Small variations in the amount of ink, drying time or speed may lead to undesirable printing results.

The film printing is followed by a sealing step, wherein bags are first cut according to the size, type of bag and pleat size, and other characteristics before sealing the bag seams. Plastic bags are the final product of this stage, which are then sent to storage and later delivered to the customer. In addition, any excess material is sent to the recovery sub-process where it is bonded and pelletized to be used for manufacturing other types of bags [19].

### 3.3. Environmental impact assessment

For the environmental impact assessment of the ozone layer depletion category, some of the substances emitted in the manufacturing process were considered, and then identified and classified according to the inventory analysis obtained in this study.

The next step of this methodology includes the characterization and the environmental profile of each stage’s contribution to the impact categories associated with the process.
- Identification, selection and characterization of environmental impact categories.

The pollutant emissions identified in the different stages of the process by way of the inventory analysis were considered as they relate to the selection of the environmental impact category: ozone layer depletion. Fig. 2 shows the identification and selection of all categories to be analyzed for the characterization and impact assessment according to the environmental action of the process. The impacts were obtained using the SIMA Pro 7.1 software package and applying the EPD 2007 methodology to the data. Given that the data sets are large and occupy many pages, they are not included in this article [12, 20].

In Fig. 2, it can be noticed that all stages of the process have the same influence in each category except for the depletion of the ozone layer. In general, the output of the extrusion process is the largest contributor, close to 50%, in all the categories because this is where oil-derived raw materials enter the manufacturing process for compounds such as HDPE and linear polyethylene, representing a high rate of contamination. High energy consumption and low efficiency in engines is also recorded at this stage [21, 22].

Secondly, the 2nd film obtained in the printing process accounts for 30% of the impact in each category. This high percentage is due to the use of materials such as alcohol, inks and ethyl. Furthermore, in this process engines work to the lowest possible efficiency, resulting in higher energy consumption. As depicted in Fig. 2, the cutting and sealing process contributes the least, with a value close to 4%, since raw materials are not required in this stage, only the product in process.

![Diagram of Environmental Impact Analysis](https://example.com/diagram.png)

**Fig. 2.** Environmental impacts associated with the manufacturing process related to the ozone layer depletion category.

*Source: The authors.*
machine is also the most efficient. Finally, the black pelletized represents 2.5%, higher than the general pelletized (2%), because the latter does not contain added substances such as inks.

As mentioned above, the highest contributors to the “ozone layer depletion” category are the film 1, film 2, cutting and sealing while the contribution of general and waste pelletization is lower. This can be explained by the fact that some oil-delivered materials such as crude oil, gasoline and naphtha are used in the extrusion and printing processes, with a very strong and negative impact on the ozone layer, in addition to those processes that lead to extrusion and transformation [23].

4. Conclusions

Using Life Cycle Analysis methodology and Sima Pro 7.1, the potential environmental impact of the ozone layer depletion has been assessed and thus it has been determined which stages of the process contribute to the environmental impact of the categories selected in this study. Based on the interpretation of these results, it was possible to conclude that:

1. The extrusion process used to produce the 1st film depletes the ozone layer to the greatest degree since fossil fuels such as gas, oil, and oil-derived raw materials are commonly used in the production of LDPE and linear polyethylene.

2. Printing is the second process that has a significant environmental impact on the ozone layer, because large quantities of some chemicals such as alcohol, acetate and inks are used. Furthermore, engines work to the lowest efficiency of the whole process resulting in higher energy consumption.

During the literature review, it was found that most studies have looked at the environmental performance of plastic bags made with paper, biodegradable plastic, cotton and other plastics that are not of the same composition as those studied in this research. As such, comparison between those studies and this one is impossible. It is also difficult because the functional unit, the scale of the scope of the system, the production materials used etc. are all different. In addition, most of the other studies only set out to determine the GHG emissions.

Declarations

Author contribution statement

Jonathan David Morales Méndez: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ramón Silva: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.
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