The Ecological Footprint of Polyethylene Terephthalate. A Case Study

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Abstract

This project analyzes the patterns of consumption and production of waste by using of polyethylene terephthalate (PET) bottles in a higher education institution, which represent a threat to the environment and due to excessive consumption have caused damage to the environment. Habitat of many species. Among the main consumption habits were identified that, of a sample of 541 students, 88% normally use plastic bottles, 70% reuse them, 9.5% yield them for their subsequent recycling. The applied method was based on the geographical and climatic conditions of the city, as well as renewable and non-renewable elements of the product life cycle, as relevant results establishes the ecological footprint of PET as $1{,}017x10^{-4}$ global hectares for every 8000 students, as an index of degradation 0.7547 representing a decomposition time between 520 and 680 years, among the weekly resources used were identified 8068 liters of fuel, 48900 watts, used raw material 6.11 kilograms, 146.71 liters of water consumed for a total mass of 12.22 kilograms of PET with an average volume of 500 milliliters.

Keywords
Ecological, Footprint, Polyethylene, Consumption Containers

1. Introduction

Polyethylene terephthalate (PET) currently occupies an important space in the manufacture of bottles for carbonated beverages and mineral water, however, its use has become another pollution problem in the world, due to the fact that most of them end up in landfills, increasing the volume of plastics waste (Prada Botia, Acevedo Peñalosa, & Orjuela Abril, 2018).

Polyethylene teraphthalate (PET) is a plastic that is generally used in the manufacture of bottles (Gonzales, 2016), one of the main characteristics of this material is that it is part of the group of materials known as polyesters, it is also characterized by its crystallinity (NAPCOR, 2016). The main component of this material is carbon and thanks to the other substances that are part of it can be molded using heat or pressure, in addition to this material properties that differentiate it from others, the most prominent is its resistance to degradation (Mansilla Pérez & Ruiz Ruiz, 2015). Currently PET is considered a serious environmental problem, since millions of products of this material are consumed in the world, and when they are discarded, they generally end up in the oceans.

Many years ago a gigantic rubbish spot was discovered in the Pacific Ocean, it currently occupies a large extension and is composed of 80% plastic waste (Ruiz, 2015)

The excessive use of polyethylene terephthalate or PET is considered an environmental problem since in the world there are large quantities of plastic waste, approximately 5000 metric tons of this type of garbage. It is very resistant, easy to manufacture and low cost; but its excessive use along with some of the components used in its manufacture is very dangerous, being a product of a long useful life, it also becomes a factor that causes damage to the environment since it has the ability to stay in the ground and in the water for hundreds of years (Braungart, 2015). In the world, the environmental impact due to the use of PET plastic bottles is great, because if a recycling culture is not adopted and if there is no study that identifies which are the factors that prevent reducing the ecological footprint, we will continue to observe the excessive use of this material.

This uncontrolled plastic waste might cause a severe environmental issue. In addition, the plastic water bottle is composed of a non-biodegradable material, and dumped waste may remain in nature for centuries. As presented, dealing with the dilemma is of great importance. Researchers around the globe looking for measures to cope up with this problem. However, due to lack of local waste generation data, this often becomes unviable to go for a strategical solution (Mohammad, Md Jobaer, & Khaled, 2018).

The ecological footprint is an index of sustainability of a single index, defined as: "the area of biologically productive territory necessary to produce the resources used and to assume the waste produced by a defined population, with a specific standard of living, indefinitely wherever that area is found " (Wackernagel & Rees, 1996).

The calculation of the ecological footprint allows to evaluate the impact of the activities on the environment anytime, there are various methods for calculating it, which can be from a study of the amount of resources a person consumes and waste what it produces (Martínez Castillo, 2015). An approximate of the mass of PET that is wasted in the dumps is known, which is 30640.61tn per year

According to studies conducted worldwide, it has been determined that the countries with the highest percentage of ecological footprints are the most developed, noting a great difference with less developed countries such as Africa. (Unesco, 2016). The calculation of the ecological footprint is of vital importance since we can analyze the impact generated by the consumption of certain materials, which although at first glance seem to be harmless, actually turn out to be a threat if we do not know how to control this use (Wackernagel & Rees, 1996).

1.1 Method

Among the main methods for the study of the ecological footprint are the compound and the component-based method, however, it is usually used for regions or countries, it has been found that the ecological footprint can be used perfectly in companies and in any type of organization, going to be called, sustainability indicator(Doménech, 2019). However, the product environmental footprint is a multicriteria measure of the environmental behavior of a good or service throughout its life cycle. The general objective of presenting information on the footprint of a product is to try to reduce the environmental impact of goods and services taking into account the activities of the supply chain (from the extraction of raw materials to the management of final waste, passing for production and use) (Official Journal of the European Union, 2013)

2. Materials and method

The research will be descriptive, will systematically describe the PET consumption dynamics, it will have a qualitative approach through the application of ordinal scales, which represent categories of belonging, with an associated but not measurable order (Orlandoni Merli, 2010). To establish the ecological footprint, the method based on the degradation of polyethylene modified by Zimmerman and Thac Kim (2014) is applied for products of human use and consumption, which has been reviewed by the Global Footprint NGO and which will apply to post-consumer polymers in this case to polyethylene terephthalate.

2.1 Determine population and sample

The study population is made up of undergraduate students distributed by faculties of the institution, so the sample will be calculated, developing a simple random sample with an accuracy of 10%, with a level of significance of 5% and a variance maximum with the formula:

$$n = \frac{N\,(Z)^2(p)(q)}{N\,(d)^2 + \,(Z)^2(p)(q)}$$

Where

n: Sample size
N: Size of the population

Z: Standard deviation (For a confidence margin of 95% it is 1.96)
p: Probability of success
q: Probability of failure
d: Accuracy expressed as a percentage

2.2 Identify consumption dynamics and recycling practices.

To identify the dynamics of consumption, a structured survey was applied to the students, to then perform a statistical study that will identify the behavior of variables, which include: consumption, frequency, reuse, classification of packaging and final disposal.

2.3 Collection of samples

For this, volunteers from all the faculties were selected and they were asked to collect samples of PET bottles consumed in a week, for their subsequent characterization, the variables to be identified included: mass and total volumes of the sample

2.4 Establish the PET degradation index

The rate of degradation of PET is the time in which the environment delays in degrading the plastic according to variables such as polymer density, climatic, atmospheric factors and height of the study site (Marazzi, 2017) in the particular case of the PET, the data in table 1 will be used according to the temperature and altitude of the city in order to obtain a degradation time interval and finally establish a relationship between the minimum and maximum value identified, when a low index is obtained it is maintained constancy and invariance, on the contrary, if it is equal to or greater than 1, means that the degradation time varies in the proposed ranges.

Table 1. Degradation of PET in years relating temperature, barometric pressure and relief.

PET degradation index					
Temperature	Degradation time in years	Atmospheric pressure Atm	Atmospheric pressure mm Hg	Relief or altitude m.a.s.l	Degradation time in years
0 ºC	1000	1	760	0	200
5 ºC	920	0,942165	716	500	280
10 ºC	840	0,886842	674	1000	360
15 ºC	760	0,83421	634	1500	440
20 ºC	680	0,78421	596	2000	520
25 ºC	600	0,736842	560	2500	600
30 ºC	520	0,690789	525	3000	680
35 ºC	440	0,648684	493	3500	760
40 ºC	360	0,607894	462	4000	840

2.5 Identification of non-renewable elements

It consists of the identification of variables such as: volume of fuel used, energy value and mass of raw material used as non-renewable elements involuntary in the life cycle of the product (Martínez, Hernández, López, & Menchaca, 2015), that is those process elements that have a single life as fuel, energy and raw material, as shown in table 2.

Table 2. Non-renewable elements that intervene in the life cycle of the product.

Elements	Description	Magnitude
Fuel Used FU	Energy required for production, distribution, use and disposal of PET. An average of 500 ml container in the three stages of the product life cycle consumes 16.5 l fuel	Volume: L (l) cubic centimeter (cm3)

Energy Used EU	potential energy efficiency or energy used in the product life-cycle management. A bottle of 500 ml using 100W.	Power supply: Watt (W)
Raw Material Used RMU	Raw material used in the life cycle of the package, without having received any type of process or additive. 1000 kg 2000 kg Petroleum produce PET	Dough: Kilogram (kg) Pound (l)

2.6 Identification of renewable elements

Next, those elements that present a cycle of renewal are identified and evaluated considering variables such as: volume of water used, rate of degradation, reference energy value and total mass of the product, as shown in table 3 to finally multiply with the values obtained from non-renewable elements.

Table 3. Non-renewable elements that intervene in the life cycle of the product.

Elements	Description	Magnitude
Water Used WU	Volume of water required for each stage of life cycle of PET in the production of 10 bottles of 500 ml 3 liters of water are used.	Volume: L (l) cubic centimeter (cm3)
Degradation Index DI	Time it takes to nature degradation PET	Weather: Years
Reference Energy RE	Energy efficiency or energy potential that is used to reference the calculation, a bottle of 500 ml using 100W.	Power supply: Watt (W)
Total Mass of the Product TMP	Total mass of the product after suffering industrial processes and received additives	Dough: Kilogram (kg) Pound (l)

2.7 Identification of the area of consumption

The consumption area corresponds to the value of the surface of mineral, natural resources that a product requires in its different stages of the life cycle, a PET 500 ml container requires 56 cm^2 or 0.0052 m^2, normally a magnitude of area or surface it is expressed in hectares (Ha) or square meters (m^2).

2.8 Application of the algorithm

Once the value of the variables has been obtained, the formula for the calculation of the footprint described below is applied, which represents the productive land surface or aquatic ecosystem necessary to maintain the consumption of resources and energy, as well as to absorb the waste generated by a certain process, product or population.

$$\text{HE} = \sqrt{\frac{Total\ elements\ with\ cycle}{Total\ elements\ without\ cycle}}$$

3. Results and Discussion

According to the department of strategic planning of the institution, the population is made up of 8862 undergraduate students, through the calculation of samples for finite populations, obtaining a result of 369 students, in which 53.1% of the respondents are gender female.

Consumption dynamics were identified through the application of a structured survey that had questions focused on the daily activities of the students. Questions were also considered recycling alternatives and reducing the use of PET. As a result, 88.1% of respondents say they consume beverages in plastic bottles, 70% of respondents say they reuse plastic containers to drink juice or water, 45.9% of students discard bottles to the dumpster more nearby, 25.2% store it for recycling, 19.3 store it for disposal at home and 9.5% give it away for further treatment.

In the collection of samples, volunteers were requested for the study, where, over the course of a week, collecting plastic bottles according to their normal use, table 4 shows a distribution of volunteers by faculties.

Table 4. Volunteers

Faculty	Volunteers
F1	77
F2	100
F3	134
F4	111
F5	119
Total	**541**

One week later, the total volume of the samples collected is 293.4 l and the total mass of the 489 samples is 12.22 kg, these values are the total sum of samples of volunteers who consume beverages in plastic containers. The volume of PET packaging that is most frequently found is 500 ml and the mass of plastic container with the highest consumption is 22.1 g. The maximum value of the volume of a PET container is in the 2000 ml equivalent to 2 l, this value is related to the maximum of the mass that for this case is 51 g and the minimum values of a container correspond to 200 ml for the volume and 17g, the containers of carbonated drinks had a mass greater than the rest of drinks.

Table 5. Maximum and minimum values of the mass and volume of the containers for N = 489

Variables	**Total**	**Minimum value**	**Maximum value**
Volume	239,4 l	200 ml	1500 ml
Dough	12,22 kg	20 gr	50gr

To determine the rate of degradation, we use the values of height and temperature, in Ibarra, according to the Climatologist Analysis XLIII (Instituto Nacional de Metrología e Hidrología, INAMHI), the average temperature of the city is 21 ° C as shows figure 1 and an altitude of 2157 m.a.s.l according to figure 2, resulting in that, the time of degradation of the PET is from 520 to 680 years as shown in table 1, to obtain the degradation index is divided the minimum value (degradation time) for the maximum of the table.

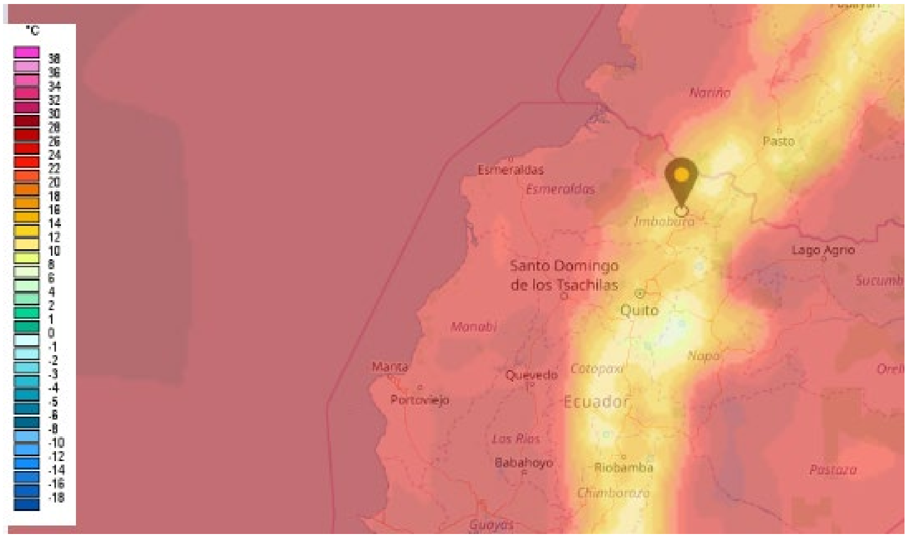

Figure 1. Average temperature of Ibarra

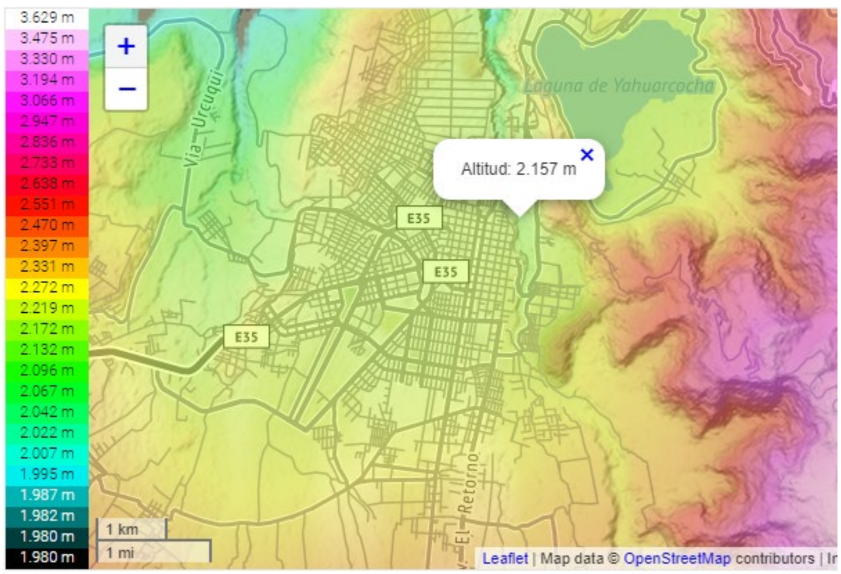

Figure 2. Georeferencing of Ibarra
Fuente:http://es-ec.topographic-map.com/places/La-Victoria-4448701/

Table 6. Degradation of PET in years relating temperature, barometric pressure and relief.

PET degradation index					
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According to the data in the table, the degradation index will be:

$$ID = \frac{520\ years}{680\ years}$$

$$ID = 0{,}7647$$

From the parameters described in table 7 and based on the 489 cataloged vessels, the results of the table were obtained.

Table 7. Results of non-renewable elements of the case

Element	Result	Unit
FU	8068	L
EU	48900	W
RMU	6,11	Kg

When applying the logarithm of ecological footprint calculation, we considered the values already established by the Global Footprint, 2015 in order to facilitate its application, we start from the proposed values and multiply by the 489 containers as shown in the table 8 the collected containers have the following values.

Table 8. Results of renewable elements of the case

Element	Result	Unit
WU	146,7	l
DI	0,7647	
RE	48900	w
TMP	12,22	kg

The consumption area (CA) was calculated according to table 4, considering that a 500 ml PET container requires 56 cm2 or 0.0052 m2, obtaining a total consumption area of 2.54 m2, corresponding to the area of mineral resources and that requires an average PET bottle in its different stages of the life cycle. The ecological footprint is calculated through the square root of the division of renewable elements for non-renewable, this result is multiplied by the area of consumption, the result is usually expressed in global hectares.

$$\mathrm{HE} = \sqrt{\frac{(\mathrm{WU\ x\ ID\ x\ RE\ x\ TMP})}{(\mathrm{FU\ x\ EU\ x\ RMU})}}\ \mathrm{x\ CA}$$

$$\mathrm{HE} = \sqrt{\frac{(146{,}7\ \mathrm{l\ x}\ 0{,}7647\ \mathrm{x}\ 48900\ \mathrm{w\ x}\ 12{,}22\ \mathrm{kg})}{(8068\ \mathrm{l\ x}\ 48900\ \mathrm{w\ x}\ 6{,}11\ \mathrm{kg})}}\ \mathrm{x}\ 2{,}54\ \mathrm{m2}$$

$$\mathrm{HE} = 0{,}4235\mathrm{m}^2\ \mathrm{m2} = 4{,}235\mathrm{x}10^{-6}\ \mathrm{hag}$$

These data indicate that the ecological footprint obtained by the consumption of polyethylene terephthalate for a sample of 489 containers in a period of 7 days corresponds to $4{,}235\mathrm{x}10^{-6}$ hag , in the same terms, making a projection for the population of the study in the same period would be equivalent to $1{,}017\mathrm{x}10^{-4}$ hag, in other words approximately a week of one meter of land would be consumed exclusively by the use of plastic.

4. Conclusions

The ecological footprint is the final indicator since it transforms every unit of consumption and waste produced into a totally significant number, offering a clear and precise idea of the impact of man's activities on daily life.

The degradation index obtained from the climatologist conditions of the city indicate that the minimum degradation time of PET is 520 years, which represents a serious environmental impact and waste of raw material for other types of processes.

The calculated ecological footprint is low, considering that it has been determined based on a single product, in comparison to the traditional ecological footprint established by the Ministry of Environment that includes many other parameters, so the value obtained represents only 0.0084 % of the ecological footprint of 1.2 hectares nationwide.

Among the weekly resources used for 489 containers were identified 8068 liters of fuel, 48900 watts, raw material used 6.11kilograms, 146.71 liters of water consumed for a total mass of 12.22 kilograms of PET with an average volume of 500 milliliters.

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