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Introduction of the circular economy to expanded polystyrene household waste: A case study from an Ecuadorian plastic manufacturer

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ABSTRACT

Transition towards a more sustainable society is a complex task. The depletion of natural resources and waste generation cannot be sustained indefinitely, i.e. as waste increases, local landfills keep growing and land availability reduces. The introduction of circular economy in effective household solid waste management practices should be considered especially for third world countries, such as Ecuador. In this context, plastic recycling is an important step, particularly the case of expanded polystyrene containers that currently are single-use only and later end up in local landfills. This paper presents a methodology for recycling Expanded Polystyrene by means of a case study from an Ecuadorian Plastic Manufacturer. First, the manufacture of resin from post-consume EPS containers was demonstrated possible by the manufacturer. Second, results show that using 30% of post-consume resin in the mix produce satisfactory laboratory results and operational recycled containers.

1. Introduction

As the Ecuadorian society grows in population and economy, its needs increases, thus rising waste generation. An increasingly stream of wastage being dispose in landfills has quickly become a significant problem for the country (Tekler et al., 2019). According to the National Institute of Statistics and Censuses (INEC) in 2016, almost 13 thousand tons of solid waste were collected daily, of which 90.3% were collected in an unsorted manner and 9.7% in a sorted manner (National Institute of Statistics and Censuses, Solid Residues Management, 2016). Also, the increasing extraction of natural resources to support economic growth has made an impact on the environmental and social sustainability of the supply networks (Koumparou, 2017, Sitepu et al., 2016). The scarcity of resources will increase in the future and the ability to recover and manage these resources will become essential for a sustainable local economy (Vea et al., 2018).

In previous research (Hidalgo et al., 2019), the authors classified and measured the amounts of waste produced per household in the city of Guayaquil. A total of 0.61 kg is generated per person daily, from which almost 76% is organic, 8% plastic, 6% paper and cardboard, 6% for glass and dust and 4% of metal and others. Considering a total of 2.291 million people for the city in the year 2010 (National Institute of Statistics and Censuses, Solid Residues Management, 2010), according to the last Census performed by INEC, almost 1780 tons of solid waste is generated every day. This represents approximately 41% of the total waste collected by the municipality.

Plastic waste has been put under scrutiny; due to, its generation has been constantly increasing over the last decades. Nowadays, the production of plastic reached about 350 million tons per year worldwide (Heidbreder and Bablok, 2019). There is growing evidence that the current use and disposal of plastic leads to substantial pollution of terrestrial and aquatic ecosystems, having a tremendous effect on various aspects including wildlife, through diverse routes. These impacts are especially noticeable for single-

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use plastics (PlasticsEurope, 2018, Xanthos and Walker, 2017), such as expanded polystyrene (EPS) which represents 6.26% of all the plastic waste in the country.

EPS is an excellent material for packaging and construction, because of its light weight, rigidity, highly desirables insulation properties and shock resistance. On the other hand, polystyrene is very stable and extremely hard to degrade in the environment after disposal (Ho et al., 2018). One study on life cycle analysis concludes that to produce 1.716 g of EPS, 87.47 mg of CO_2 are released in the atmosphere (Tan and Khoo, 2005, Leejarkpai et al., 2016).

The city hall of Guayaquil, aims to regulate the manufacture, trade (of any type), distribution and delivery of single-use plastics. Within this ordinance, the manufacturers of single-use EPS items must change the formula in their process, to a new formula or product agreeing with any of the following options: 1) products are 100% biodegradable, 2) 70% of total product mass comes from recycled materials and 3) using other reusable materials in the lapse of 30 months (Ecuador. Autonomous Decentralized Government Municipality of Guayaquil, 2018). In concordance with the local ordinance are international regulations that the country needs to accomplish. For example, in July 2019, the Associated States of the Pacific Alliance, from which Ecuador is a new member, referred to the importance of developing new policies to promote the integral management of waste and reducing the production of single-use plastics (Ecuador. Autonomous Decentralized Government Municipality of Guayaquil, 2019).

Importantly, Guayaquil is the city with highest plastic manufacturing, according to the Ecuadorian Plastic Associantion (ASEPLAS), 64% of the 600 companies nationwide are localted in this important and this single industry generates more than 19,000 direct and 120,000 indirect jobs (Magazine, 2008). Furthermore, nationwide EPS container manufacturers do not comply with any of the three choices the city hall ordinance has set as acceptable. This is the main reason why EPS item producerś opinion is that the local ordinance could harm the industry in its production processes and risk the stability of many workers.

Thus, the following question arises: what strategy should plastic manufacturing companies follow to survive in this new local eco-friendly environment?

One contributing solution is shifting from a linear economy to a circular economy in single-use items production by means of reusing and recycling expanded polystyrene products. Manufacturers already reuse their scrap as part of their production process (between 30 to 40%), so if they add post-consume resin as raw material, they could achieve the 70% recycled material objective set by the municipality.

This study focuses in giving feasible options to the single-use plastic manufacturers to redesign their products, so they can increase the use of recycled (post-consume) material; applying the concept of circular economy to strengthen their competitiveness and supporting resource sustainability.

For this purpose, the linear typical economy and circular economy proposal set by the authors are presented in the methodology (Section 2). The process description to obtain the recycled resin from post-consume containers effectuated by the manufacturer is then presented. Production of new recycled containers and laboratory test values are presented in the results (Section 3). Finally, conclusions and discussion are presented in Sectons 4 and 5.

2. Methodology

The prevailing linear economic system in local plastic manufacturers accumulates waste, while depleting natural resources. Limitations of natural resources and a growing world population have set the idea of a circular economy in the focus of research, industry and politics in recent years (Spierling et al., 2018).

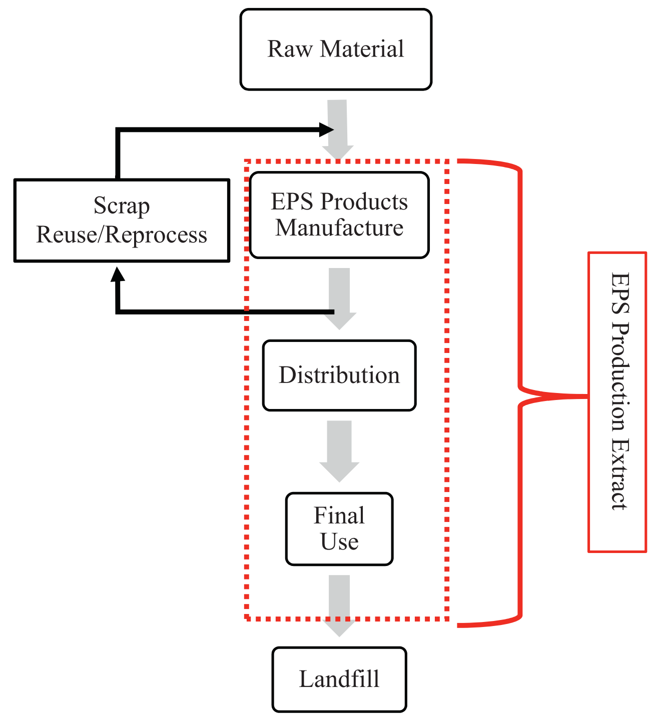

Fig. 1. Linear economy EPS cycle.

2.1. Linear economy EPS production cycle

Plastic is present everywhere, every day; either as a raw material or as finished product. As a result, plastic is a continuous growing industry. Indeed, its sales has reflected a steady growth of about 9% in the period from 2014 to 2018 (Mativenga et al., 2017). This industry has made rapid progress, since plastic is an element used in different sectors. In addition to being the main raw material, it is a product on which many other processes depend. It is estimated that between 70 to 80% of necessary plastic is supplied by local industries (Magazine, 2008), only importing highly specialized plastic products or in large volumes. Nevertheless, most residues end up in landfills, culminating a linear economy and affecting the environment. Fig. 1 shows the current linear economy to manufacture EPS products in the country. Next, each of the steps presented in the scheme of EPS lineal economy cycle will be explained in detail.

2.1.1. Raw material

According to ASEPLAS, the import of plastic resins reached 381 thousand tons in 2017 (Magazine, 2008). Plastic companies acquire almost all its raw material from abroad, because there is no local petrochemical industry that can produce in large volumes to meet the demand of national industries. Futrthermore, plastic companies in Ecuador make no-efforts to obtain raw materials from recycling of EPS waste and donť attempt to find alternative materials, given that EPS is very ingrained in the culture of society.

2.1.2. EPS product manufacture and Scrap reuse/reprocess

In an attempt, to reduce the use of “virgin resin” residues from the manufacturing process are collected (scrap) for reuse. For this purpose, the raw material in the form of a mix of “virgin” and “scrap” resin pellets, enters the manufacture process to obtain expanded polystyrene products, such as: dishes, plates, drink containers. Also, residues from this process are collected in the form of scrap for later treatment and reuse. The latter tries to avoid residues within the boundaries of the company.

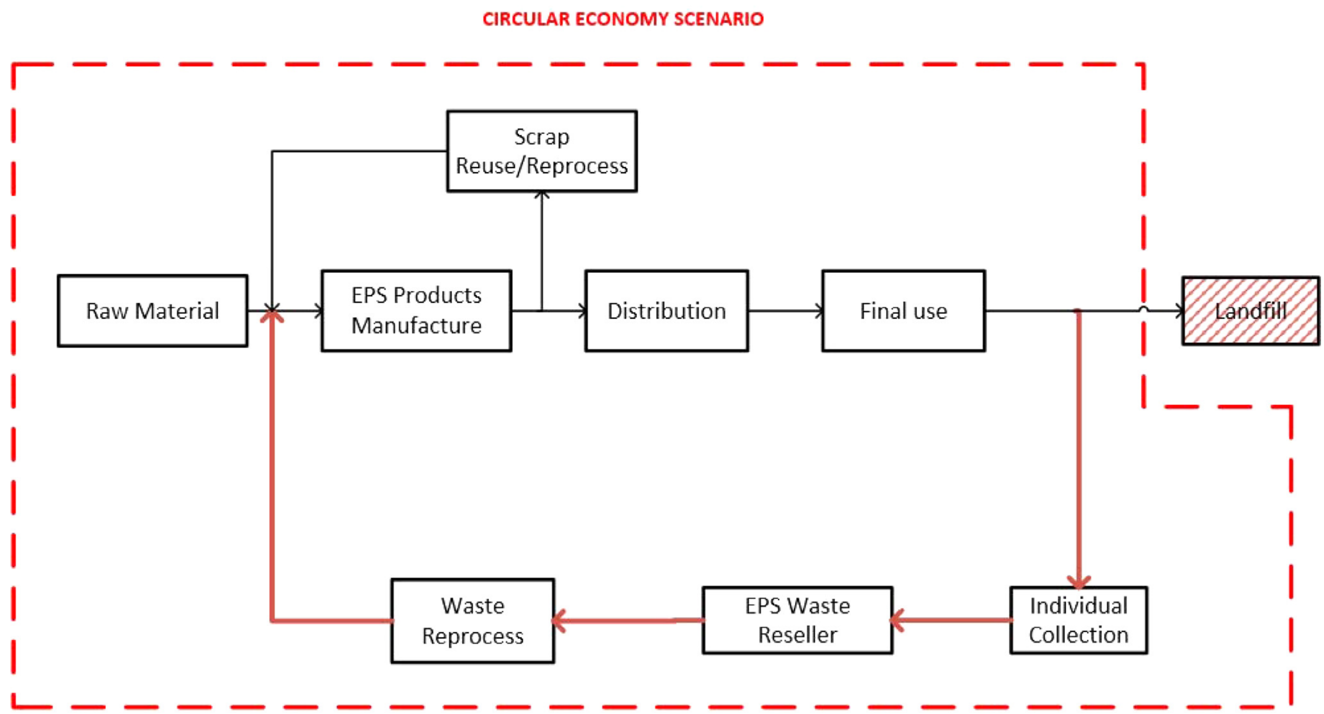

Fig. 2. Proposed circular economy cycle

2.1.3. Distribution

The EPS products are transported to intermediary businesses such as: fast food companies, grocery stores, restaurants, resellers and many others that will deliver the products to the final users.

2.1.4. Final use

The final user for this cycle is the household owner that acquires these products and then throws it away as waste, usually without sorting it first as written in the previous section.

2.1.5. Landfill

According to the Ministry of Environment (MAE), nowadays 49% of the municipalities dispose of their waste in landfills and emerging cells. The rest still dispose the final waste in open-air dumps, which generates direct effects on the soil, landscape, air, health and water. EPS waste takes as much as 500 years to degrade without oxygen, but the expiration time of landfills is not as long.

2.2. Proposed circular economy EPS production cycle

In a circular economy, resources are kept in use for as long as possible, extracting the maximum value from them whilst in use, then recovering and regenerating products and materials at the end of each service life (Cabello, 2014). The circular economy concept provides a key opportunity to address the challenge of resource scarcity for both policy makers and industries. Companies are urged to play their part and integrate circular economy in their business (Stewart et al., 2018, Biganzoli et al., 2018).

Nowadays, single-use expanded polystyrene manufacturing companies in Ecuador dont́ recycle post-consumption plastic for their production process. In fact, they reprocess the scrap material left from the molding and cutting of the plastic products and other forms to process post-industrial resin, applying the reuse of the 3Rś of circular economy inside the boundaries of the company. After, the post-industrial and virgin resin are mixed to create new EPS products. However, this doesnt́ mean that less EPS waste is being buried in local landfills. As shown in the previous section, almost 92% of all waste is buried and between 6 to 8% is recycled. Fig. 2 shows the proposed circular economy model for EPS waste in dashed red lines. The landfill is removed in this model by attempting to reprocess the post-consume waste.

2.2.1. Individual collection

In the current way to recycle waste, household owners leave their waste bags outside their homes in the set garbage truck schedule. Afterwards, individual collectors check the waste and separate all that they think has value. In order to recycle EPS waste, first household owners must be conscientized on the separation of their residues inside their homes.

Secondly, monetary value must be given to EPS residues by waste recycle companies and/or resellers to make individual collectors also take that type of waste.

2.2.2. EPS waste resellers

The waste is after taken for storage and reselling. Such businesses already exist and operate in the city, so EPS waste must be added to their structure.

2.2.3. Waste reprocesses

The collected EPS must be retransformed in resin pellets to be used in the manufacture of new products. This process may be done by the plastic manufacturer or by a third party if it is economically attractive. Further information of this process can be seen in Section 3.1.

3. Results

In order to achieve this proposed circular economy scenario, problems and constraints must be alleviated first. One of them is precise data on the possibility of obtaining high quality EPS products using recycled post-consume products combined with the used “scrap” and “virgin” resin for the manufacturing process. In this context, from June to August 2019, the authors collaborated

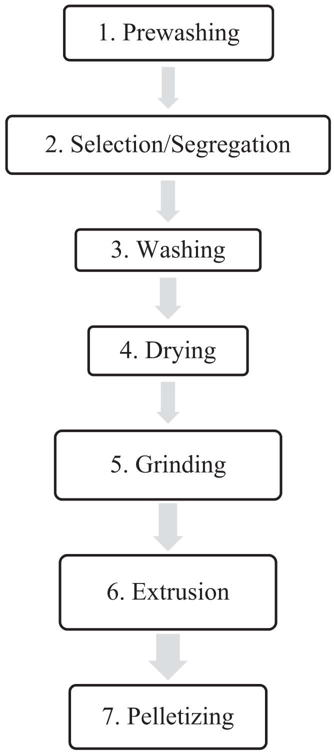

Fig. 3. Post-Consume EPS resin transformation process

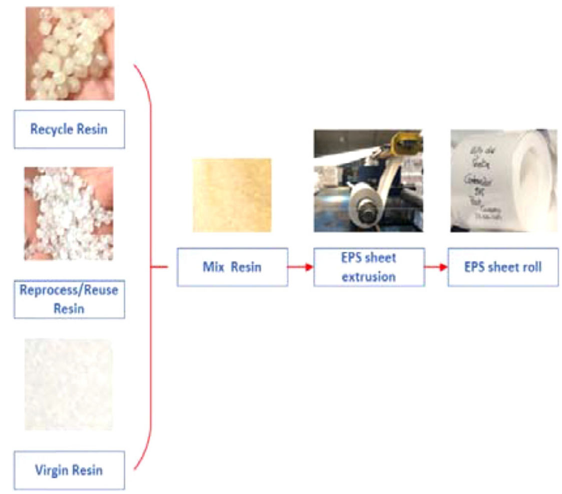

Fig. 4. Manufacturing of post-consume extruded sheet

with a local plastic manufacturer in order to formalize the recycling of single-use expanded polystyrene post-consume containers. The goal was to obtain at least 100 kg of the post-consume recycled EPS.

For this purpose, one hundred volunteer students from two local universities participated in the collection process, and a total amount of 230 kg was collected. After collection, the manufacturer continued with the protocol agreed for the post-consume recycling process at their quarters. The experiment formalization includes all the process starting from the arrival of post-consume EPS waste where the authors helped with the collection through the production of recycled resin and subsequent elaboration of new EPS containers.

3.1. Manufacturing of waste recycle resin pellets

Fig. 3 shows the recycling process of the post-consume plastic waste until it becomes resin pellets done by the manufacturing company. The first 4 steps were done in an artisanal manner by just one operator. It started with the *1. prewashing* of all waste using a hose with pressurized water to remove any remains of organic matter impregnated to the waste. Continued with the *2. selection/segregation* of the waste, where the operator proceeded to divide the waste between the colors of presentation and excluding any material that could not continue the process.

After came the *3. washing* in a washing-machine where liquid detergent, degreaser and liquid chlorine were added and after *4. drying* at medium temperature. This process lasted around 45 min (25 min washing + 20 min drying) per cycle and even though the maximum capacity of the washing-machine and dryer is 20 kg, only 600 g approximately could be introduced inside the machines during each batch, because of the high volume (low density) of the waste. The washing and drying of enough material took approximately 2 weeks to obtain almost 14 kg of dry waste. After, it was transported to the reprocess area where the company transforms the scrap into resin as previously stated. There, the waste followed three more steps: *5. grinding, 6. extrusion* and *7. pelletizing* where waste was crushed into small fragments and granules in the grinder, then passed to the extruder through heat and pressure until it dissolved and finally flew out of a small outlet and solidified into a continuous thin line. The extruded plastic stream was then cut into pellets by a pellet cutter with a rotation knife and cooled in a water bath at room temperature.

3.2. Manufacturing of post-consume new EPS containers

Before the test, the company used 70% of virgin resin and 30% of scrap reprocessed/reused resin for their process. Depending on the type of container built, they programmed the sheet extrusion machine for certain thickness of the sheet.

For the experiment, the manufacturer decided to combine all three types of resin before entering the EPS sheet extrusion line using the following mix as shown in Fig. 4:

- 40% Virgin Resin (18.0 kg)
- 30% Scrap Reprocess Resin/Reuse (13.5 kg)
- 30% Recycled Post-Consume Resin (13.5 kg)

The machine was already in operation with a previous batch when they entered the mix and set to produce 2.2 mm plates. So, the first two rolls (see Fig. 4) were marked as transition, since they contained the previous and new mix and the following two were marked as post-consume.

Total weight of transition rolls were 43.6 kg and the weight of the post-consume rolls were 21.6 kg, giving a final weight of 65.2 kg. The transition roll occurred when shifting from the usual mix to the new proposed mix, therefore there were 20.2 kg of extra EPS sheet. After this, the four rolls were separated and storage for further use in a next session, given that all thermo forming machines were busy at the time of the experiment, as shown in Fig. 4.

One week after the sheet rolls of expanded polystyrene were made, the manufacturer decided to make 5 in. x 5 in. foam food containers as the trial run of the new process using the recycling resin. They set the post-consume rolls in the machine and started running it. Some post-consume containers were taken away for laboratory analysis with other previous ones in order to compare properties.

Table 1
Laboratory report for characteristics of normal, transition and post-consume recycled containers.

Container description	Average weight (g)	Average resistance (kgf)
A. Normal	5.00	10.12
B. Transition	4.80	7.54
C. Post-consume recycled	4.70	9.26

3.3. Laboratory analysis tests

Based on the previous sections, five samples of each of the three type of final products were collected for posterior analysis:

A Regular mix EPS containers.
B Reformulated mix EPS containers transition roll.
C Reformulated mix EPS containers post-consume roll.

All samples were weighed, and their resistance measured after 24 hours. Average values are shown in Table 1. We consider the A containers as the base sample. The presence of recycled materials seems to make the mixture more rigid (Barrera Castro) in the transition sample. However, the analysis for the transition was made only 2 hours after production, in a previous day, so that may be the reason for the difference.

Also, microbiological analysis is necessary for these products to ensure quality through the application of procedures to test the presence of microorganisms and compare them to standardized limits (Mirzaei et al., 2016). This becomes very important in the context of a circular economy, since microorganisms present in food industry as a microflora may penetrate EPS waste food containers. The reprocess of new recycled resin pellets could lead to undesirable effects on public health.

Nonetheless, laboratory analysis effectuated by the manufacturer showed no presence of microorganisms in any of the samples. This can be explained because the extrusion process occurs at a temperature higher than 200 °C for the recycled resin manufacture and almost 120 °C for the roll production. Both processes add almost 18 min of total time and at these temperatures, no microorganisms can survive.

Finally, containers or other expanded polystyrene elements can release particles that can be absorbed by food. The certification of these products is done by the migration test. Plastic materials and objects should not yield their components to food products in quantities exceeding 10 mg/dm^2 or 60 mg/kg (limit of Global Migration by Ecuadorian Technical Standard NTE INEN-EN 1186-1).

For this experiment, migration test results, although being a little higher for recycled containers, still showed much lower levels than the limits set by the Ecuadorian Technical Standard (Table 2).

4. Conclusions and final remarks

Based on the literature and the countryś actual recycle scheme; a circular economy model scenario has been proposed. Unarguably, the benefits derived from the implementation of circular economy are due to the reduction in the consumption of natural resources. However, the economic and environmental benefits are not self-evident and need to be proven by an in-depth analysis such as life cycle assessment of the current and proposed scenarios.

The primary aim of this research was to contribute to the private single-use plastic industry to redesign their products using recycled materials. To attain this purpose, it was made clear that EPS waste reprocess to form new resin pellets is possible and that mixing with virgin and reused pellets can create high quality new products.

There is a great plastic waste problem, and it is an issue that must be considered. Most post-consume EPS containers are discarded in landfills and pollute the environment. The rates of waste recovery in Ecuador are very low, so it is of vital importance for policy making institutions to increase the knowledge of circular economy and help them asses the feasibility of recycling EPS and develop a supportive system that facilitates and encourages recycling activities among recyclable waste collectors' associations.

5. Discussion and future research

The plastic companies in the country reuse/reprocess the scrap left from the production lines. This prevents the scrap to end-up in landfills and damage environment. Nevertheless, the reprocess means more energy is needed to recover material through post-industrial pellets. Thus, more analysis is needed to evaluate the total damage done to the environment between the two choices by life cycle assessment, which is a systematic analysis of the environmental impact of products during their entire life cycle (production, use and disposal phases).

This first attempt to demonstrate the mechanical recyclability of EPS single use products, in Ecuador, proves the potential for the development of a circular economy around this type of waste material. However, more trials are need to be set in place to diminish the difference in values for weight and resistance. In practice, unfortunately, remelting and forming new post-consume resin often degrades the properties of the recycled items products. Thus, the amount of virgin resin shall increase to keep the quality of the final product and some waste will always be created.

Also, in order to develop a circular economy around domestic waste, people need to participate in the process of separation. Studies indicate that when made available people will use the colored recycle bins. Government intervention is important, to surveillance and reinforcement of already made policies, for managing possible recycling items. Also, reprocess companies must have the technology to decontaminate the polymers before melting and resell high quality recycled plastic raw material to the manufacturers.

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Table 2
Migration test results.

Parameter	Results Normal EPS container (mg/dm^2)	Results Recycled EPS container (mg/dm^2)
Global Migration Test (ISO Octane Simulant)	4.3	4.6
Global migration test (Simulant Ethanol 10%)	0.8	1.6
Global Migration Test (Distilled Water Simulant)	0.5	1.2
Global Migration Test (Acetic Acid Simulant)	1.0	1.0

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