Streamlined Life Cycle Assessment of Glass Bottle End of Life Strategies in Puerto Rico

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ABSTRACT

In the following study, a streamlined life cycle assessment (SLCA) of different end-of-life strategies for repurposing or recycling glass bottles is modelled to compare the environmental impact of each strategy. This SLCA was restricted to the transportation of glass bottles, the filling process and use phase, and finally the disposal stage such as landfill, sterilization process, and cullet production for aggregate. Also includes the amount of material (glass bottle mass) used, energy and water consumption of each process modelled. Challenges in data collection were found but the research done in collecting data from literature, field visits and questionnaires lays the foundation to conduct a modelling of the SLCA using GaBi Software. The assessment was carried out according to TRACI v.2 to calculate the emissions and their impact categories values. In conclusion, the results of this SLCA contributes not only on clearing the picture of the environmental impact caused by the lack of recycling and solid waste management strategies but to organize the data collected not found anywhere else. This way it facilitates the decision-making process for modifying or implementing a new strategy for the end of life of glass bottles.

RESUMEN

En el siguiente estudio, se modela una evaluación simplificada del ciclo de vida (SLCA) de diferentes estrategias de final de vida para reutilizar o reciclar botellas de vidrio y comparar el impacto ambiental de cada estrategia. Este SLCA se restringió al transporte de botellas de vidrio, el proceso de llenado y la fase de uso, y finalmente la etapa de disposición, como en el relleno sanitario, el proceso de esterilización y la producción de vidrio para el agregado. También incluye la cantidad de material (masa de la botella de vidrio) utilizado, el consumo de energía y agua de cada proceso en el modelo. Se encontraron desafíos en la recopilación de datos, pero la investigación realizada en la recopilación de datos de la literatura, las visitas de campo y los cuestionarios sienta las bases para realizar un modelo de la SLCA utilizando GaBi Software. La evaluación se realizó según TRACI v.2 para calcular las emisiones y sus valores de categorías de impacto. En conclusión, los resultados de esta SLCA contribuyen no solo a aclarar el cuadro del impacto ambiental causado por la falta de estrategias de reciclaje y manejo de residuos sólidos, sino a organizar los datos recolectados que no se encuentran en ningún otro lugar. En fin, de esta forma se facilita el proceso de toma de decisiones para modificar o implementar una nueva estrategia para el fin de vida de las botellas de vidrio.

Esta tesis está dedicada a mi abuelo, José Francis y Santos, y a mi madre, Gloria Cordero Cancel, por siempre creer en mí.

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GLOSSARY OF TERMS

Ac	Acidification
CaO	Calcium Oxide
CF	characterization factor
CML	Centrum voor Milieukende Leiden
Eu	Eutrophication
EoL	End of Life
FSW	Final Solid Waste
GaBi	Ganzheitliche Bilanzierung
GWP	Global Warming Potential
HT	Human toxicity
kWh	kilowatts hour
km	kilometers
L	Litters
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
I	Impact potential
i	category
ISO	International Standard Organization
m	media
MRFs	Material Recovery Facilities
MADM	Multiple Attribute Decision Making
Na_2O	Nitrogen Oxide
OD	Ozone Depletion
POC	Photo Chemical Ozone Depletion
SiO_2	Silica
SETAC	Society of Environmental Toxicology and Chemistry
SLCA	Streamlined Life Cycle Assessment
TRACI	Tool for Reduction & Assessment of Chemical & Other Environmental Impacts
V_a	Critical Air volume
V_w	Critical Water volume
WMO	World Meteorological Organization
x	chemical

1 INTRODUCTION

1.1 State of Solid Waste

Over the years, environmental awareness has increased worldwide among government agencies, the private sector, and society in general. Since the manufacturing companies have exponentially increased the production of goods/products, leading to an increased exploitation of natural resources[1]. Solid waste management agencies have struggled in keeping up with the excess of municipal waste generated daily. For this reason, it is imperative that Puerto Rico's Solid Waste Authority develops new decision-making strategies to avoid an environmental crisis.

Sustainable development has been the path of interest for the public and private sector to achieve better quality of life. To mitigate the poor waste management practices, the government of Puerto Rico has enacted three laws related with solid waste management. The first was passed in September 1992, Law 70 called "*The Law of Reduction and Recycling of Solid Waste in Puerto Rico*", it sets as public policy the development and implementation of economic viable and environmentally safe strategies for the reduction of solid waste volume[2]. The next year, 1993, an executive order was presented, which established that all commonwealth agencies were required to have recycling stations for paper and recyclable materials[2]. And the third law, Law 411, which mandated a recycling rate of thirty-five percent of the solid waste by the year 2006[3]. Despite the fact of having all these public policies and laws, currently less than ten percent of the ten thousand tons of solid waste produced daily in Puerto Rico is recycled, which causes that all landfills on the islands reach their full capacity in three to four years. This crisis was worsened due to the accumulation of solid waste after Hurricane Maria in 2017[4].

To deal with this solid waste crisis, materials recycling has been explored for decades, but few companies have prospered in the recycling business on the island. Solid waste management, machinery and operating cost, and logistics are some of the challenges of materials recycling [5]. However, when it comes to establishing and operating material recycling facilities, economic factors tend to have greater weight than recycling potential of the facilities. Such is the case of the glass manufacturing company, Owen Illinois, which recycled post-consumer glass containers, in Vega Baja, Puerto Rico in 2008, but ceased operations because of the elevated cost of glass recycling machinery[6].

In Puerto Rico, glass bottles of different sizes are used by rum and beer companies such as Bacardi and Cerveceria de Puerto Rico respectively, to bottle their products. Since there is no glass bottle sterilizing or recycling facilities, both companies are constantly in the need of importing glass bottles to keep up with production. In other words, large amounts of glass bottles end up in landfills or are illegally dumped.

1.2 Life Cycle Assessment

It is important to consider not only the economic aspects of a recycling or repurposing facility on the island, but the environmental aspects as well, to have better knowledge of the benefits and consequences. This can be done through life cycle environmental analysis and a benefit assessment, tools for analyzing the environmental impacts associated with inputs and output of a product's life cycle as well as including the benefits of using glass bottles as in the following study.

Since late 1960s, companies such as Coca Cola have been trying to relate resource consumption and the ecological footprint associated with soft-drink containers [7]. In Europe a methodology was developed called the Eco balance [8]. It was not until the 1990s that a methodology for conducting an analysis of the life cycle of a process or product was standardized.[9]

A detailed description of the methods used by environmental professionals when conducting an LCA is presented. The methodology of an LCA study are based on the ISO 14040-44 which defines an LCA as a process that evaluates the ecological footprints and the potential impact to human health of a product life cycle, from cradle to grave, gate to grave, gate to gate, and the most optimal cradle to cradle as shown in Figure 1.1. [10] An LCA is divided into four phases shown in Figure 1.2.

This analysis can provide an overall understanding on how the modeling six end-of-life scenarios using dedicated life cycle software for glass bottle can help on the decision making of industries.

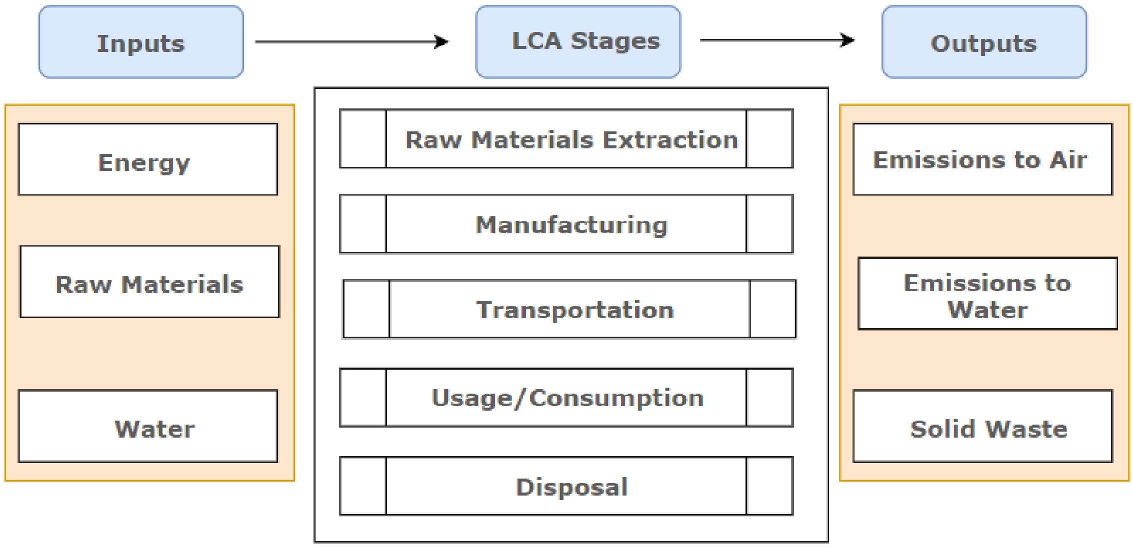


Figure 1.1 Life Cycle diagram of cradle to grave of a product system.

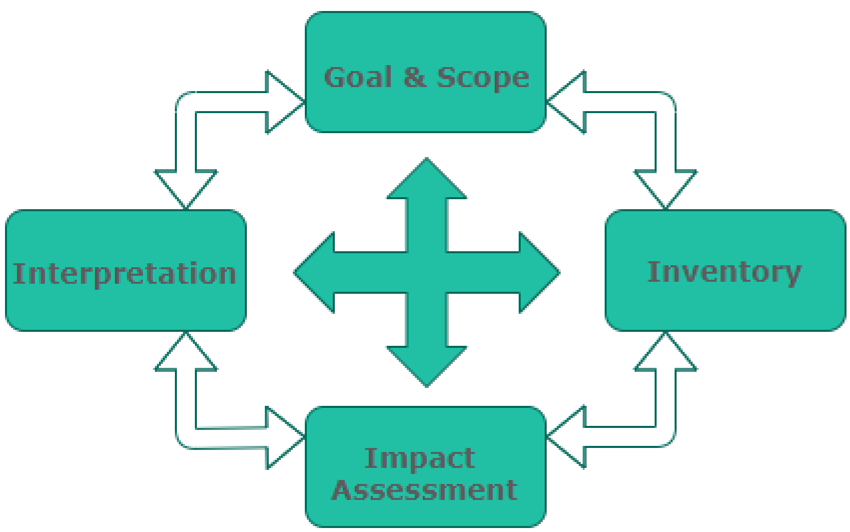


Figure 1.2 Life Cycle Assessment phases. (Arrows are in both direction meaning it is an iterative process.)

1.3 Proposed Work

This work proposes the use of the streamlined life cycle assessment (SLCA) methodology and modeled a gate to grave analysis of different glass bottle end-of-life (EoL) scenarios and understanding their environmental impact. Streamlined means simplifying or limiting the scope of the study[9]. The interpretation of this study provides a clearer picture of which scenario has less ecological footprint to have better criteria for implementation. The reason for choosing glass as the focus of this study is that it has one specific advantage, it can be recycled indefinitely because the mechanical properties do not deteriorate between cycles, making it a sustainable material [11]. The first three models are: glass bottles transported to sterilization for repurpose, to a crushing glass (cullet) facility as an aggregate for construction concrete blocks or beach nourishments, and the actual scenario of depositing glass bottles in landfills. Scenarios 4, 5, and 6 are made combining the first three scenarios: Landfill with Sterilization, Landfill with Cullet production as an aggregate, and Sterilization with Cullet Production as an aggregated, respectively. LCA methodology is used for this research because is also a standard procedure created by the International Standard Organization for analyzing a part or the complete life cycle of a system or product[12]. Conducting an LCA of different end of life management scenarios of glass bottles is a starting point with respect to integrated solid waste management strategies and policies on the island because it takes into consideration not only the economic factors but environmental factors as well.

This research consists of a review of how post consume glass containers are managed and how it is managed in Puerto Rico in Chapter 2, LCA methodology explain step by step in Chapter 3, discussion of the SLCA modeling results and impact assessment in Chapter 4, and in Chapter 5, the conclusions and recommendations made by interpreting its results.

2 LITERATURE REVIEW

In this section, a review of the literature related to each of the components of the proposed project was provide. These components include glass bottles recycling, process of glass containers such as sterilization process and cullet production for bottle manufacturing or environmental remediation. Finally, a review of LCA's studies made in Puerto Rico and examples of its application.

2.1 Glass Containers

Glass containers are mainly used for the food and beverage industry. They can be seen in different sizes depending on the product, they range from small sizes of 1 oz for baby food, 6 oz for jelly, 12 oz for soda or beer, to bigger ones of 25 oz for wine or rum. Once the glass bottle is used, the glass containers are disposed into landfills or they can be recycled. The composition of glass is predominantly silica (SiO_2) which is mostly high-quality sand, sodium oxide (Na_2O) and calcium oxide (CaO). These materials are classified as renewable resources; hence glass can be categorized as a sustainable material. A sustainable material is a material that is made of renewable resources and has the benefits of low maintenance, energy efficiency, nonhazardous properties, as well as being environmentally responsible materials[13].

Glass take too much time to degrade when dumped in landfills, causing piles of waste glass which may contribute to a decrease in landfill capacity[11]. This is the case for Puerto Rico, where landfills diminished their capacity, especially after Hurricane Maria, the amount of waste has increased so much that the life expectancy of landfills have been reduced [3]. Also, energy recovery from waste glass is not possible, making incineration not feasible. For this reason, alternative EoL or repurposing of glass becomes more sustainable alternatives method.

2.1.1 Repurposing process

In 2017 in the United States, approximately eleven and a half million tons of glass were generated and almost twenty seven percent was recovered for recycling, which means a recovery of almost three and half million of glass[14]. Although glass bottles are found in large numbers, Material Recovery Facilities (MRFs) have to meet the government agencies regulations if post-consumer bottles are to be used for refilling such as title 40 of the federal code[15]. When glass containers reach the MRFs a sorting process begins. It gets either manually or mechanically sorted by color or by shape, followed by a washing process with hot water and soda for cleaning and removal of labels. Once the containers are clean, they are grouped in bundles for packaging and transported to the brewery, rum, or wine company for repurposing. If the containers are in bad conditions, meaning that they are broken or damaged, they are transferred to a crushing machine for cullet or crushed glass production. Cullet has more than one use. It is used for the manufacturing of new containers such as soft drinks, wine, or beer bottles[11], [16]. Larsen establishes that less energy is used to produce cullet than virgin material for glass manufacturing. This is because the cullet has a lower melting point and reduces environmental impact of transporting virgin raw material[16].

2.1.2 Cullet as aggregate

Another use for cullet is as a filler material for concrete blocks. Concrete is mainly composed of cement, sand, and gravel [17]. It has been proved that aggregation of cullet as a filler material to concrete mix still maintains the physical, chemical and mechanical properties of the concrete while reducing costs [18]. Table 2.1 shown below, displays the composition of traditional cement compared to the composition of cement mixed with glass. Also, the values of the compressive strength test made on the specimens at day 2, day 7 and day 28 for the traditional cement were 21.9, 39.6, 55.1 MPa, respectively and for the cement mix with crushed glass the values were 20.3, 36.5, 53.5 MPa, respectively. A slightly decrease can be seen but in conclusion the used of cullet as a feed material can meet with the general requirements of cement production.

In San Sebastian, Puerto Rico, a company named “Comercial la Pino” mixes cullet, cement, sand and water for the production of construction blocks. To be clear, La Pino used to receive the glass waste from another local business that has an industrial garbage bin for glass and once the bin is full, the glass was transported to La Pino for cullet production. Since glass bottles were not being consistently thrown in the garbage bin and it was transported for free, the transporting services of the glass to La Pino is still discontinue.

Table 2.1 Composition of traditional cement compared with cement mixed with cullet.

Impact on cement quality of glass feeding		
Composition	Normal Cement	Cement with glass addition, second test
Na_2O(%)	0.1	0.2
K_2O(%)	0.32	0.31
Total Alkali (%)	0.31	0.4
SO_3 (%)	2.49	2.47
Free lime (%)	1.25	1.2
SiO_2(%)	20.7	21.3
CaO(%)	65.2	65.1
Fe_2O_3(%)	3.33	3.37
Al_2O_3(%)	4.96	5.37
MgO(%)	0.57	0.61
Tricalcium Silicate (C_3S)(%)	62.7	55.6
Blaine (m^2/kg)	308	304
Fineness(-325)(%)	93.5	94.4
EN Compressive Strength		
2 day (MPa)	21.9	20.3
7 day (MPa)	39.6	36.5
28 day (MPa)	55.1	53.5

2.1.3 Cullet for environmental remediation

Beach nourishment have been the latest alternative for using cullet. Studies from the University of Puerto Rico in Mayaguez proposed to used cullet as beach nourishment to mitigate the erosional damages from the coast of the island [19]. In the present study, beach nourishment was included as a variation of cullet production scenario.

2.2 LCA in Puerto Rico

Up to this moment there have been a few life cycle assessments in Puerto Rico. In 1998, F. Monroig [20] carried an analysis and evaluation of the environmental performance of a refrigerator's using the LCA methodology. This was one of the pioneers in LCA in Puerto Rico and was used to evaluate the different designs of refrigerators and alternative ways of home refrigerators disposal in the island and identifying the benefits of each one along with the environmental impact associated. Another study made was by J. Cruz-Luciano [21] who conducted a streamlined LCA for the environmental performance evaluation of transportation modes in the San Juan metropolitan area. The main goal was to evaluate different transportation modes such as automobiles, busses, and heavy rail or "Tren Urbano" as it is known. Cruz Luciano, et. al, were able to use the LCA methodology to evaluate the use stage of transportation modes and determine the environmental concerns of each mode. A third research was made by Monserrate [19] in 2018 which studied the economic feasibility of using recycled glass as beach nourishment to mitigate Puerto Rico coastal erosion problems. Here, the LCA methodology was used to evaluate the implications of dispose used glass bottles in landfill compared with using for beach replenishment. Echevarria [22] proposed to use a benefit assessment to evaluate products and services in combination of the current LCA methodology.

2.3 Example of LCAs

LCA methodology contributes on having a clearer picture of the environmental, social, and economical impact of any activity or process of product manufacturing in all stages of it. Interest in this kind of analysis is significantly increasing because LCA are being used in different areas such as universities, public agencies, and private companies. Although it is possible to analyze each stage of extraction, transportation, manufacturing, use, and disposal, practitioners tend not to study all stages at one. For example, Asif [23] at Napier University in Edinbrugh, UK, made a study of a life cycle assessment of the list of materials used for the construction of a home in Scotland. The materials included were wood, glass, ceramic, aluminum, and concrete tiles and were being analyze for to determine the environmental impact and the energy embodied of each one. The findings are that in a home, concrete has the highest contribution of energy embodied distribution in the house with a 61% of the total.

Another major concern of packaging material is the increasing amount of solid waste. The European Commission and the Directive on Packaging and Packaging Waste indicates that the *"...reuse of packaging and recovery of packaging waste (and hence recycling) are both valid means for minimizing its impact on the environment"*. For this reason, the application of an LCA contributes to the evaluation for packaging materials. The goal of the study was to measure the ecological impact linked to the returnable and non-returnable glass beer bottles to compare them with different reuse percentage. The functional unit, which is the value used as a reference unit[12], was the distribution of 330 liters of beer, which is equivalent to 1000 bottles of 0.33 liters amber glass.

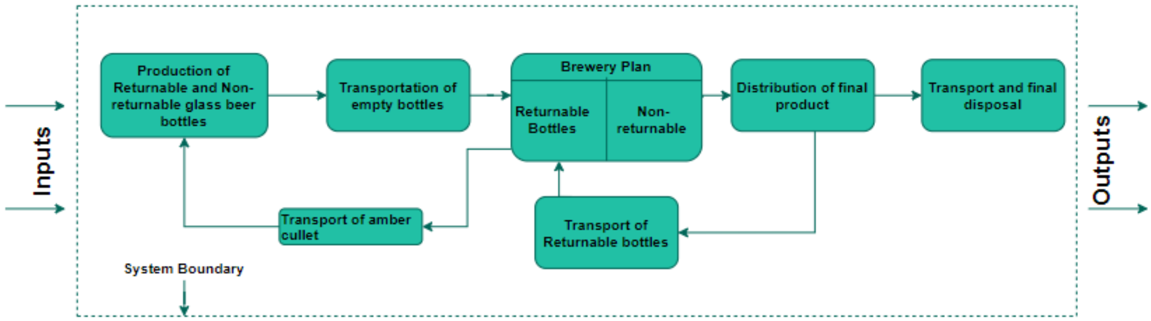


Figure 2.1 System Boundaries of the LCA for the returnable and non-returnable glass beer bottles

In Figure 2.1, a system boundary is presented containing a flow diagram of the complete life cycle of both bottles being analyzed. These stages include the raw material purchase, glass bottle manufacture, cleaning, filling, transportation from the bottle producer to the brewery, and the distribution of the beer to the consumer, etc. In geographical terms, the study was conducted only for the production and distribution in the metropolitan area of Porto, Portugal. The life cycle inventory data was collected from literature, engineering calculations and data from the glass bottle manufacturer and the brewery, both from Porto. It is important to emphasize in the difficulty and challenge of this step because not every value is explicitly given or cannot be found. The data includes inputs and outputs of each process, such as, amount of material, water and energy consumption, wastewater, air emissions, and solid waste from both companies and the brewery wastewater treatment plant. It is important to acknowledge the assumptions that were made in the study, for example, the extraction and processing of natural resources, electricity generation, and the consumer's behavior at home between both cases, the returnable and the non-returnable bottle, were similar. Also, transportation, energy and waste in landfills, and auxiliary material chains (labels, glues, crowns, etc) were assumed to be similar for both scenarios. After gathering the inventory data and making the assumptions, the results of the life cycle impact assessment were calculated as stated in ISO 14042. All flows of every process in the system boundary were normalized to be able to meet with the goal and consider the functional unit. The CML 2001[1] method was used for the impact assessment. The impact categories from the CML method are focused on global and regional effects such as the critical water and air volumes (Vw and Va, respectively), human toxicity (HT), ozone depletion (OD), photochemical ozone creation (POC), global warming (GW), acidification (Ac), eutrophication (Eu), and final solid waste (FSW).

When comparing non-returnable bottles with the 20 and 30% reused returnable bottles, it is apparent that the returnable bottle creates much less environmental impact in all categories. It is the same behavior for 40% reuse except for the solid waste category. For the 50% reuse, the returnable bottle had smaller impact in categories such as Va and Vw, HT, GW, Ac, POC, energy and raw material consumption than the non-returnable but for Eu, OD, FSW, and water and auxiliary materials consumption, the returnable has bigger impact than the non-returnable. As for the 60% the GW, and energy consumption categories are smaller for the returnable bottle after the fourth cycle, and for the Va, Vw, Ac, POC, and raw material consumption are smaller after the third cycle but for the categories of OD, Eu, FSW, water consumption and auxiliary materials consumptions the

[1] Centrum voor Milieukende Leiden method is a database containing characterization factors for life cycle impact assessment[42].

impact is larger for the returnable bottle than the non-returnable. In 70% reuse, the impact is larger for the returnable bottle in most impact categories such as GW, OD, Eu, FSW, water, energy and auxiliary materials consumption, except for Va, Vw, HT, Ac, POC and raw materials consumption which was smaller after the sixth cycle. Finally, at 85% reuse, the environmental impacts of the returnable bottle were larger than the non-returnable in all impact categories. A sensitivity analysis was made to demonstrate that a variation of 10% in each of the data values, creates an error of about 0.1 in all impact categories. Some the findings of the study were that the returnable bottles have the possibility to be sterilized and reused for approximately six cycles in one year before the need of recycling. Is important to remember that for the bottle to be recycled it must be broken and transported to the bottle manufacturer. The sensitive analysis concluded that errors in the data, if any, had little or no effect of one bottle being superior or inferior to the other. This also tells that the quality of data indicates a good representation of the glass bottle life cycle.

3 SLCA METHODOLOGY

3.1 LCA Background Methodology

To conduct an LCA study, one must start by defining the goal and scope, as presented in ISO 14-041 LCA-Goal and scope definition and inventory analysis. This first phase sets the problem, defines the objectives and range of the study, and determines the system boundaries and the functional unit. The second step is to make an inventory analysis which consist of compiling required raw materials and the air, water, soil emissions of the system being analyzed. The impact assessment is the third step, and the fourth step is the evaluation or interpretation of the LCIA results. A detailed description of the goal and scope, and the inventory analysis are found in the next section.

3.1.1 Streamlined LCA

The study conducted is called a streamlined LCA because some stages of the life cycle are assumed and some parameters are omitted[10]. Section 3.1.2.1 explains in detail what is and what is not included in the system boundary. In general, this was decided because for example, for all scenarios, the crown, the cardboard boxes, and the bottle labels were not included in the LCA models. Since these three materials were equal for all models, they were omitted. The brewery process is also outside of the scope's study because of the complexity of the process. For modelling purposes, water was used at the filling process because beer is 90-95% water. Even though a local brewery company shared some information, the data used for the making the models is generic.

A screening was made of the most important parts of the life cycle to be able to simplify and focus on the important areas. And finally assessing reliability is needed to see if simplifying affects the reliability of the results.

3.1.2 Goal & Scope of the study

When defining the goal of SLCA, it is important to establish the purpose of the study. It is imperative that the goal of an LCA presents the intended application, the reason for carrying out the study and the audience to which it is directed. The scope of the study is where the system boundaries are included, and which detailed assessment methods are to be used. LCA is an iterative process, therefore the scope may be modified as long the study is being conducted, because additional information appears [24]. In this study, the purpose is to understand the life cycle of glass bottles in Puerto Rico, focusing on the bottling, distribution, use and end of life phases. For this it is necessary to evaluate the current scenario (importation, bottling, transportation, disposal). Another reason for selecting glass bottles for this study is because of the apparent lack of glass bottle recycling in Puerto Rico. In addition, six different glass bottle recycling scenarios were modeled to compare each of them and have a clear view for making decisions in respect to glass container recycling. The functional unit, or the reference to which the input and output flows of the inventory data phase was be related, is 1 L of beer (equivalent to three 12 fl.oz bottles), or for modeling purpose 1L of water since beer is 90-94% water[25].

The six scenarios to be modeled for comparison in the study are shown in table:

Table 3.1 EoL Scenarios of Glass Bottles to be model.

	Scenarios
1	Landfill (100%)
2	Sterilization (100%)
3	Cullet Production for Aggregate (100%)
4	Landfill/ Sterilization (50-50)
5	Landfill/ Cullet Production for Aggregate (50-50)
6	Sterilization/ Cullet Production for Aggregate (50-50)

3.1.2.1 System Boundaries of the SLCA Modelling

The input and output parameters in the system boundaries are explained here. The energy consumed in transportation and the use phase such as bottling and handling the bottle up to the final product are included in the system boundaries of modelling the SLCA, the energy use for sterilizing and the production of cullet is also included. As for the water consumption, the water used for the sterilization process, the cullet production for aggregate and for bottling process is included as part of the system boundaries, however since the focus of the study is on the disposal stage, the bottling process will have minor relevance when analyzing the results. The material required as an input was the mass of the glass bottles, which is essential for the software modelling. Another input that is essential is the distance travel by the ship and the trucks to transport the material between stages. To clarify, energy, water, and material consumption of the extraction of raw materials stage and the manufacturing of glass bottles stage are not being consider in the

SLCA. As well as the auxiliary materials mentioned earlier are also not included in the system boundaries. In Figure 3.1, a system boundary of the SLCA is presented.

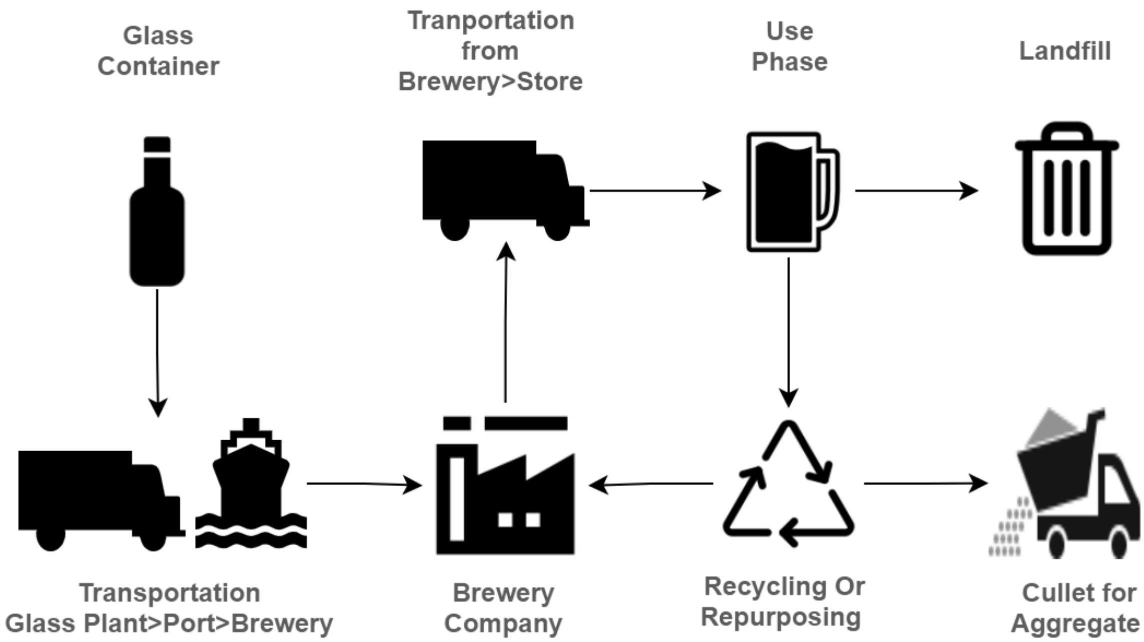


Figure 3.1 Streamlined life cycle of glass bottles.

3.1.3 Life Cycle Inventory

The second phase of the LCA is the inventory analysis which contains a compilation of the inputs and outputs when bottling, transporting and disposing of the functional unit, as known, in this case the glass bottles. [24] It is necessary to collect the data from each stage of the life cycle being analyzed.

The data can be quantitative as well as qualitative. In Table 3.2 is shown the data that was used for modeling each process in all six scenarios. The values for energy and water consumption (kWh and L, respectively), transported distance (km) and glass bottles mass (kg) are presented. These values were gathered from literature[19,26], a local microbrewery company (*Appendix A*) and data from solid waste management agencies. The distance traveled by the ship was gathered from a web page called *"searates"*, which contains information of distance travel of cargo ships between destinations, cargo fees, etc[27]. As for the truck distance, the average of the distance traveled from the San Juan to Mayaguez, was calculated by using any traditional map. It is important to define the truck parameters in the software such as seen in Figure AC. 3 in *Appendix C* because setting the average distance and the weight input of the material will be used for computing the number of emissions caused for example by fuel combustion.

Table 3.2 Input values of glass bottle weight, transportation and energy and water consumption.

Input Data	*Values*
Glass Container	**Weight (kg)**
1 Bottle	0.233
Transportation	**Distance (km)**
Ship	2104-3180.8
Road Truck	0-200
Energy Consumption	**Joules (kWh)**
Brewery Plant	0.975
Sterilization Facility	0.305
Concrete Block Company	0.0354
Water Consumption	**Volume (L)**
Brewery Plant	7.84
Sterilization Facility	1
Concrete Block Company	2.76

3.1.3.1 Data Collection and Validation

To collect the data was necessary to create questionnaires for the companies such as Appendix A. Here the company was ask to offer information of energy and water comsumtion, amount of material used, transportation distances, etc. If it was possible, field visits helped to understand each process in more details. Data that was not available or accessible, past studies and estimations were used.

Since this data is collected from different sources such as past studies, questionaries, and personal interviews validation of this data becomes a difficult task because there are no other study to evaluate with.

3.1.3.2 GaBi Software Modelling

As mentioned before, the study was directed to the transportation, usage, and disposal of the glass bottles and. For this research, a LCA software tool was be used called GaBi Software developed by Thinkstep Company[2]. A detailed description of the features and functionality of the GaBi Software is describe in the manual which includes, an introduction, basic principles of the software, and how to conduct a modelling a product or a system life cycle[28]. This software is a tool that models every element of a product or system from the life cycle perspective and contains an accessible and constantly refreshed database from different countries that details the costs, energy and environmental impact of sourcing and refining every raw material or processed component of manufactured item. It also presents alternative options for material manufacturing, energy generation and water distribution, as well as recycling options. The software has capacity to conduct the impact assessment phase where it quantifies the emissions of each stage of the life cycle and evaluate them by classifying, categorizing, and characterizing the emissions have with each

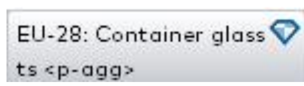
[2]Thinkstep Company website: https://www.thinkstep.com/software/gabi-software

of the impact categories. Displays of an example on how the software works can be found in *Appendix D*. This example of an LCA of a paperclip is given by the company[29], and evaluates the life cycle of a one paperclip to conduct a simple tutorial on how to carry out LCA modelling.

The plan modeled contains three end-of-life scenarios. Figures 9.1-9.4 (*Appendix D*) shows the GaBi software flow diagram and Figure 3.2 presents how each process of each stage of the life cycle is display in the software. GLO, US, and EU-28 are related to the region where the process parameters were documented[30]. United States Life Cycle Inventory (USLCI) is a database created by the National Renewable Energy Laboratory and partners included in GaBi Software and contains accountability of inputs and outputs of cradle-to-grave, gate-to-grave, and gate-to-gate process[31]. The transportation, electricity generation and distribution, and water distribution parameters are found in the software database, but when modelling the values of electricity and water consumption in each process and the distance traveled in transportation are needed to be set in the process settings such as in the Figure 8.3. For modelling purposes, the glass containers manufacturing data will be use as the input in material. The filling process and the EoL scenarios required to be created and the input data used was gathered from the questionnaire to each company such as in *Appendix A*. The electricity selected from database when modeling the life cycle was Hawaii’s electricity generation, since its similarity to Puerto Rico’s power supply[32]. Also a variation in electricity supply in the sterilization process such as energy from renewable resources was included to evaluate the possibility of using alternative energy supplies. To be clear, in the modelling it was only include just the supply of photovoltaic panels and not the manufacturing of the panels.

Initially, after the glass bottles are manufactured, the bottles are transported by truck to a port, and then shipped to Puerto Rico in a cargo ship. When the ship arrives to island, the bottles are loaded on a Truck 26-28t [3] and transported to the brewery company for the filling process. Finally, the glass container is gathered in bundles of 24, packed in carton boxes and delivered to its different destinations in similar trucks. The auxiliary materials such as the carton boxes, the crowns and labels are not included at the bottling process in the inventory because of the streamlining.

Glass Manufacturing



Transportation

Use Phase (Brewery and Usage)

[3] Gabi Software- Documentation Truck Transport Process

End-of-Life Scenarios

Electricity, Water, and Fuel Consumption

Figure 3.2 Glass Production life cycle phases presented in GaBi modelling.

It is important to emphasize that the processes of manufacturing, transportation and packaging of the bottles are equal for all scenarios. The disposal phase is what changes in each of the scenarios. The first scenario the post-consumer bottle is ends in landfills. The second scenario the post-consumer bottles are transported to a sterilization facility which uses hot water to sterilize the bottles. Hence, water and energy consumption are needed. Once the bottles are clean, they are transported back to the brewery company creating a closed loop recycling. For this study, it is assumed that all bottles in the sterilization scenario return to the brewery, meaning that all bottles were in good conditions.

The third scenario represents cullet production. As mentioned before, the importation, transportation to the brewery and packaging of the beer is the same as the other two scenarios, and the disposal phase changes. Here, when the beer is consumed, the glass bottles get transported to a concrete block manufacturing plant. Here the bottles are crushed and converted into cullet, which later is mixed with the gravel, cement, and water, and shaped into a construction block. After this process, the concrete blocks are left outside the plant to cure. As part of the third scenario using as a reference the study made by Monserrate in 2018, the cullet was transported for beach nourishment. For comparison purpose the other three scenarios that will be analyzed, the first will be combining end of life (EoL) scenarios such as depositing 50% of the bottle into landfills and 50% sterilizing for refilling. The fifth scenario modeled was combining 50% landfill and 50% cullet production. And the sixth scenario was 50% sterilization with 50% cullet production.

After gathering the inputs for transportation, electricity and water consumption for the filling and disposal process, GaBi software was used to complete an impact assessment to evaluate any effect an action has on the environment, human welfare, and health. The next phase is the life cycle impact assessment.

3.1.4 Life Cycle Impact Assessment

This phase is where the results of the LCI are converted to impact measures allowing the interpretation of the total environmental effects of system that is being study. Here is where the Life Cycle Impact Assessment (LCIA) develops an impact factor for each category and consists of three-phases: classification, characterization and valuation [33]. First, the classification process takes place and consist of dividing into homogeneous impact groups all LCI data provided. For example, SETAC proposes four general impact categories such as environmental or ecosystem quality, quality of human life, natural resource utilization, social welfare. The categories for this research were defined after gathering all LCI data.

At the characterization process, is necessary to identify impacts that needs to be address and selects characteristics that describe the impacts. The purpose of this step is to convert the LCI results into impact descriptors. This sub-phase must assign the relative contribution of each input and output to the selected impact categories. In the current study, the LCIA of the functional unit of 1L of water, is done using TRACI v2.1 (the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) [34]. This method quantifies the stressors with potential effects such as acidification, eutrophication, global warming, ozone depletion, human health cancer, non-cancer, and particulate effects. It also includes ecotoxicity, fossil fuel depletion, and photochemical smog formation[34]. In the TRACI v2.1 user's guide, a description of each of the impact categories is presented. Acidification is defined as the increasing in hydrogen ion (H+) concentration in a local environment. Eutrophication relates with the increasing of nutrients in an aquatic ecosystem. Global warming or climate change refers to the increase in temperature caused by an increased in greenhouse gases and TRACI uses the global warming potentials (GWPs) to measure the potency of greenhouse gases relative to CO_2. As for the Ozone Depletion category is describe by the World Meteorological Organization (WMO)[35], as a metric to calculate the relative importance of substances that have a direct effect on the ozone layer deterioration. The human health particulate category its related to the negative effects caused by the small particles suspended in ambient air which may cause respiratory problems or even worse, death. In relation to human health cancer, non-cancer and ecotoxicity, the guide includes a lists over three thousand substances that are related to have cancer and non-cancer impacts and freshwater ecotoxicity impact[36]. Smog formation is related to the chemical reactions caused by nitrogen oxides and volatile organic compounds. The resource depletion or in this case fossil fuel depletion, is associated with the use of fossil fuel. GaBi Software has the ability to compute each impact category, in this case TRACI method was chose, by using the equation below:

$$I^i = \sum_{xm} CF^i_{xm} * M_{xm}$$

Where:

- I^i is the impact potential of all chemicals (x) for the impact category (i) in evaluation.
- CF^i_{xm} is the characterization factor of chemical (x) discharge into the media (m) for the impact category (i) in evaluation.
- M_{xm} is the mass of chemical (x) discharge to media (m).

Finally, weighting process from the TRACI method assigned to the different impacts which allows integration across impact categories. Weighting means using numerical factors to convert the results of each impact category. This final step is called valuation which is a weighting and normalization process that aims to rank the results of the different LCIA categories to achieve the relative importance based on preferences of the different results. Once all the LCIA is complete, the overall potential impacts of each product, process, system or activity under consideration are ready for comparison[37]. Now is time for the interpretation phase where the stakeholders or the organization can express the relative preference base on the goals, policies or even opinions and beliefs common to the group.

3.1.5 Life Cycle Interpretation

The final phase of the LCA is called the interpretation phase. It is defined by the ISO 14043 as the systematic procedure that evaluates and identifies the environmental implications that result from the results of the LCI and the LCIA [10]. Also, the interpretation of these results gives credibility to the results of the previous phases and is useful in the decision-making process. At this point, an evaluation is needed to see if the methodology and results are consistent, as well as to check with the conclusion if the requirements of the goal and scope of the research are being satisfied, particularly the data requirements, predefined assumptions and values, and application-oriented requirements. It is possible that the process of interpretation redirects the study to begin with the first phase or reconsider if the input-output data is clear enough. Therefore, an LCA is an iterative process.

Finally, an interpretation of the impact analysis was carried out. At the end, the decision-makers have a generic and clearer view of the ecological footprint of the life cycle of the glass bottles.

3.2 Sustainability Analysis (Decision Making)

In this section of the study, a multiple-attribute decision making method (MADM) was used for evaluation of benefits or also called a benefits assessment for using glass bottles[38]. This method makes easier to select an alternative between the multiple benefits or attributes of a an object or act[38]. Also, it is possible to convert qualitative to quantitative data for better selection of alternative. At first, a list of multiple benefits of using glass bottles was made. The list included the following attributes of a glass bottle:

- Barrier for gases and liquids
- Resistant pathogens
- Recyclable Material
- Low-Cost Product
- Nondegradable product and good shelf life
- Low Transparency
- Solid material
- Inert material

Since selecting which of the attributes is more important is a difficult task, that is when the MADM comes into action. All attributes were compared with each other as seen in Appendix E and based on the survey results and using the MADM a comparison matrix was constructed shown in Table 10.1 to rank them and obtain a weighting value for each attribute. Finally, the values are normalized.

4 RESULTS & DISCUSSION

The results of this study represent how a streamlined LCA methodology may be developed to evaluate and compare the disposing stage of glass containers. The following section describes the difficulty of gathering data and shows the results of the GaBi LCA modelling. Graphs of the environmental impact assessed with the TRACI v.2.1 method are presented.

4.1 Data Collection Issues

To complete a robust life cycle modelling, it is important to gathered representative data of each process[24]. Data acquisition is one big challenge of conducting LCA, because of lack or availability of information, and the toughest is the willingness of the company to share information. A possible reason of companies limiting access to information to outsiders is that since the study is directed to make visible the ecological footprint of each process of the system, creates a concern of harming the reputation of any company. Since the study is directed to the EoL scenarios of glass bottles, harming reputations of a company is not the objective. Also is necessary to emphasize that the EoL scenarios are modeled with the shallow information that could be acquired.

4.2 Gabi Software Results

After configuring the models in GaBi, the cases were calculated. Even though, these results of environmental impact are not an exact representation because of availability of data, it shows an idea on how the inputs and outputs parameters causes an environmental burden described by EPA with TRACI. To start the impact analysis, each value was characterized, categorize, given a weighting factor and normalize using the TRACI 2.1 method. Table 4.1 and 4.2 shows the values of emissions and impact categories after being normalized, for ease comparison as stated by the TRACI method.

Table 4.1 Emissions of each EoL scenarios (in kg)

	Landfill	*Sterilization*	*Cullet*	*50% Landfill/Sterilization*	*50% Landfill/Cullet*	*50% Sterilization/Cullet*	*3/3*
Resources	27%	23%	19%	26%	24%	21%	24%
Emissions to air	66%	61%	75%	65%	70%	71%	68%
Emissions to fresh water	9%	18%	6%	11%	8%	10%	9%
Emissions to sea water	0%	0%	0%	0%	0%	0%	0%
Emissions to agricultural soil	-1%	-2%	-1%	-2%	-1%	-1%	-1%
Emissions to industrial soil	0%	0%	0%	0%	0%	0%	0%

As shown in the tables, each scenario presents their respective values of the environmental impact that is associated with them. Table 4.1, which represents the emissions, shows how the use of fuel combustion for electricity, water consumption and material resources are related with the emissions to the environment. It is clearly show that in all six scenarios of the different EoL scenarios, emissions to air have the highest relative contribution, hence it is contributing more to the global warming impact factor. In the resource category is also reflecting high values since in all cases, transportation and electricity are constantly using fossil fuels.

Table 4.2 TRACI v2.1 Weighted and Normalized Impact factors of each EoL scenarios.

Categories	*Landfill*	*Sterilization*	*Cullet*	*50% Landfill/Sterilization*	*50% Landfill/Cullet*	*50% Sterilization/Cullet*	*3/3*
Acidification (kg SO2 eq.)	20%	22%	18%	20%	19%	19%	19%
Ecotoxicity (CTUe)	2%	4%	1%	2%	1%	2%	2%
Eutrophication (kg N eq.)	3%	2%	3%	3%	3%	3%	3%
Global Warming Air incl. biogenic carbon (kg CO2 eq.)	17%	18%	23%	17%	19%	21%	19%
Human Health Particulate Air (kg PM2.5 eq.)	5%	6%	5%	5%	5%	5%	5%
Human Toxicity Cancer (CTUh)	3%	4%	3%	3%	3%	3%	3%
Human Toxicity Non-canc. (CTUh)	8%	11%	11%	9%	10%	11%	10%
Ozone Depletion Air (kg CFC 11 eq.)	0%	0%	0%	0%	0%	0%	0%
Resources Fossil fuels (MJ surplus energy)	28%	25%	20%	27%	24%	22%	25%
Smog Air (kg O3 eq.)	15%	9%	17%	14%	16%	14%	15%

Figures 4.1-4.5 exhibits a better visualization of the tables above. Each one displays the absolute values of the environmental impact categories of the TRACI method. As for the first one, Figure 4.1, all process in each scenario using electricity from the grid mix and it is clearly seen the cullet production EoL scenario presents the highest environmental impact. The reason is that when manufacturing concrete blocks, the air is being contaminated with the dust particles of crushing glass and by handling large amount

of cement. This data agree with the results of an LCA of a dwelling home in Scotland[23], which states that the concrete releases various pollutants creating a high environmental burden compare to other process. It also needs a high demand in energy consumption. Therefore, the global warming impact category has the largest values.

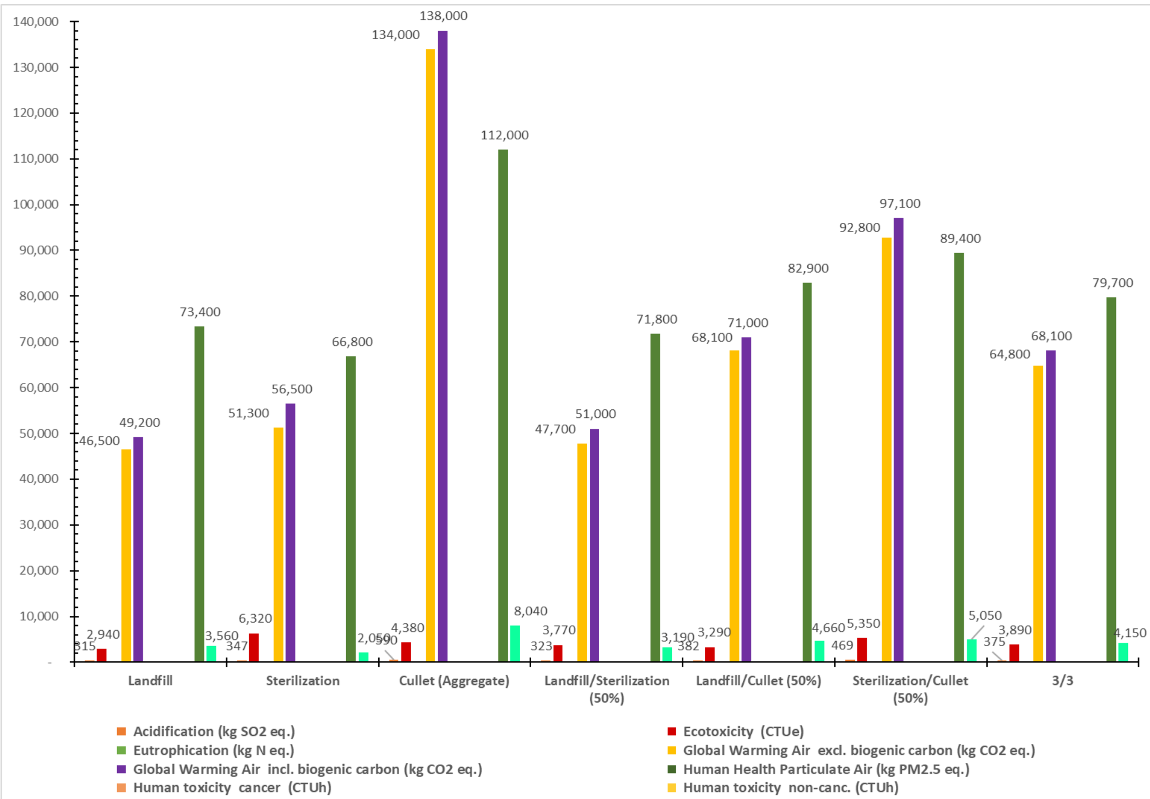


Figure 4.1 Impact factors of each EoL scenario using electricity from the grid mix.

To be able to see clearer the other categories, is necessary to hide the global warming values as shown in Figure 4.2. Here, it is easier to appreciate the smaller values. In construction blocks manufacturing, smog air category has the largest value because of particulate that suspends in the air. In ecotoxicity, since this category is related to contamination of freshwaters, the sterilization process has the highest value because of the large amounts of water for cleaning which in turn discharges the used water to waterbodies.

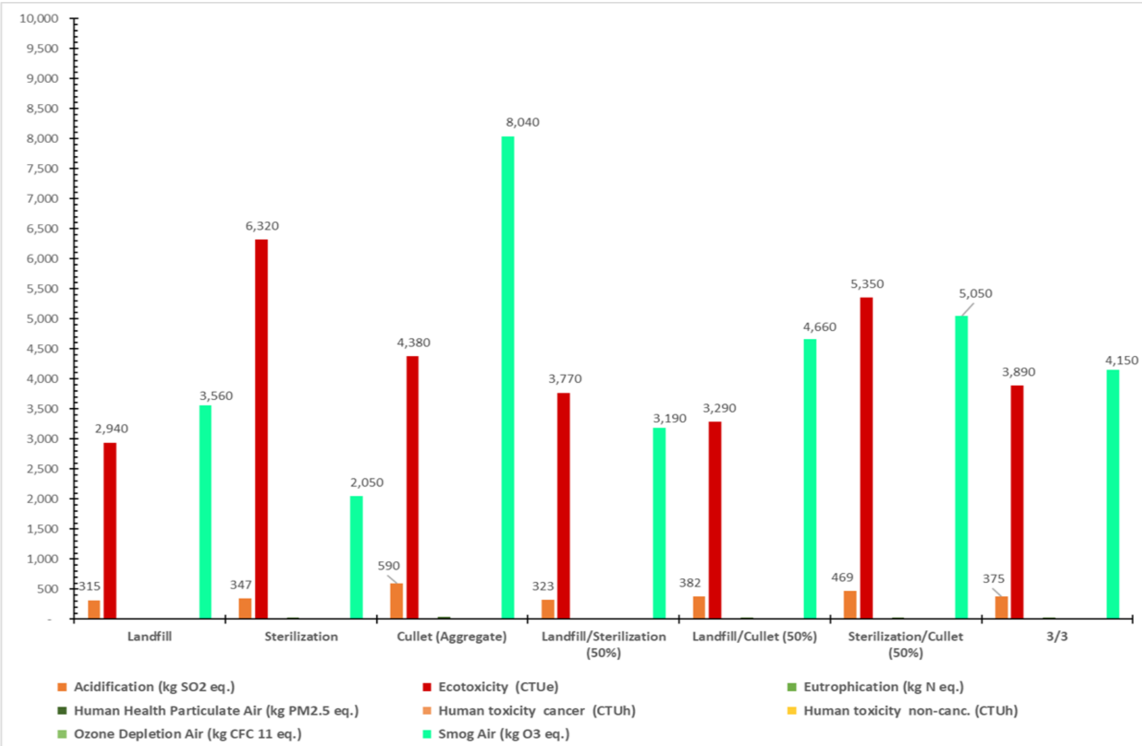


Figure 4.2 Impact factors of each EoL scenario using electricity from the grid mix. (without GWP)

In Figure 4.3, the electricity from the sterilization process was changed to being supplied by photovoltaic solar panels. This change created a noticeable decrease in the global warming environmental impact category. the reason for this drastic change is because the electricity for the sterilization process is not directly supplied by the burning of fossil fuels, however the manufacturing of photovoltaic panels and its environmental impact, as mentioned before, was not included in this SLCA (the greatest impact or benefit is in the use phase not in the manufacturing phase). At the same time when comparing the impacts with Figure 4.1, using photovoltaic solar panels for electricity lowers the environmental impact in scenario 4 and 6, where 50% of the bottles end up in landfills and the other 50% are sterilized and 50% of the bottles are sterilized and the 50% are delivered for cullet production, respectively. Excluding the global warming impact values from the results, will display as shown in Figure 4.4. Here, its visible how changing energy supplied by burning of fuel combustion with renewable energy, decreases in ecotoxicity and smog air in sterilization scenario. Also, it can noticeable a negative value in smog air meaning that contributes to reduction of particulate in the air.

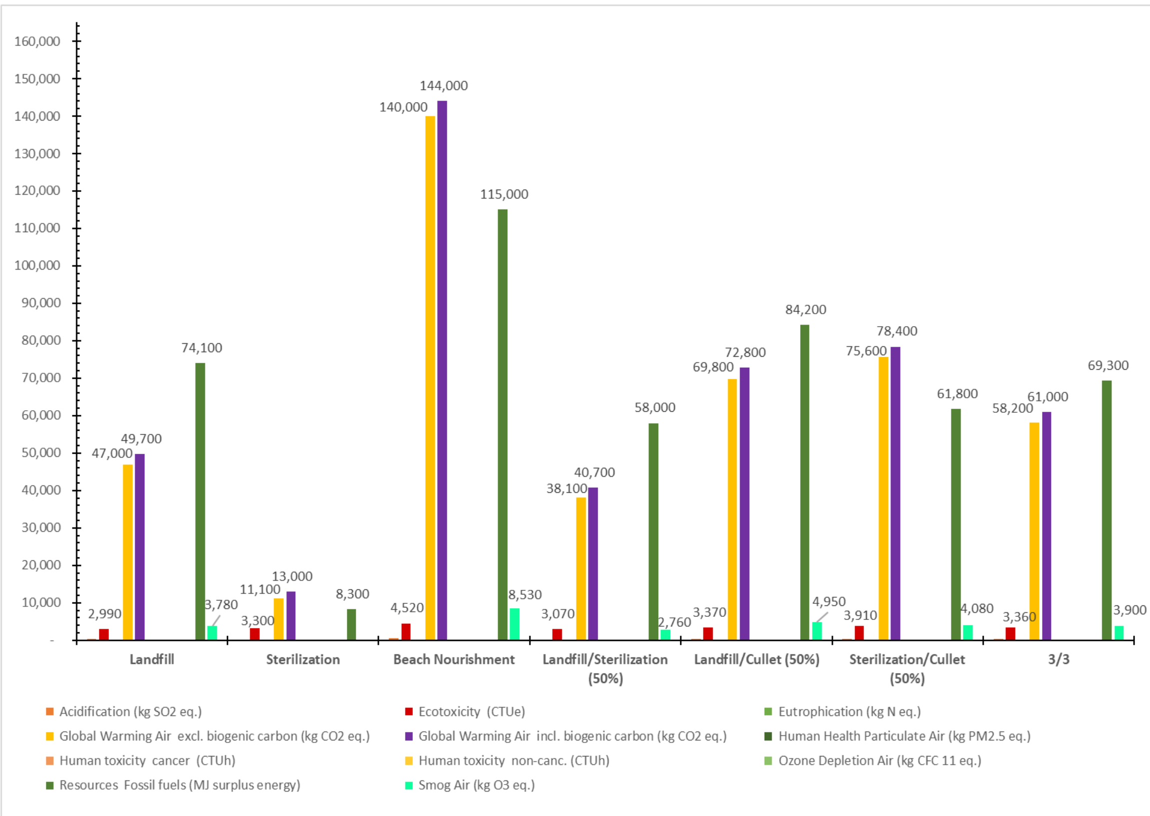


Figure 4.3 Impact factors of each EoL scenario modeled with photovoltaic electricity in the sterilization process.

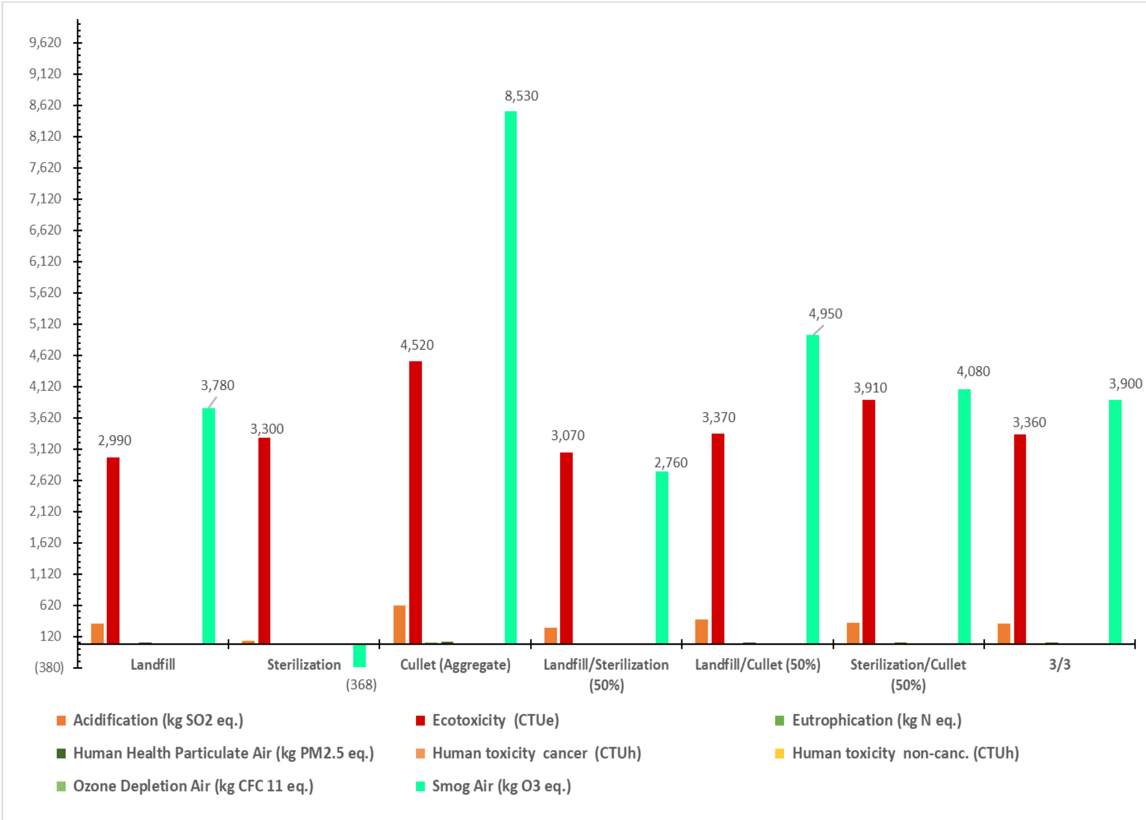


Figure 4.4 Impact factors of each EoL scenario modeled with photovoltaic electricity in the sterilization process (without GWP).

Shown in Figure 4.5, a decrease in global warming potential is seen when using the cullet for beach nourishment. The reason for this declining is because after crushing the glass is delivered for beach nourishment and all emissions associated to glass bottles with concrete block production are eliminated. At the same time helps lowered diminished the environmental impact of the combined scenarios with landfill and sterilization.

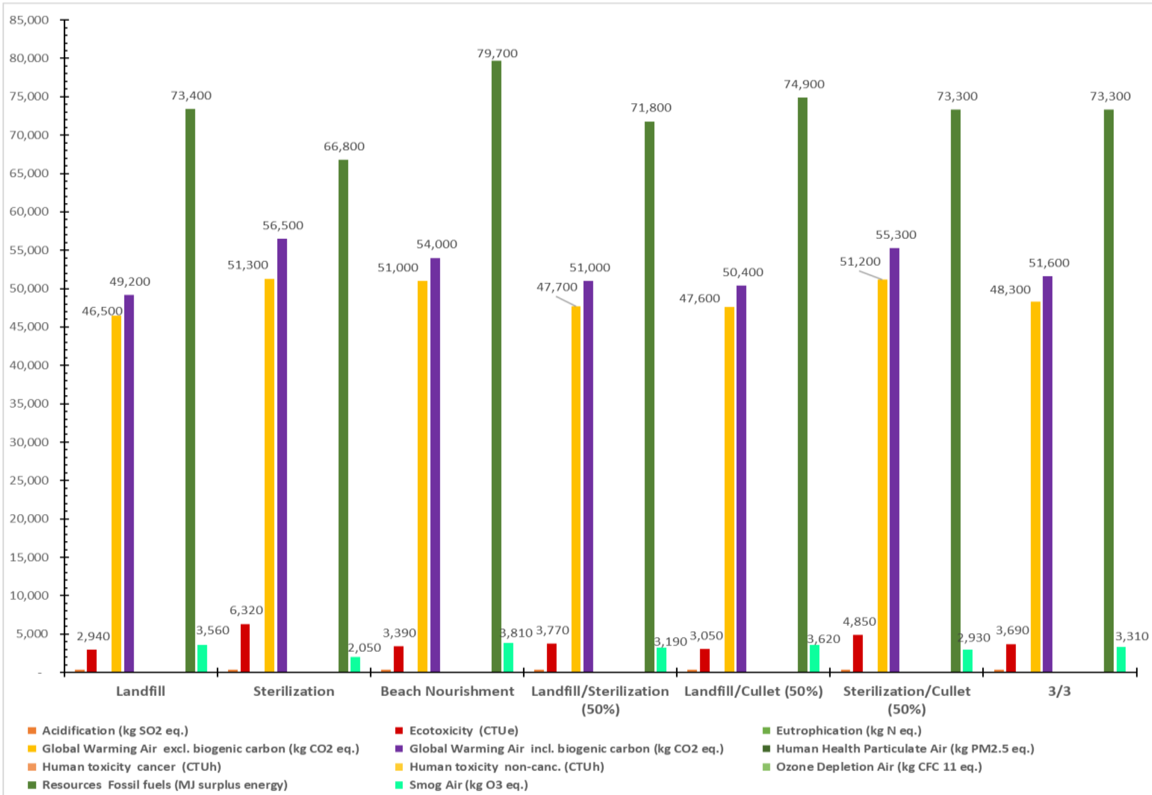


Figure 4.5 Impact factors of each EoL scenario modeled using electricity from the grid mix and using the cullet for beach nourishment.

4.2.1 Sensitivity Analysis

Since the data in the LCI was collected from different sources, uncertainty in the input parameters exists which leads to uncertainty in LCA outcomes. A challenge of the study was the lack of share information of this sources, which in turn causes to have unknow quantities in the system life cycle and creates an epistemic uncertainty. This is the reason for conducting a sensitivity analysis.

As seen in figure 4:3, electricity was change from being supplied from the grid mix to photovoltaic energy. It displays a drastic change in the LCI results and environmental impacts. Another way of conducting the analysis is by assuming a variation of more or less 15% in the quantity of material entering the three EoL scenarios. Table 4.3 presents the LCIA results of the model. Since there are some values that are close cero would be left out for better visualization. The values from health particulate and acidification are small in contrast with ecotoxicity, smog air, and global warming, so were not included as well. A variation of 15% originates an error of less than 5% in the remaining categories such as ecotoxicity, smog air, and global warming potentials. See table 4.4 for the results of the sensitivity analysis. This variation shows little effect in the LCI results and the impact categories. However, in the table, the values in Landfill scenario show a different behavior. When using 15% less material in the software model, it appears to have increase in the value of each category and when using 15% more material, it causes a decrease in each category. Even though is a relatively small change, this behavior is seen because of uncertainty in process parameters when modeling in GaBi Educational software.

Table 4.3 Impact Category results for the sensitivity analysis

TRACI Impact Categories	*Total*	*Units/Normalization*
Human toxicity, cancer	2.67E-05	CTUh
Ozone Depletion Air	0.000952	kg CFC 11 eq.
Human toxicity, non-canc.	0.00191	CTUh
Eutrophication	12.6	kg N eq.
Human Health Particulate Air	24.3	kg PM2.5 eq.
Acidification	375	kg SO2 eq.
Ecotoxicity	3.89E+03	CTUe
Smog Air	4.15E+03	kg O3 eq.
G.W. Air, excl. biogenic carbon	6.48E+04	kg CO2 eq.
G.W. Air, incl. biogenic carbon	6.81E+04	kg CO2 eq.

Table 4.4 Sensitivity results for the impact categories variating 15% of the input material.

	Acidification		*Ecotoxicity*		*Smog Air*		*GW excl.*		*GW incl.*	
EoL	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**
Cullet	-2.18%	2.18%	-1.12%	1.12%	-3.22%	3.22%	-4.02%	4.02%	-3.86%	3.86%
Landfill	1.04%	-0.92%	1.57%	-1.39%	0.90%	-0.79%	1.82%	-1.61%	1.79%	-1.59%
Sterilization	-0.27%	0.27%	-2.60%	2.60%	1.05%	-1.05%	-0.23%	0.23%	-0.33%	0.33%

4.3 Life Cycle Benefit Assessment

The survey used for this section, *Appendix E*, was only directed to undergrad or graduate students from the University of Puerto Rico at Mayaguez Campus. It was made to determine what is the student perception of the benefits of using glass as containers for example a glass bottle (amber color). The multiple attributes that were assessed were the following:

- Barrier for gases and liquids
- Resistant pathogens
- Recyclable Material
- Low-Cost Product
- Nondegradable product and good shelf life
- Low Transparency
- Solid material
- Inert material

After the participants submitted their perception, through the MDAM, it was possible to order the attributes from the most important to least in respect to the general perception. The normalizing, the results of the method, presents that the attribute of glass, being recyclable material, was the most important with a 23% of weighting factor. The second attribute was glass as inert material with 20%, the third was a material resistant to pathogens with 18%, barrier for gases and liquids with 14%, with 9% was a product of low cost, and the last two were solid consistency and low transparency with 7% and 0%, respectively. These results mean that the respondents prefer a packaging material that as well as being inert with the environment, is also a recyclable container giving the possibility of having a closed loop recycling process when using glass bottles. This can help in achieving a higher degree of sustainability in the brewery industry.

Table 4.5 Results of MADM method from the survey

Attributes of Glass Bottles	***Normalize Results***
Barrier for gases and liquids	14%
Resistant pathogens	18%
Recyclable Material	23%
Low-Cost Product	9%
Nondegradable product and good shelf life	9%
Low Transparency	0%
Solid material	7%
Inert material	20%

4.4 LCA Results' Discussion

Table 4.6 Values of energy consumption per bottle in each scenario and its emissions.

EoL Scenarios	***Energy/Bottle (MJ/unit)***	***Emissions (kg)***
Landfill 100%	2.93	1.23
Cullet for Concrete Blocks 100%	3.23	25.2
Sterilization 100%	1.76	2.21

Table 4.5 shows another way of using the LCA results. Here, the values of energy consumption of each stage of the life cycle, per bottle are presented. As well as the emission of each scenario which helps contrast how much energy is consume per bottle with its overall number of emissions. The stages include were glass manufacturing, transportation, bottling, and disposal or repurposing. If 100% of post-consumer glass bottles are sterilize and returns to the brewery company, less energy per bottle is required because the energy from the glass manufacturing plant is avoided. The energy required to ship the empty bottles is also avoided. With this type of energy analysis, enhances the criterion for implementing glass bottle repurposing strategies like sterilization process for post-consumer glass bottles.

5 CONCLUSION & RECOMMENDATION

5.1 Findings of GaBi Modelling Results

The main goal of using LCA methodology was to evaluate the environmental impact of glass bottles during the actual disposal management and compare the present strategy with alternative recycling scenarios. Input and output data of each process of the glass life cycle was collected to be able to model a streamlined life cycle in the GaBi software. Using this software for the modelling the SLCA was important contribution because it facilitates the impact assessment and proved that it can be used not only for modelling the EoL scenarios but to compare each EoL scenario of glass bottle at the same time, which have not been done before specifically in Puerto Rico. Also helps to understand that uncertainty in the data collection creates uncertainty in the results. The scenarios models started with the glass bottle already manufactured, transported to the port, shipped to the island, transport to a warehouse, from the warehouse to the brewery, from the brewery to a local market, consumed at the local market and finally disposed. The present disposal stage of dumping glass bottles in landfills was contrasted with five alternative scenarios: sterilization, cullet production, 50% landfill and 50% sterilization, 50% sterilization and 50%cullet production, and 50% landfill and 50%cullet production. Energy usage was also varied between electricity from the present grid mix and photovoltaic solar panel. After conducting the LCA impact analysis of each end-of-life scenarios, the production of cullet for construction blocks has the most impact to the environment. The scenario with the least environmental impact was the sterilization of glass bottles with a reduction of 76.8% in global warming potential value using photovoltaic energy as the power source. For further analysis of this kind, another alternative is using solar water heaters could be included to see the changes in the environmental impact, but it was limited by the software database.

5.2 Observations of the SLCA

First, an important aspect of conducting this SLCA is a new way on how to use this methodology in a different approach. Most LCA are directed to manufacturing and operations of a product life cycle, while in this study the methodology is used to evaluate different EoL scenarios of glass bottles specifically in Puerto Rico, which makes it one of its kind. Therefore, is necessary to emphasize that the difficulty of founding local data of energy and water consumption, a refreshed solid waste data, creates uncertainty in results. As a final phase of interpretation, decision makers may use this type of studies for different motives. For example, if a company's product is generating large amounts of solid waste that may be causing environmental impacts, using SLCA may help to have a better criterion for implementing a different strategy to reduce their impact.

Also, a brewery company would have a better criterion to decide if implementing sterilization process of the returnable bottles is a good strategy. This way they can reduce their ecological footprint and improve the public perception of the company. It also would be increasing the percentage of recycling of solid waste generated annually. Also, will directly contribute on creating business and jobs in Puerto Rico solid waste management department such as transportation and operating machinery, which may have direct contribution in reducing the costs of importing glass bottles. Based on the results of this LCIA confirms that implementing a system of returnable bottles helps reduces the environmental impact since less bottles need to be manufactured, hence less raw material extraction, less energy required[39].

Governments could have the advantage of using LCA methodology when creating and passing laws. Like for example, if a government agency study and evaluate the life cycle of any material that is being imported, in this case, glass bottles, they could pass a law that when the material reaches high levels of solid waste, the company that produces or imports it must pay higher tax. As in the case for glass bottles, the government could also help on having a closed loop system while reducing their environmental impact by implanting a bottle bill such as the Puerto Rico's House of Representative "*P. de la C. 2141*"[40], which is a bill already used in the states of California, Connecticut, Hawaii, Iowa, Maine, Massachusetts, Michigan, New York, Vermont, Guam, and Oregon being the first to pass it in 1971[41]. This bill works by making the consumer to pay a deposit when buying ta beverage to the retailer and when returning the empty bottle to a redemption center, the consumer receives a refund. This way enforces the citizens to practice recycling even more and reducing litter. It could also include other materials and products such plastic bottles, and aluminum cans.

The main challenge in any LCA study is obtaining the actual data for each stage. This is evidenced by the challenges faced by the author of obtaining actual. Nevertheless, the main value of this project development of a structured life cycled based evaluation methodology to understand the environmental impact of using glass bottles for beverages. For future works, its recommended to improve data acquisition of each process parameters to enhance modeling in GaBi Software and repeat the impact assessment as the data is being available. Also, a social economic analysis would display better criterion for the decision makers, especially in the interpretation phase.

Finally, it is recommended that the Government of the Commonwealth of Puerto Rico in collaboration with local industry and other sectors, develop a structured data collection system for materials, energy, and waste management so that policy making, and implementation can use an LCA based methodology with actual data that could be validated constantly with source data. For example, agencies or companies could register and acknowledge the total amount of energy in each process or each machine if possible for easier collection of energy input data as well as other parameters such as water consumption.

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7 APPENDIX A

Glass Bottle in Puerto Rico- Packaging Survey

Saludos,

Este cuestionario de 21 preguntas contribuye a un análisis de ciclo de vida de la botella vidrio (12 oz. Color Ámbar) en Puerto Rico. Para esto es necesario conocer ciertos parámetros sobre las botellas y que procesos es sometida la misma. Este estudio viene siendo mi tesis de maestría en Ingeniería Mecánica. Cabe recalcar que la información recopilada será mantenida confidencial y los datos se usaran de forma genérica para el análisis sin divulgar la fuente. Gracias por su tiempo y ayuda al estudio.

De tener duda, se puede contactar a mi numero personal 787-362-2171 o a mi correo electrónico francis.francis1@upr.edu.

Favor de contestar con la mayor certeza posible las siguientes preguntas:

1. ¿De qué país es la planta manufacturera de botellas de vidrio color ámbar (12 oz)? ¿Cual es el código de la botella?

- USA
- Código: N15 01 19 W-35

2. ¿En qué municipio/puerto se recibe el material?

- San Juan

3. ¿Cuál es el tipo de transporte que se utiliza para traer la botella a la planta?

Seleccione una.

Figure AA. 1 Truck transportation classification

a. Truck 20-26 t (Warehouse a brewery)

b. Truck 26-28 t

c. Truck 28-32 t (Puerto a warehouse)

4. ¿Es el mismo transporte utilizado para salir de la planta cuando el producto está finalizado?

- No.

5. ¿Cuántos viajes se dan al día para traer las botellas vacías a la planta?

- 1 (a veces menos dependiendo de la necesidad)

6. ¿Cuántos viajes se dan al día para llevar el producto final a su destino?

- Tenemos de 8-9 carreros todos los días que salen a la calle a entregar el producto final a su destino. Básicamente 1 viaje por carrero al día.

7. ¿Cuántas botellas de vidrio color ámbar para envasar cerveza se ordenan? ¿Cada cuánto tiempo?

- 100,000 bisemanal

8. Costo de 1 botella de vidrio vacía.

- Incluyendo costo de shipping (landed) = $0.19 por botella

9. ¿Cuánto pesa la botella (12 oz.) vacía? ¿Peso al final (con cerveza)?

- Vacía 6.8oz
- Llena 1.4lb

10. ¿De dónde provienen: la tapa, la etiqueta de la botella, y el cartón para empacar? Especifique lugar de procedencia.

- Tapa: Grecia
- Etiqueta: NY
- Botella: USA (Texas)
- Cartón: USA

11. Mencione en orden cronológico los procesos que es sometida la botella desde que entra en la planta hasta que sale de la misma.

- Botella se depaletiza para entrar en proceso
- Se etiqueta
- Se lava
- Se llena de cerveza

- Se enchapa
- Se seca
- Se entra en su empaque final (24x o 4x6)

12.¿Cuántas botellas (12 oz. color ámbar) de cerveza se envasan en un año; mes; y/o día?

- 15,000 por día

13.En términos de consumo energético, ¿Cuánto es el consumo energético total de la cervecera anual/mensual/diario? ¿Cuánto es el porcentaje relacionado al proceso de manufactura del producto?

14.¿Cuál es el consumo total de agua de la cervecera? (anual; mensual; y/o diario)

15.¿Cuál es el consumo de agua en el proceso de lavado? (Anual; Mensual; y/o Diario)

16.¿Cuál es la proporción (%) de agua por cada botella?

- 90%

17.¿La planta tiene proceso de tratamiento de agua usada? ¿Cuánto volumen de agua usada se desecha?

- No

18.¿Qué sucede con la botella cuando esta no pasa inspección?

- Se bota

19.¿Utilizarían botellas recicladas en su proceso? ¿Si o No? Explique su respuesta.

- Sí, nos encantaría crear conciencia y contribuir a reducir el impacto ambiental.

20. ¿Si hubiera algún método para reciclar o reusar las botellas de vidrio, cual sería la preferencia de la compañía?

- Cualquier método es bienvenido siempre y cuando se mantengan los estándares de calidad y parámetros físicos de la botella y el material.
- Ej. Propiedades del material, presión de ruptura, propiedades de compresión, cuan quebradiza (que no se rompan más rápido)

8 APPENDIX B

Calculations

- Energy for construction block production
    - Approximated Monthly Energy Bill: $7000.00
    - Approximated cost of energy consumption per hour: $0.2441/

$$\frac{\$7{,}000.00/\text{monthly}}{\$0.2441/\text{kWh}} = 28{,}676.77\ \text{kWh/montly}$$

$$28676.77\ \left(\frac{\text{kWh}}{\text{monthly}}\right)\left(\frac{1\text{month}}{30\ \text{days}}\right) = 955.89\,\frac{\text{kWh}}{\text{day}}$$

$$955.89\left(\frac{\text{kWh}}{\text{day}}\right)\left(1\,\frac{\text{day}}{27000\ \text{blocks}}\right) = \ 0.0354\ \text{kWh/block}$$

- Energy for sterilization process
    - From literature[26] for beer production: 3.52 MJ/L
    - 1 litter equals 3 (12 oz) bottles

$$3.52\ \left(\frac{\text{MJ}}{\text{L}}\right)\left(\frac{1\text{L}}{3\ \text{bottle}}\right) = 1.173\,\frac{\text{MJ}}{\text{bottle}}$$

8 APPENDIX C

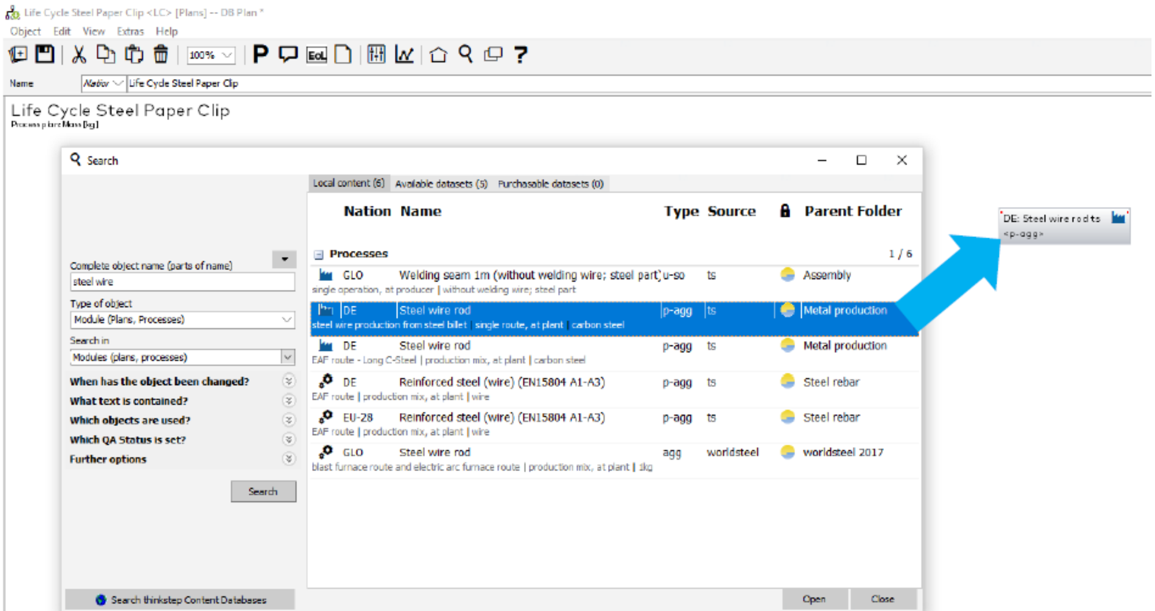


Figure 8.1 Adding the material input of steel wire to begin the LCA of the paper clip.

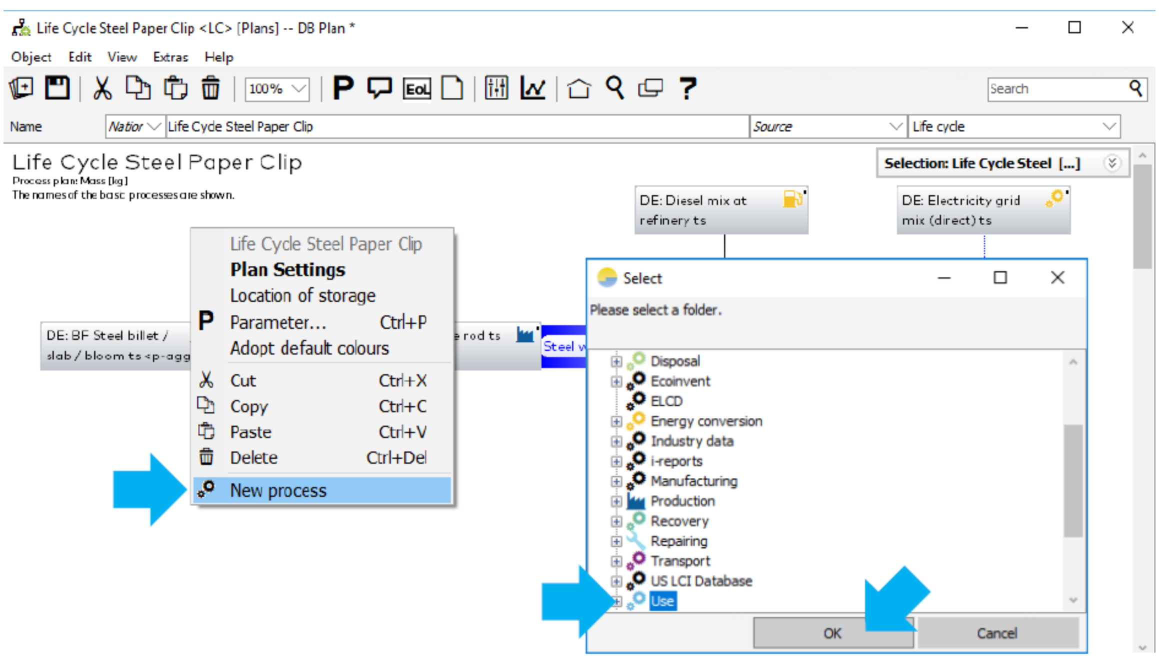


Figure 8.2 Creating a new process for the use phase of the paper clip.

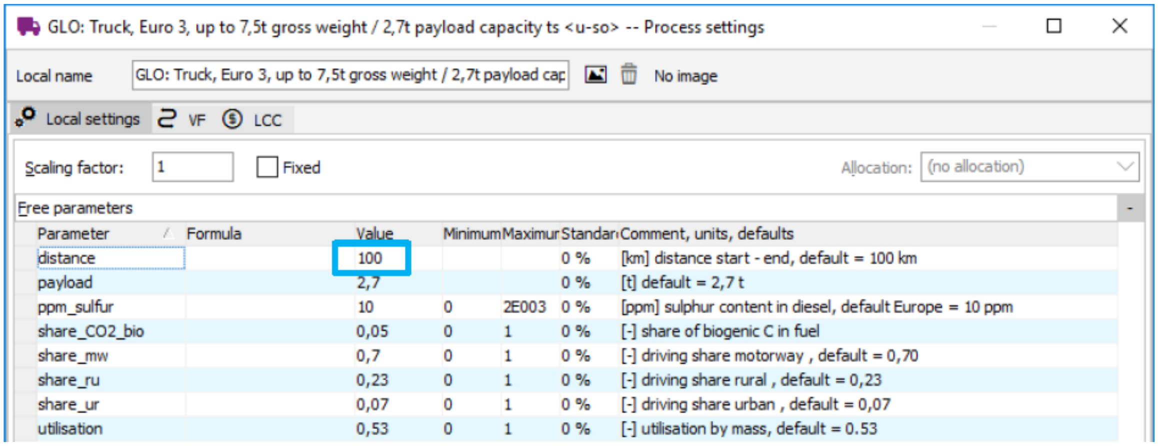


Figure 8.3 Setting the parameters for the truck transportation

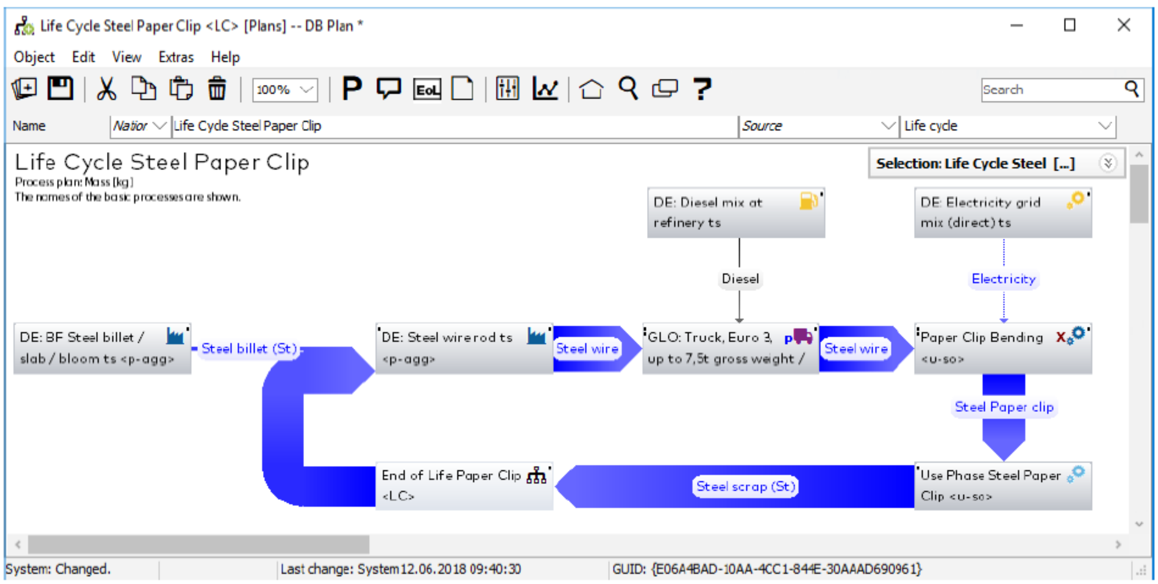


Figure 8.4 Complete life cycle of the steel paper clip with close recycling.

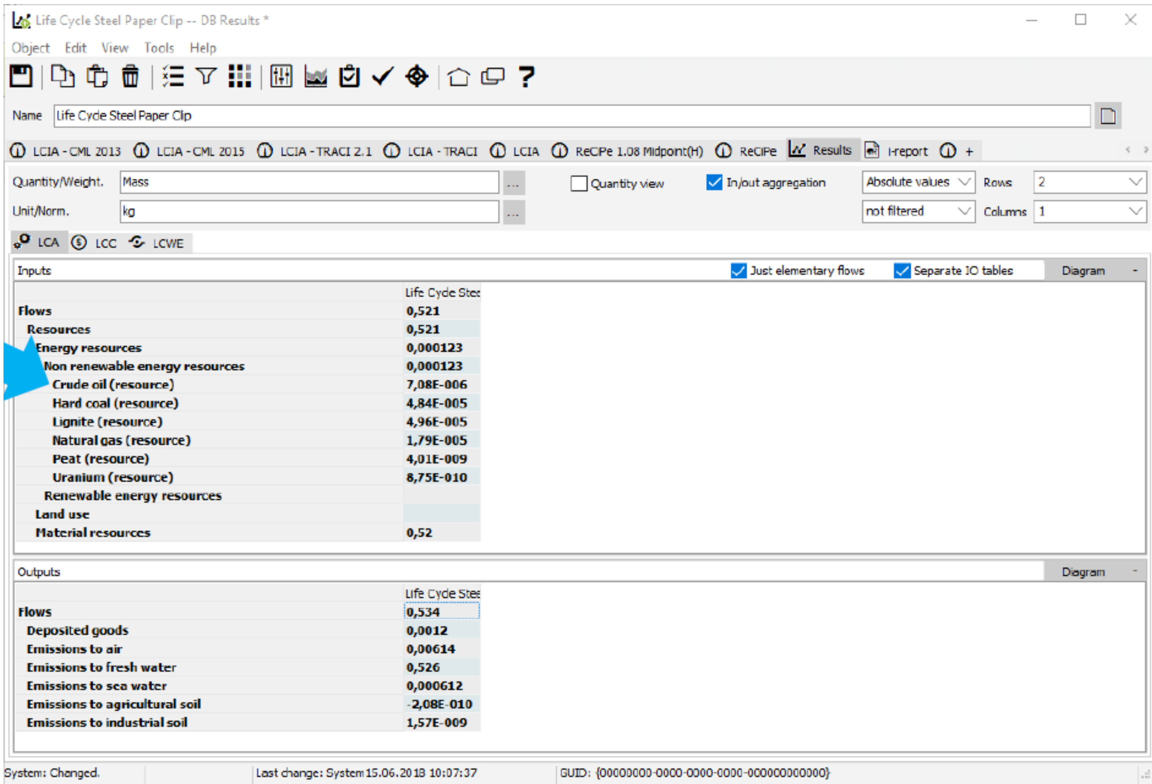


Figure 8.5 Emissions results of the paper clip LCA

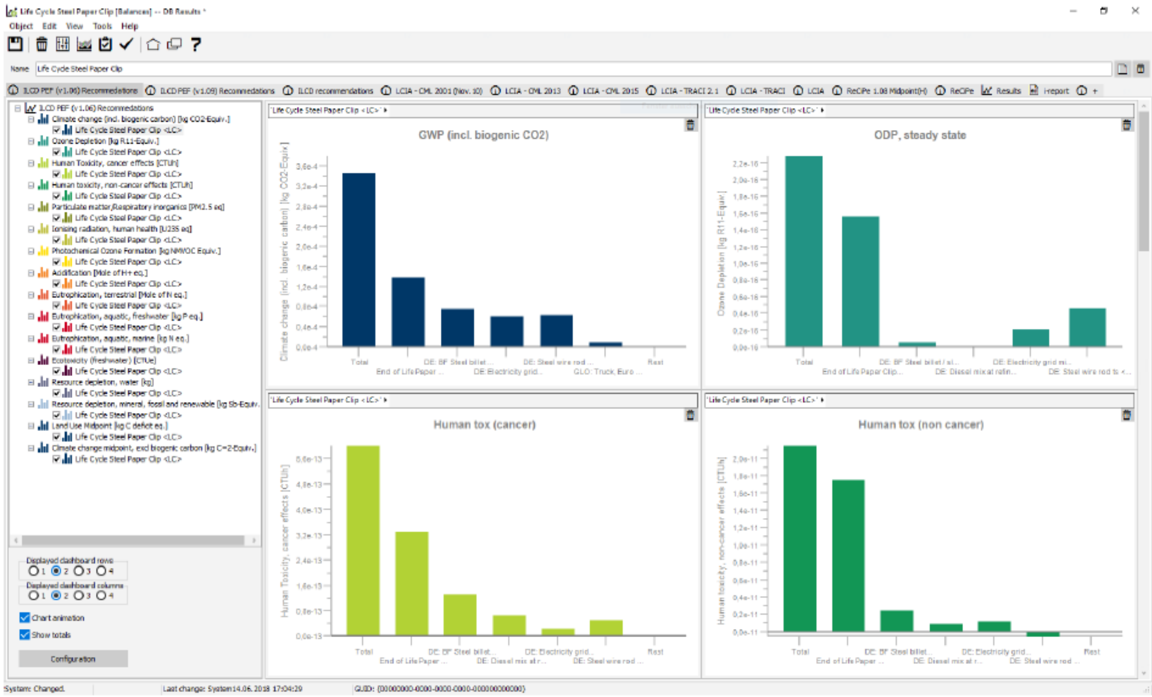


Figure 8.6 Impact categories chart of the results of the paper clip LCA

9 APPENDIX D

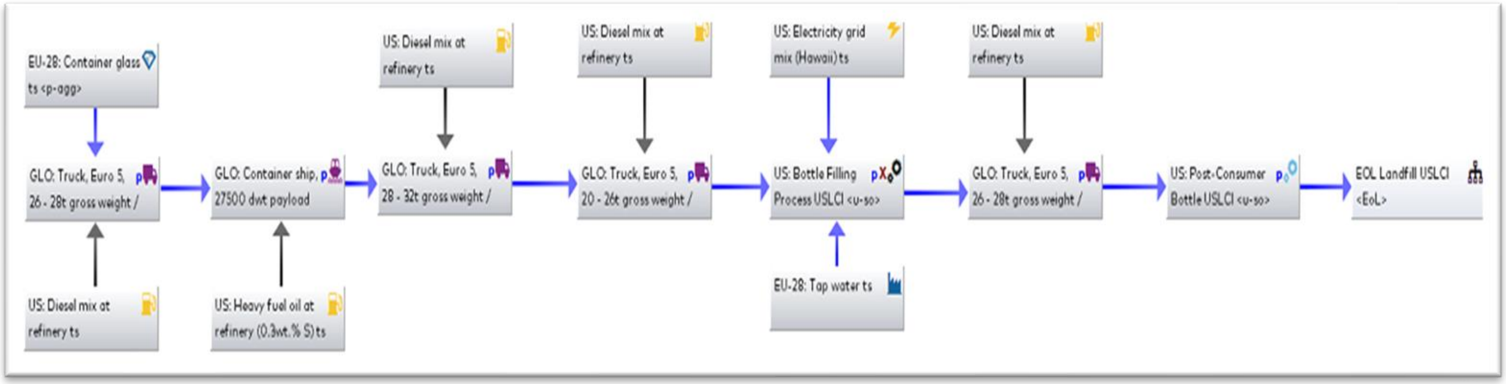


Figure 9.1 GaBi Software LCA flow diagram of landfill scenario.

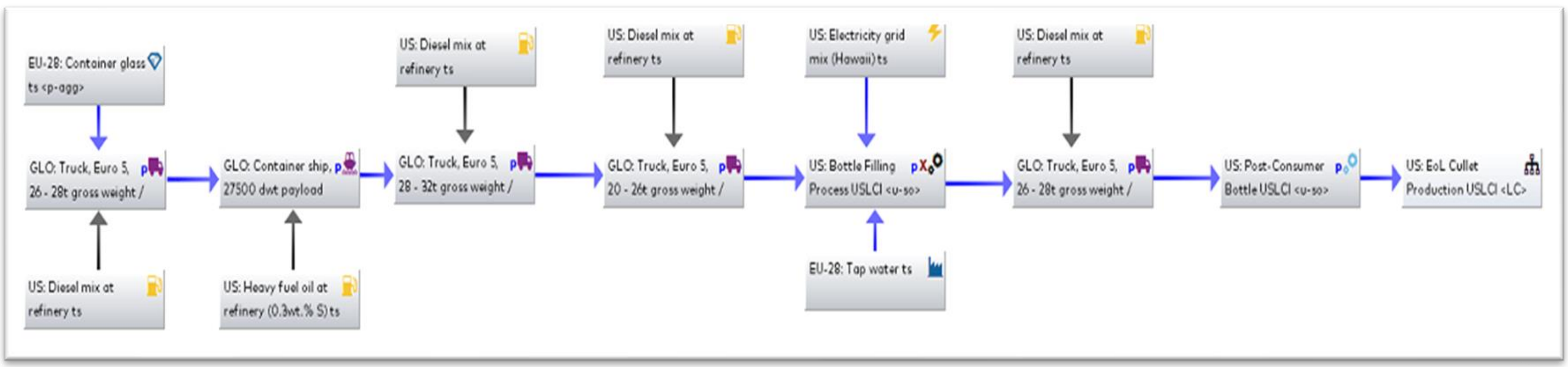


Figure 9.2 GaBi Software LCA flow diagram of cullet production scenario.

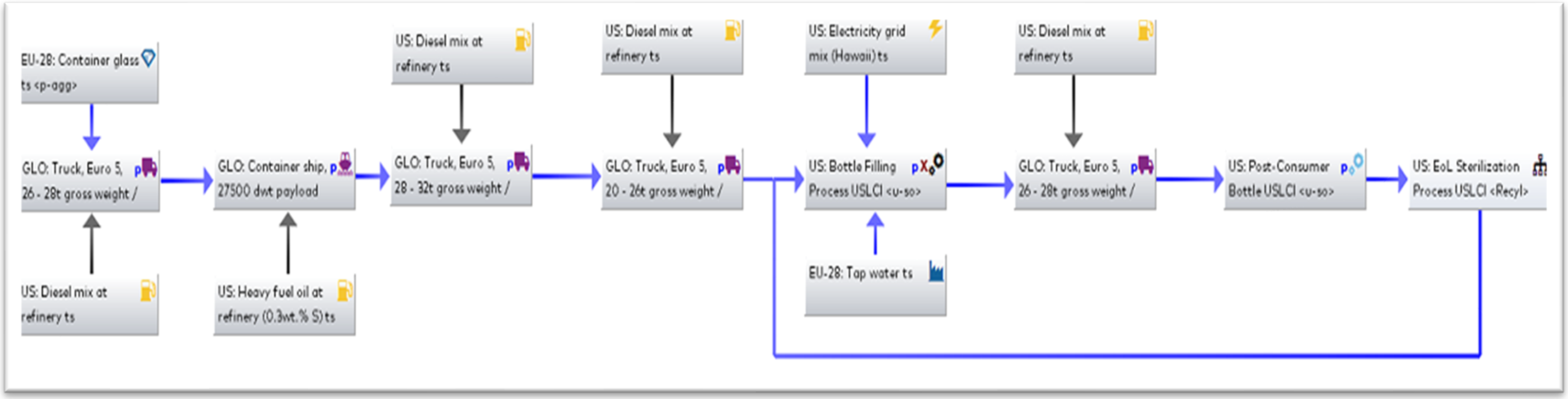


Figure 9.3 GaBi Software LCA flow diagram of repurposing or sterilization process scenario

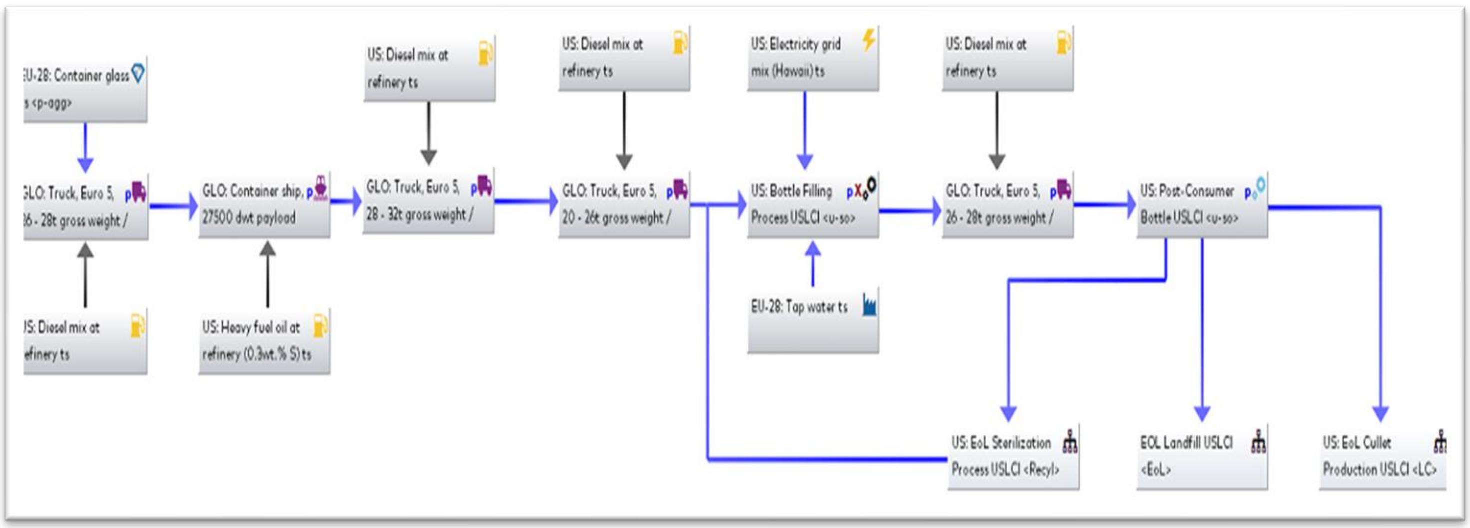


Figure 9.4 GaBi Software LCA flow diagram of all scenarios combined.

10 APPENDIX E

Nota aclaratoria

Aunque sí culmine el curso que brinda el IRB sobre cuestiones de ética en investigación con seres humanos, no se pudo completar la certificación de este cuestionario debido a la presente situación de la pandemia. De igual manera al ser este una primera iteración del cuestionario se obtuvo resultados del mismo gracias a una cantidad limitada de 25 estudiantes voluntarios dentro del Recinto de Mayagüez de la UPR y nos permite tener una idea de como llevar a cabo el proceso de evaluación de beneficios utilizando el MADM. Además, como fue notificado a cada voluntario que acepto participar, el cuestionario es de muy bajo riesgo para los humanos y no se recopilo información personal de ningún participante que ponga en peligro la privacidad de cada cual.

Cuestionario de Percepción de Beneficios Botellas de Vidrio

Mi nombre es Francis A. Francis Cordero estudiante graduado de Ingenieria Mecanica y he creado este cuestionario con el propósito de caracterizar los beneficios que promueven el uso de las botellas de vidrio según la percepción pública de los individuos encuestados y contribuye a la tesis titulada "Análisis comparativo de reciclaje botellas de vidrio en Puerto Rico utilizando la metodología de avalúo de ciclo vida". La primera parte de la encuesta de 28 preguntas es para comparar y seleccionar entre dos alternativas cual es la más importante o si le parece que son igual de importantes. Se comparará entre los beneficios y/o las distintas propiedades que tiene el uso de las botellas de vidrio para embotellar. La segunda parte es sobre reciclaje de botellas de vidrio y la tercera parte es para conocer el perfil de los encuestados. Cabe recalcar que, aunque la investigación es de muy bajo riesgo la participación es totalmente voluntaria y pueden retirarse en cualquier momento. No se solicitarán datos personales y la información recopilada se utilizara generalmente para el análisis.

De tener dudas, me pueden contactar a mi correo electrónico francis.francis1@upr.edu.

Si desea o no participar de la investigación seleccione:

☐ Acepto.

☐ No acepto.

Parte I. Compare entre las alternativas y seleccione la que usted entiende que es la más importante.

1. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) excelente barrera para gases y líquidos; y/o (2) resistencia a microbios y agentes bioquímicos?
   - ☐ Excelente barrera para los gases y líquidos.
   - ☐ Resistencia a microbios y agentes bioquímicos.
   - ☐ Son igualmente ambas importantes.

2. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) excelente barrera para los gases y líquidos; y/o (2) material reciclable?
   - ☐ Excelente barrera para los gases y líquidos.
   - ☐ Material reciclable.
   - ☐ Son igualmente ambas importantes.

3. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) excelente barrera para los gases y líquidos; y/o (2) producto de bajo costo?
   - ☐ Excelente barrera para los gases y líquidos.
   - ☐ Producto de bajo costo.
   - ☐ Son igualmente ambas importantes.

4. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) excelente barrera para los gases y líquidos; y/o (2) producto no degradable y de buena vida útil?
   - ☐ Excelente barrera para los gases y líquidos.
   - ☐ Producto no degradable y de buena vida útil.
   - ☐ Son igualmente ambas importantes.

5. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) excelente barrera para los gases y líquidos; y/o (2) opaco o baja transparencia del producto?
   - ☐ Excelente barrera para los gases y líquidos.
   - ☐ Opaco o de baja transparencia del producto.

☐ Son igualmente ambas importantes.

6. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) excelente barrera para los gases y líquidos; y/o (2) consistencia sólida y duradera?
   - ☐ Excelente barrera para los gases y líquidos.
   - ☐ Consistencia sólida y duradera.
   - ☐ Son igualmente ambas importantes.

7. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) excelente barrera para los gases y líquidos; y/o (2) inerte en la naturaleza?
   - ☐ Excelente barrera para los gases y líquidos.
   - ☐ Inerte en la naturaleza.
   - ☐ Son igualmente ambas importantes.

8. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a microbios y agentes bioquímicos; y/o (2) material reciclable?
   - ☐ Resistencia a microbios y agentes bioquímicos.
   - ☐ Material reciclable.
   - ☐ Son igualmente ambas importantes.

9. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a microbios y agentes bioquímicos; y/o (2) producto de bajo costo?
   - ☐ Resistencia a microbios y agentes bioquímicos.
   - ☐ Producto de bajo costo.
   - ☐ Son igualmente ambas importantes.

10. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a microbios y agentes bioquímicos; y/o (2) producto no degradable y de buena vida útil?

☐ Resistencia a microbios y agentes bioquímicos.

☐ Producto no degradable y de buena vida útil.

☐ Son igualmente ambas importantes.

11. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a microbios y agentes bioquímicos; y/o (2) opaco o baja transparencia del producto?

☐ Resistencia a microbios y agentes bioquímicos.

☐ Opaco o de baja transparencia del producto.

☐ Son igualmente ambas importantes.

12. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a microbios y agentes bioquímicos; y/o (2) consistencia sólida y duradera?

☐ Resistencia a microbios y agentes bioquímicos.

☐ Consistencia sólida y duradera.

☐ Son igualmente ambas importantes.

13. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a microbios y agentes bioquímicos; y/o (2) inerte en la naturaleza?

☐ Resistencia a microbios y agentes bioquímicos.

☐ Inerte en la naturaleza.

☐ Son igualmente ambas importantes.

14. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) producto de bajo costo?

☐ Material reciclable.

☐ Producto de bajo costo.

☐ Son igualmente ambas importantes.

15. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) producto no degradable y de buena vida útil?
    - [ ] Material reciclable.
    - [ ] Producto no degradable y de buena vida útil.
    - [ ] Son igualmente ambas importantes.

16. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) opaco o baja transparencia del producto?
    - [ ] Material reciclable.
    - [ ] Opaco o baja transparencia del producto.
    - [ ] Son igualmente ambas importantes.

17. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) consistencia sólida y duradera?
    - [ ] Material reciclable.
    - [ ] Consistencia sólida y duradera.
    - [ ] Son igualmente ambas importantes.

18. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) inerte en la naturaleza?
    - [ ] Material reciclable.
    - [ ] Inerte en la naturaleza.
    - [ ] Son igualmente ambas importantes.

19. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto de bajo costo; y/o (2) producto no degradable y de buena vida útil?
    - [ ] Producto de bajo costo.
    - [ ] Producto no degradable y de buena vida útil.
    - [ ] Son igualmente ambas importantes.

20. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto de bajo costo; y/o (2) opaco o baja transparencia del producto?
    - [ ] Producto de bajo costo.
    - [ ] Opaco o baja transparencia del producto.
    - [ ] Son igualmente ambas importantes.

21. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto de bajo costo; y/o (2) consistencia sólida y duradera?
    - [ ] Producto de bajo costo.
    - [ ] Consistencia sólida y duradera.
    - [ ] Son igualmente ambas importantes.

22. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto de bajo costo; y/o (2) inerte en la naturaleza?
    - [ ] Producto de bajo costo.
    - [ ] Inerte en la naturaleza.
    - [ ] Son igualmente ambas importantes.

23. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto no degradable y de buena vida útil; y/o (2) opaco o baja transparencia del producto?
    - [ ] Producto no degradable y de buena vida útil.
    - [ ] Opaco o baja transparencia del producto.
    - [ ] Son igualmente ambas importantes.

24. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto no degradable y de buena vida útil; y/o (2) consistencia liviana y durable?
    - [ ] Producto no degradable y de buena vida útil.
    - [ ] Consistencia liviana y durable.

☐ Son igualmente ambas importantes.

25. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto no degradable y de buena vida útil; y/o (2) inerte en la naturaleza?

☐ Producto no degradable y de buena vida útil.

☐ Inerte en la naturaleza.

☐ Son igualmente ambas importantes.

26. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) opaco o baja transparencia del producto; y/o (2) consistencia sólida y duradera?

☐ Opaco o baja transparencia del producto.

☐ Consistencia sólida y duradera.

☐ Son igualmente ambas importantes.

27. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) opaco o baja transparencia del producto; y/o (2) inerte en la naturaleza?

☐ Opaco o baja transparencia del producto.

☐ Inerte en la naturaleza.

☐ Son igualmente ambas importantes.

28. ¿Cuál usted entiende que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) consistencia sólida y duradera; y/o (2) inerte en la naturaleza?

☐ Consistencia sólida y duradera.

☐ Inerte en la naturaleza.

☐ Son igualmente ambas importantes.

Parte II. Disposición de las botellas de vidrio

1. ¿Cuál es su interés de que exista reciclaje de botellas de vidrio en Puerto Rico?

☐ Mucho

☐ Moderado

☐ Poco

2. De haber reciclaje de botellas de vidrio, escoja uno de los posibles escenarios de reciclaje de las botellas de vidrio.

☐ Triturar las botellas para rehacer botellas, otros envases y/u otros productos

☐ Esterilización de botellas en buenas condiciones para reusarse.

☐ Triturar botellas para utilizarse como arena en la fabricación de bloques de concreto

Parte III. Perfil de los encuestados

1. Es usted:

☐ Estudiante

☐ Docente

☐ No Docente

2. Escoja la facultad del RUM a la que pertenece. (Si aplica)

☐ Artes y Ciencias

☐ Ciencias Agrícolas

☐ Administración de Empresas

☐ Ingeniería

3. Seleccione el año de estudio que cursa actualmente. (Si aplica)

☐ 1er año

☐ 2do año

☐ 3er año

☐ 4to año

- [ ] 5to año
- [ ] 6to año en adelante

4. ¿Cómo considera su nivel de conocimiento acerca del tema de los beneficios de las botellas de vidrio?
   - [ ] Ninguno
   - [ ] Poco
   - [ ] Regular
   - [ ] Sobresaliente.

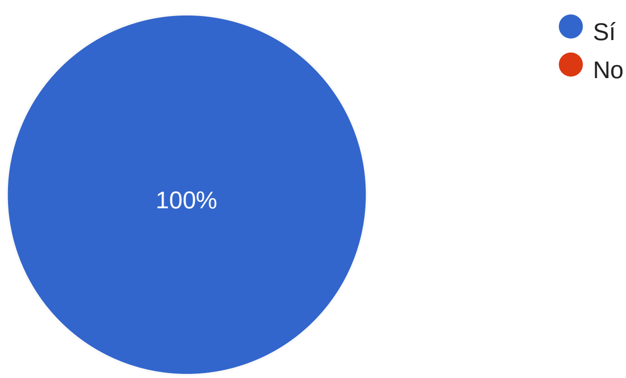
Resultados del Cuestionario de Percepción sobre los Beneficios de las Botellas de Vidrio

Cuestionario de Percepcion sobre los Beneficios de las Botellas de Vidrio

25 respuestas

Deseo continuar:

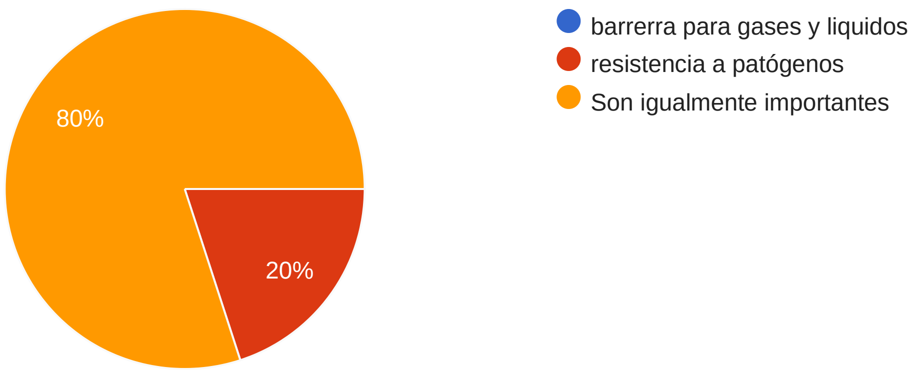
25 respuestas



Parte 1. Compare entre las alternativas y seleccione la que considere mas importante

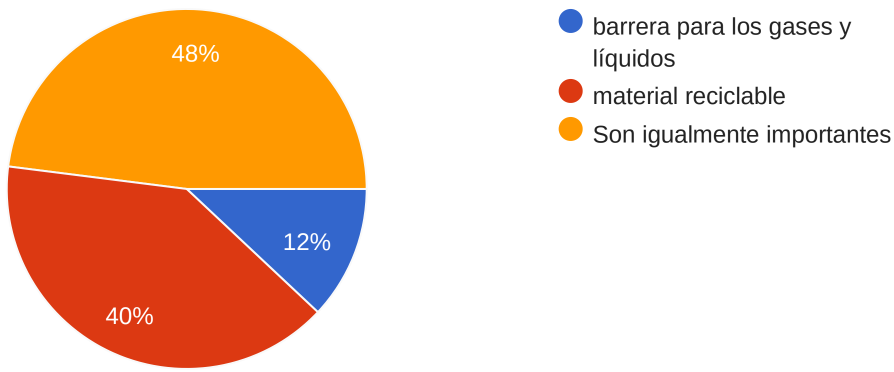
¿Cual considera que es mas importante entre las siguientes propiedades de las botellas de vidrio: (1)barrerra para gases y liquidos; y/o (2) resistencia a patógenos?

25 respuestas



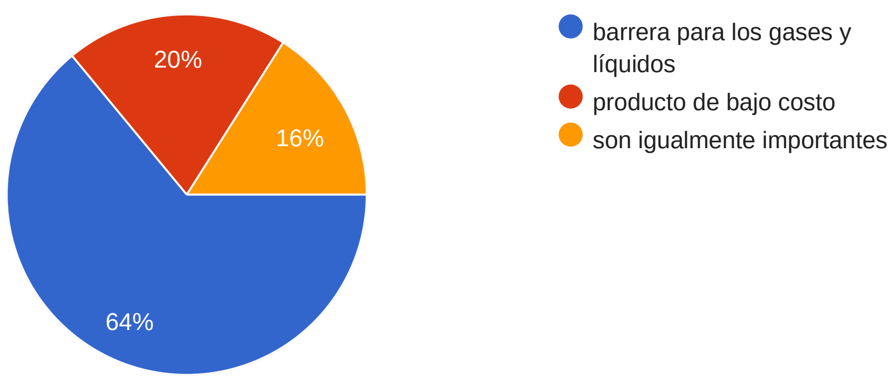
2. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1)barrera para los gases y líquidos; y/o (2) material reciclable?

25 respuestas



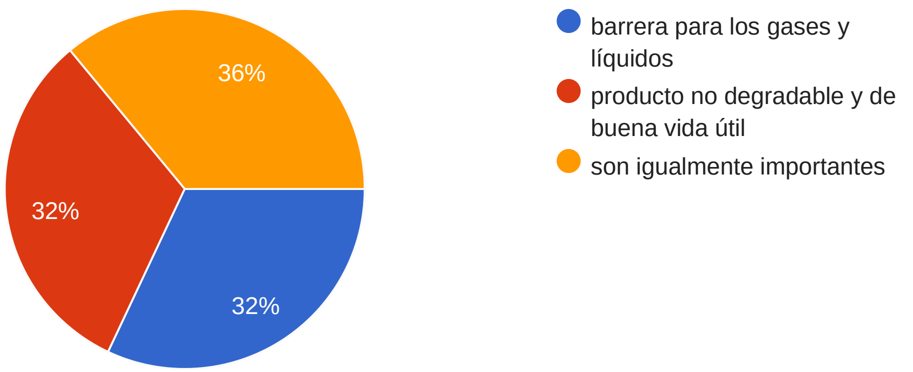
3. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) barrera para los gases y líquidos; y/o (2) producto de bajo costo?

25 respuestas



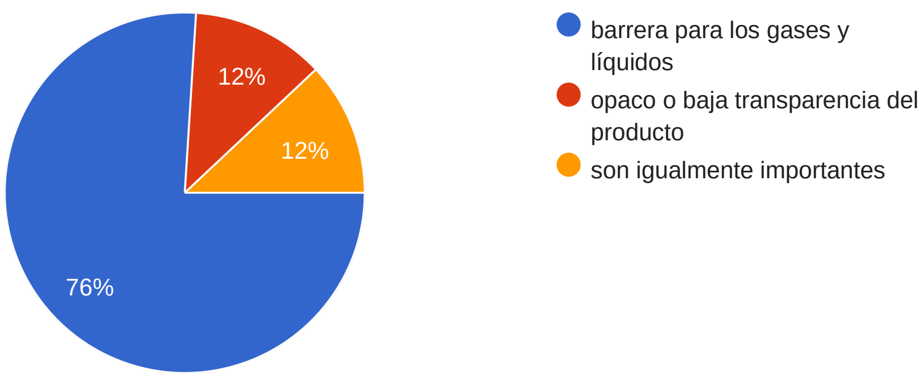
4. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) barrera para los gases y líquidos; y/o (2) producto no degradable y de buena vida útil?

25 respuestas



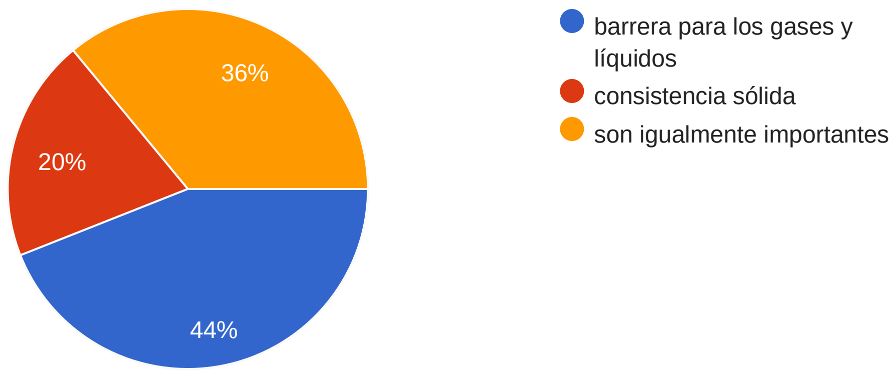
5. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) barrera para los gases y líquidos; y/o (2) opaco o baja transparencia del producto?

25 respuestas



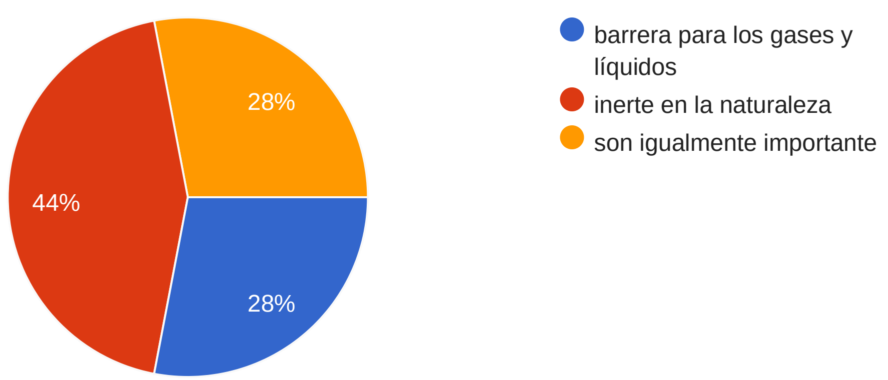
6. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) barrera para los gases y líquidos; y/o (2) consistencia sólida?

25 respuestas



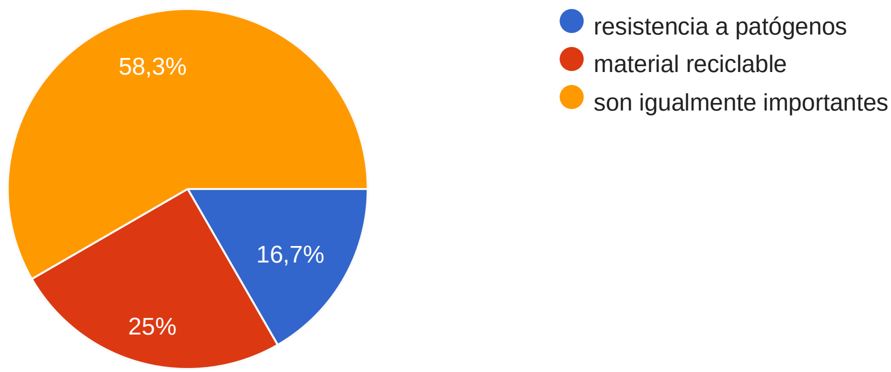
7. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) barrera para los gases y líquidos; y/o (2) inerte en la naturaleza?

25 respuestas



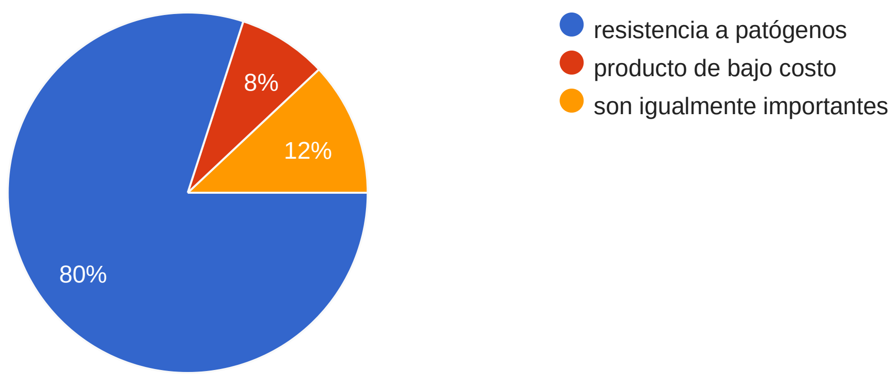
8. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a patógenos; y/o (2) material reciclable?

24 respuestas



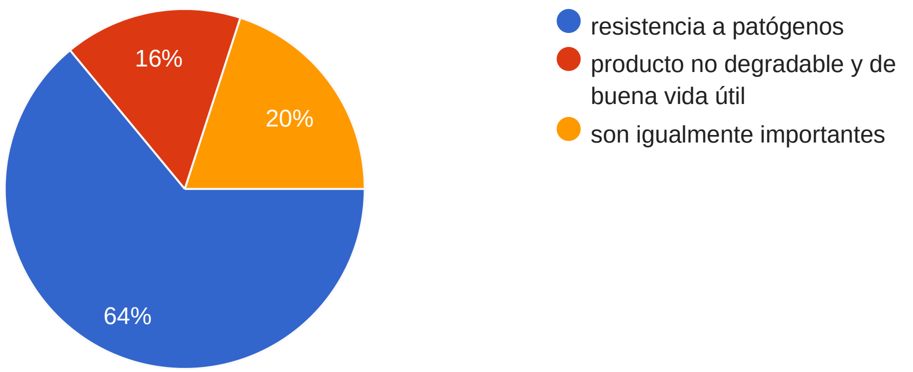
9. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a patógenos; y/o (2) producto de bajo costo?

25 respuestas



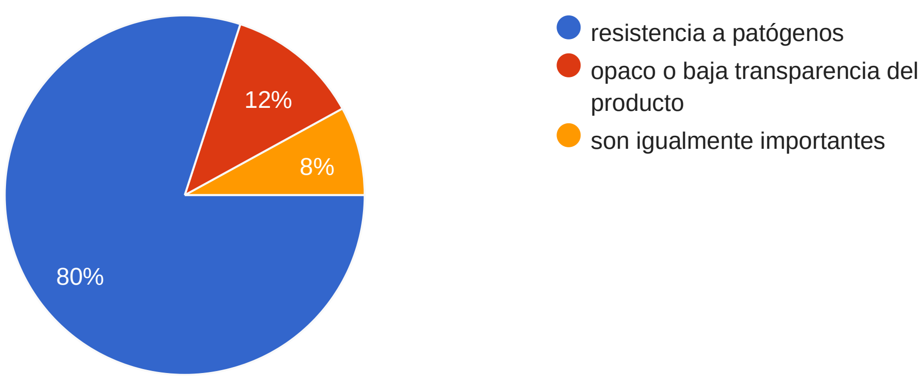
10. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a patógenos; y/o (2) producto no degradable y de buena vida útil?

25 respuestas



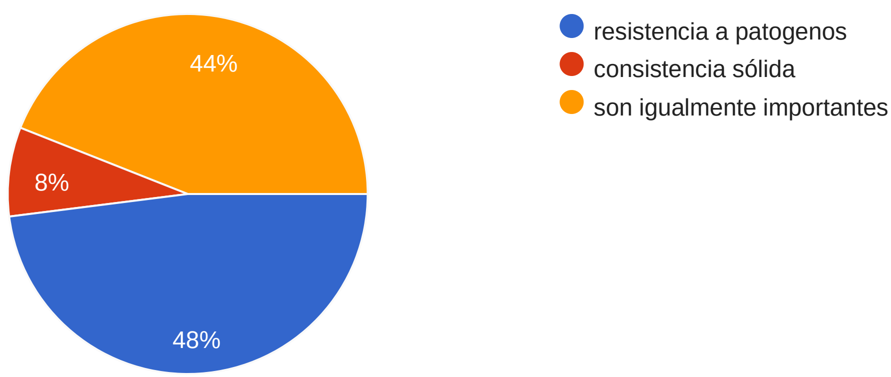
11. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a patógenos; y/o (2) opaco o baja transparencia del producto?

25 respuestas



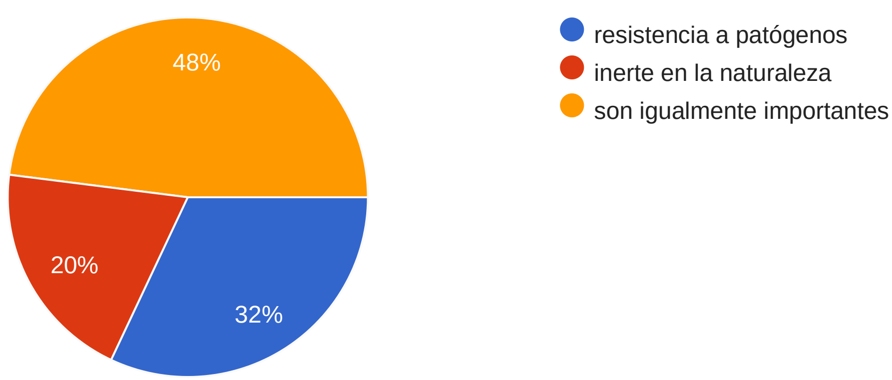
12. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a patógenos; y/o (2) consistencia sólida?

25 respuestas



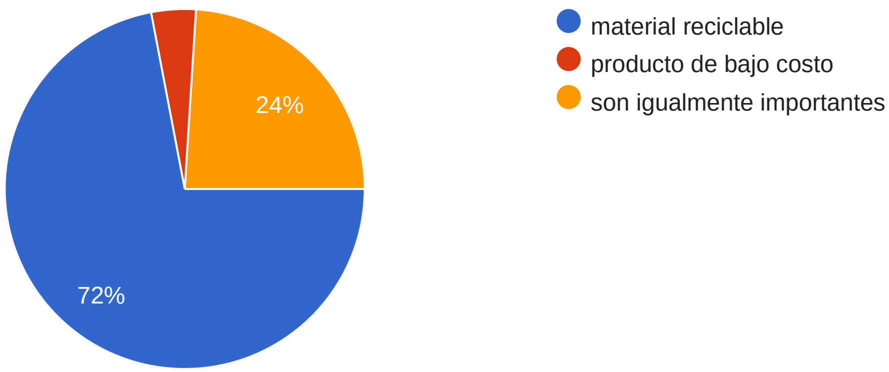
13. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) resistencia a patógenos; y/o (2) inerte en la naturaleza?

25 respuestas



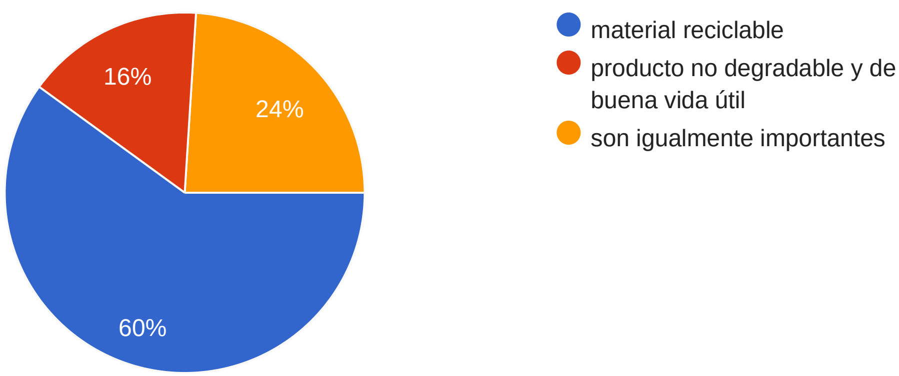
14. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) producto de bajo costo?

25 respuestas



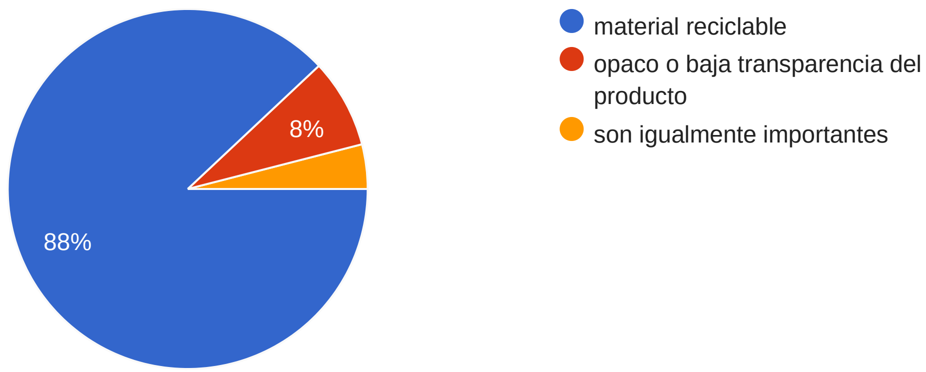
15. ¿Cuál consideraque es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) producto no degradable y de buena vida útil?

25 respuestas



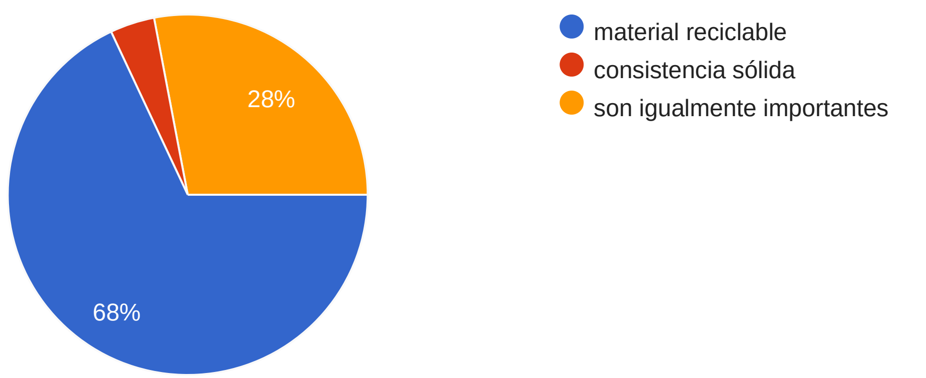
16. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) opaco o baja transparencia del producto?

25 respuestas



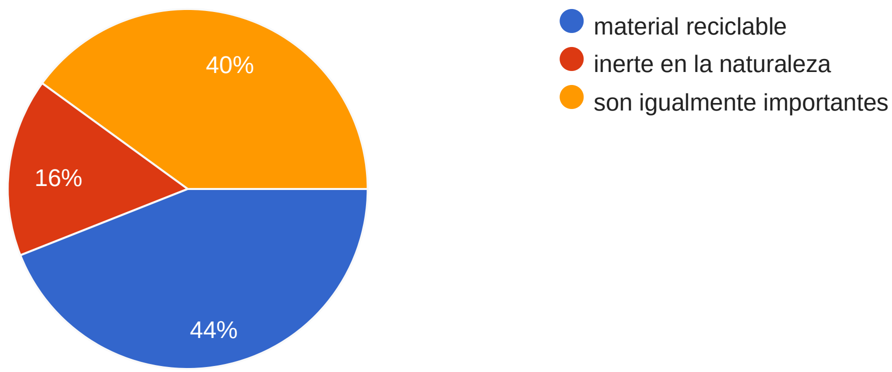
17. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) consistencia sólida?

25 respuestas



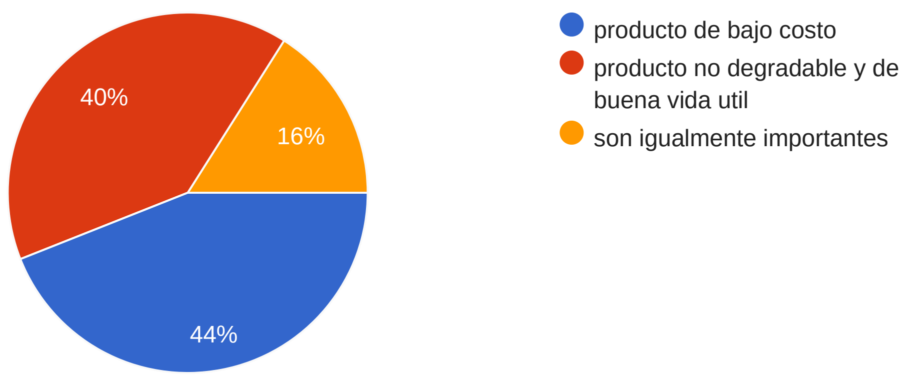
18. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) material reciclable; y/o (2) inerte en la naturaleza?

25 respuestas



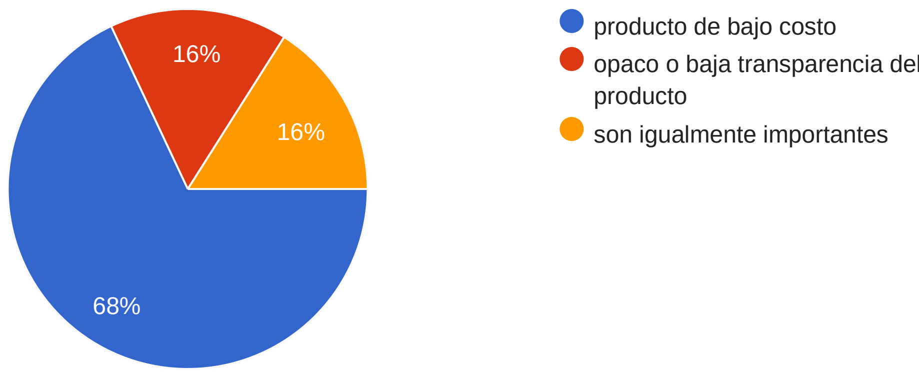
19. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto de bajo costo; y/o (2) producto no degradable y de buena vida util?

25 respuestas



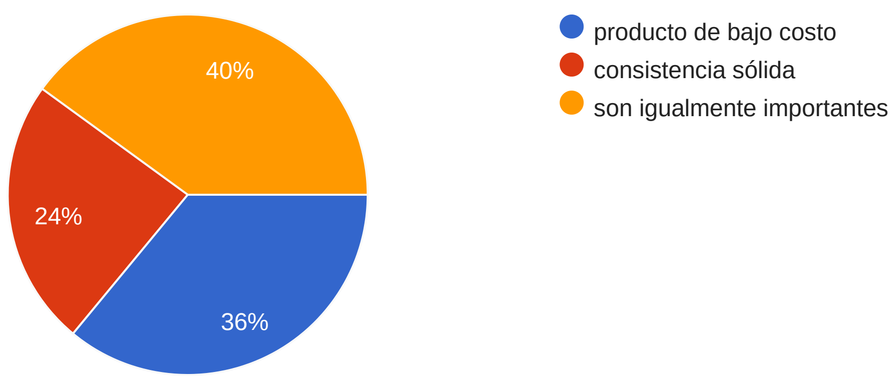
20. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto de bajo costo; y/o (2) opaco o baja transparencia del producto?

25 respuestas



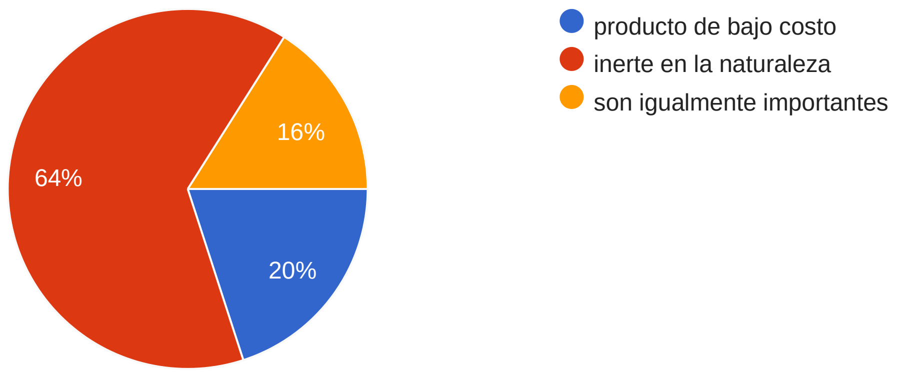
21. ¿Cuál considera que es mas importante entre las siguientes propiedades de las botellas de vidrio: (1) producto de bajo costo; y/o (2) consistencia sólida?

25 respuestas



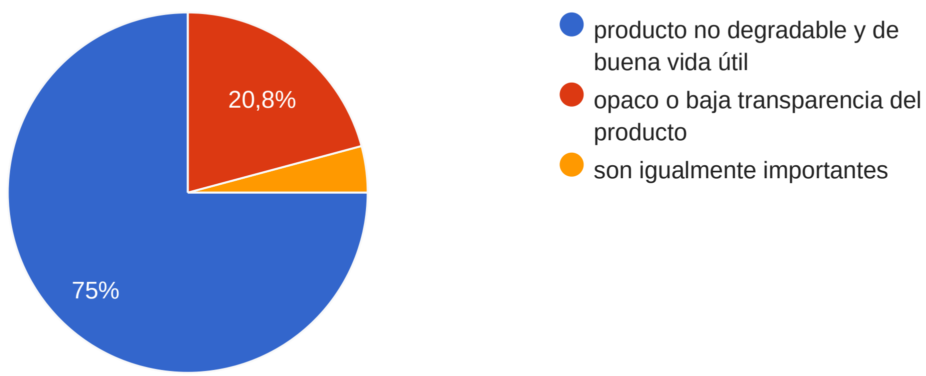
22. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto de bajo costo; y/o (2) inerte en la naturaleza?

25 respuestas



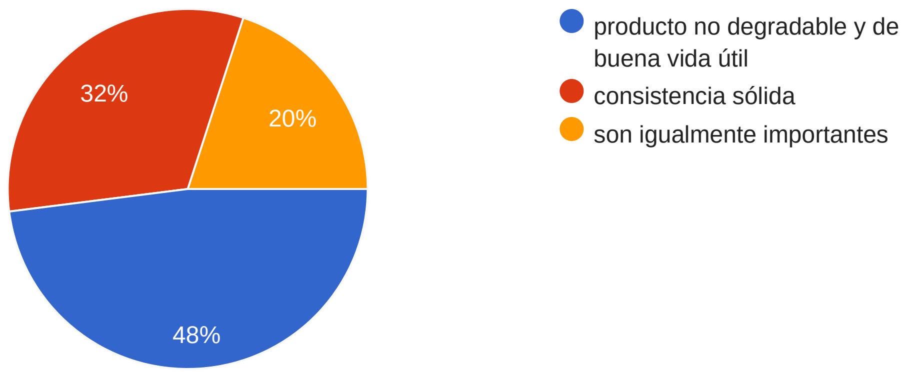
23. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto no degradable y de buena vida útil; y/o (2) opaco o baja transparencia del producto?

24 respuestas



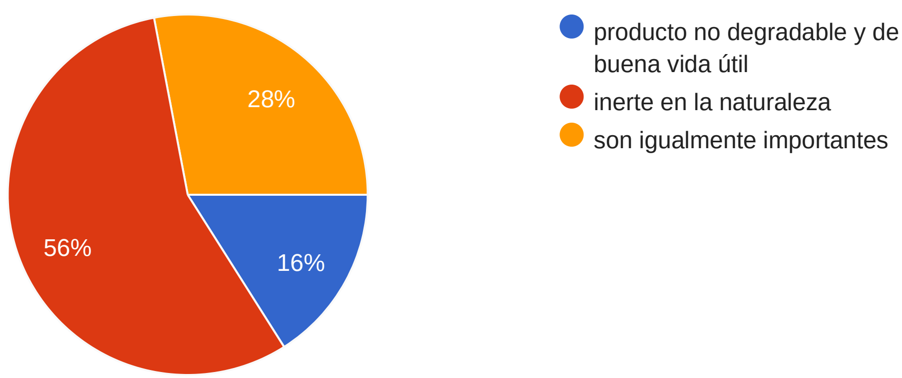
24. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto no degradable y de buena vida útil; y/o (2) consistencia sólida?

25 respuestas



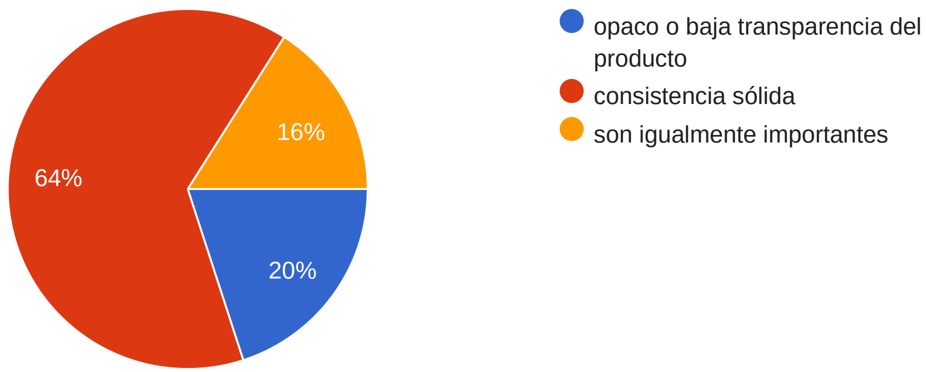
25. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) producto no degradable y de buena vida útil; y/o (2) inerte en la naturaleza?

25 respuestas



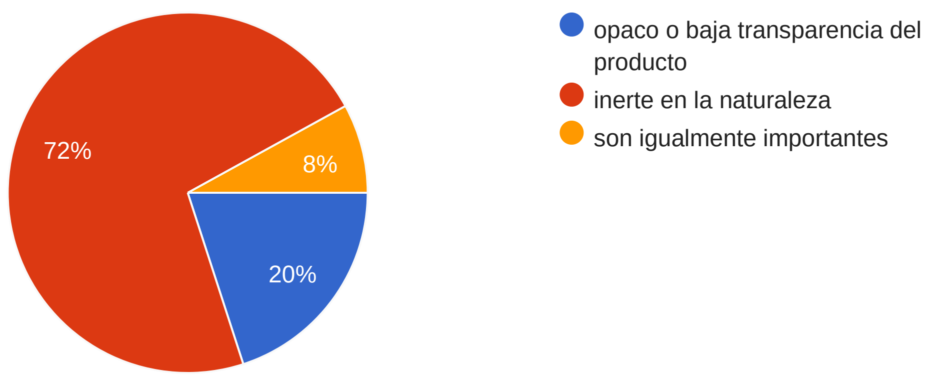
26. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) opaco o baja transparencia del producto; y/o (2) consistencia sólida?

25 respuestas



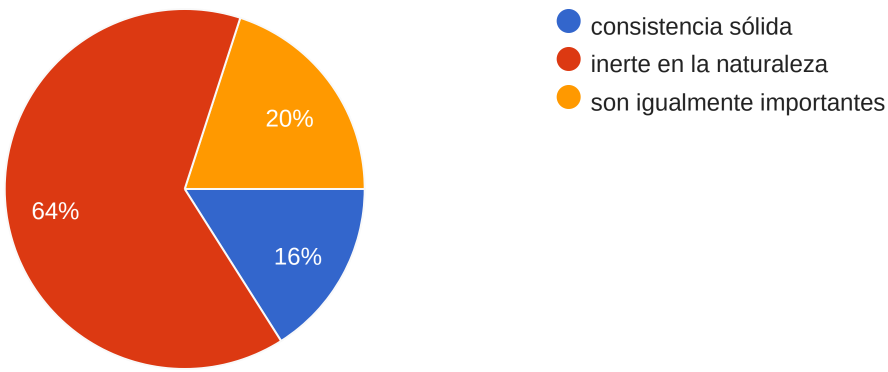
27. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) opaco o baja transparencia del producto; y/o (2) inerte en la naturaleza?

25 respuestas



28. ¿Cuál considera que es más importante entre las siguientes propiedades de las botellas de vidrio: (1) consistencia sólida; y/o (2) inerte en la naturaleza?

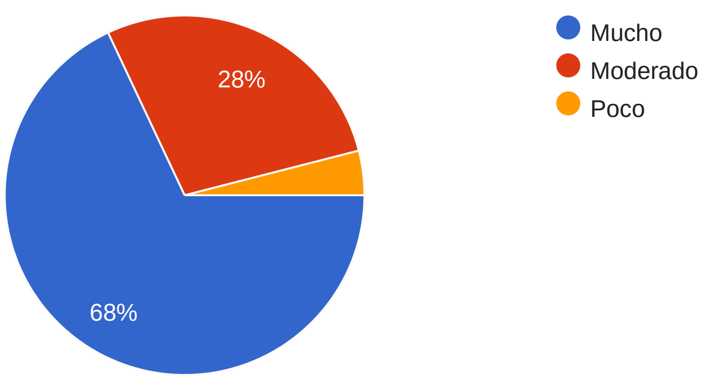
25 respuestas



Parte II. Disposicion de las botellas de vidrio

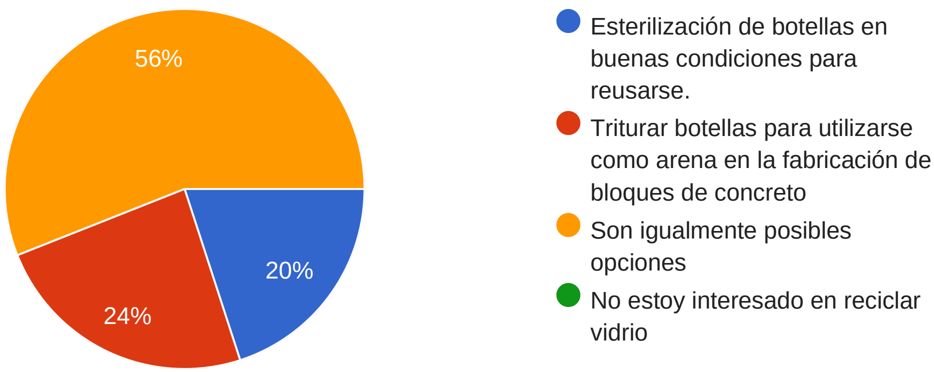
1. ¿Cuál es su interés de que exista reciclaje de botellas de vidrio en Puerto Rico?

25 respuestas



2. De haber reciclaje de botellas de vidrio, escoja uno de los posibles escenarios de reciclaje de las botellas de vidrio.

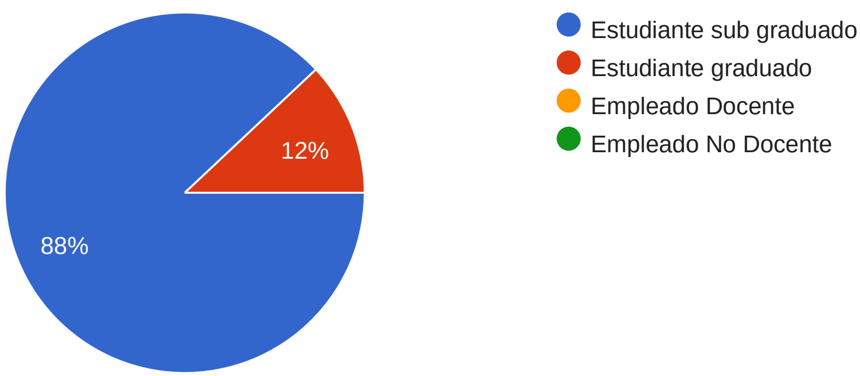
25 respuestas



Parte III. Perfil de Participantes

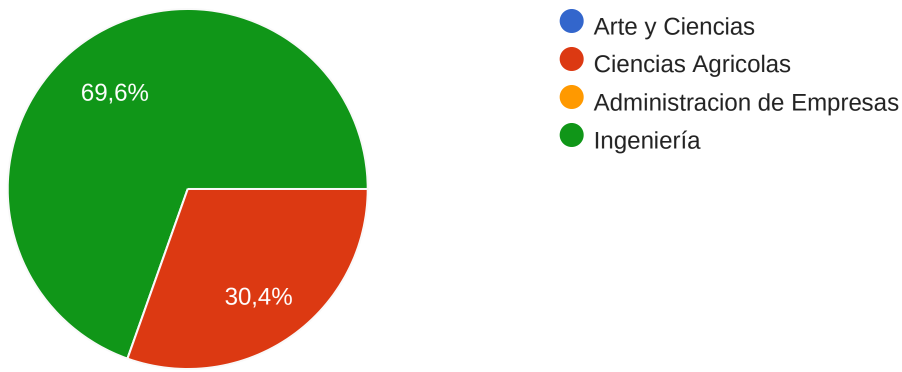
Es usted:

25 respuestas



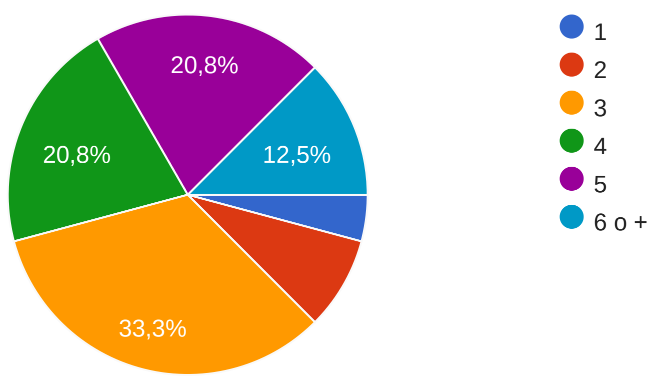
A que facultad pertenece (si aplica):

23 respuestas



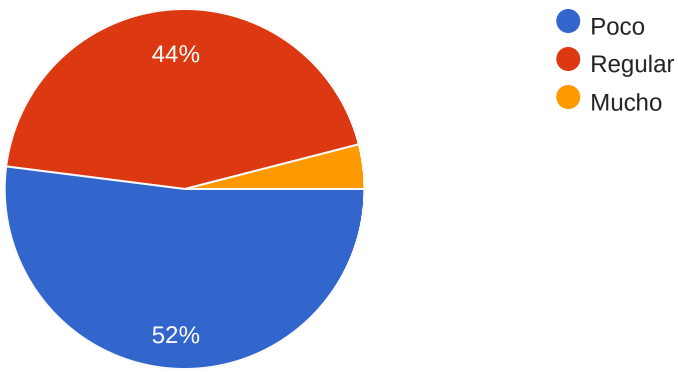
Año que cursa actualmente:

24 respuestas



¿Como considera su nivel de conocimiento sobre el benficio de las botellas de vidrio?

25 respuestas



CITI PROGRAM

Completion Date 14-Sep-2020
Expiration Date 14-Sep-2023
Record ID 38212179

This is to certify that:

Francis Francis-Cordero

Has completed the following CITI Program course:

Not valid for renewal of certification through CME. Do not use for TransCelerate mutual recognition (see Completion Report).

Social & Behavioral Research - Basic/Refresher (Curriculum Group)
Social & Behavioral Research - Basic/Refresher (Course Learner Group)
1 - Basic Course (Stage)

Under requirements set by:

University of Puerto Rico Mayaguez (UPRM)

CITI
Collaborative Institutional Training Initiative

Verify at www.citiprogram.org/verify/?wf1ccf211-abcc-454f-b753-08b36e7515d6-38212179

Figure 10.1 IRB Certification of course approval

Table 10.1 Comparison of each attribute using the MADM method.

	Barrier for gases and liquids	*Resistant pathogens*	*Recyclable Material*	*Low-Cost Product*	*Nondegradable product and good shelf life*	*Low Transparency*	*Solid material*	*Inert material*	*Total*	*Normalize*
Barrier for gases and liquids		**0.5**	**0**	**1**	**0.5**	**1**	**1**	**0**	**4**	**14%**
Resistant pathogens	**0.5**		**0.5**	**1**	**1**	**1**	**0.5**	**0.5**	**5**	**18%**
Recyclable Material	**1**	**0.5**		**1**	**1**	**1**	**1**	**1**	**6.5**	**23%**
Low-Cost Product	**0**	**0**	**0**		**1**	**1**	**0.5**	**0**	**2.5**	**9%**
Nondegradable product and good shelf life	**0.5**	**0**	**0**	**0**		**1**	**1**	**0**	**2.5**	**9%**
Low Transparency	**0**	**0**	**0**	**0**	**0**		**0**	**0**	**0**	**0%**
Solid material	**0**	**0.5**	**0**	**0.5**	**0**	**1**		**0**	**2**	**7%**
Inert material	**1**	**0.5**	**0**	**1**	**1**	**1**	**1**		**5.5**	**20%**