Economic feasibility and public perception of using recycled glass as beach nourishment material to mitigate Puerto Rico erosion problems

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ABSTRACT

A portion of the Rincón coastline in Northwestern Puerto Rico has experienced an erosion rate of approximately 1 meter per year; the problem was significantly aggravated with the strong hit of hurricane María in September 2017. Evaluation of using a 50/50 percent mixture of recycled glass cullets (524K tons, 2.5 billion of glass bottles) and native beach as filling material was conducted using economic and social feasibility analyses, in conjunction with a life cycle assessment of glass bottles. Cost estimates of three beach nourishment scenarios, considering this technique and traditional offshore dredging methods indicates that total project costs increase proportionally with the increased distance between the dredging and filling areas, as well as with increased use of crushed glass. Given the cost of glass crushing, using recycled glass as beach nourishment material is not the most economically feasible alternative, roughly 7 times more expensive than the other methods. The social feasibility aspect of the project indicates that 63% of individuals would engage in glass recycling practices, which could potentially yield to 50K m^3 of saved landfill space per year. Moreover, public perception of the project was found to be overwhelmingly favorable. To evaluate the potential environmental and public health benefits of using glass as a beach nourishment material as opposed to disposing in landfills, a life cycle assessment was conducted. Disposing of glass bottles in landfills presented a higher potential for global warming, ozone depletion and ecotoxicity in air and water. However, as distance between the origin of the glass waste and the location of the crushing plant increases, so does the potentially negative impacts to the environment and human health; with 45 miles marking the threshold for similar effects between both scenarios.

RESUMEN

La línea de costa del municipio de Rincón en Puerto Rico ha experimentado una erosión severa de aproximadamente 1 metro por año; problema que se ha agravado tras el paso de huracán María en septiembre de 2017. Diferentes alternativas, como la realimentación de playas, han sido consideradas para restaurar las costas. Este estudio evalúa la viabilidad de usar una mezcla de 50/50 porciento vidrio triturado (524K toneladas, 2.5 billones de botellas de vidrio) y arena natural de la playa como material de relleno. Análisis económicos y sociales en conjunto con un análisis de ciclo de vida de las botellas de vidrio forman parte del estudio. Estimados de costos considerando esta técnica, así como métodos de dragado tradicionales indican que existe una relación proporcional entre el costo total del proyecto y la distancia de dragado, así como la cantidad de vidrio triturada. De las alternativas propuestas, la realimentación de playa con la mezcla de vidrio resultó el escenario económicamente menos factible por el alto costo de trituración; con un costo total de proyecto de aproximadamente 7 veces más que los otros escenarios.

Los resultados del análisis de viabilidad social reflejan que el 63% de individuos en el estudio estarían envueltos en reciclaje de vidrio; lo que podría representar un ahorro de espacio en el vertedero de 50K m^3 cada año. Asimismo, la percepción pública del proyecto también resultó favorable. Un análisis de ciclo de vida (LCA) fue realizado para evaluar el potencial impacto ambiental y a la salud pública de utilizar vidrio triturado para rellenar playas en vez de disponer de éste en el vertedero. Los resultados sugieren que disponer de vidrio en el vertedero aporta más al calentamiento global, agotamiento de ozono y ecotoxicidad del aire y el agua. Asimismo, los resultados del LCA reflejaron que triturar vidrio para rellenar playas sólo resulta favorable cuando

la planta de trituración se encuentra en un rango menor de 45 millas; un aumento en la distancia de transporte de las botellas de vidrio hacia la planta trituradora genera impactos potencialmente negativos al entorno y la salud humana.

...to God and my family.

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CHAPTER 1. INTRODUCTION

1.1 Background and Motivation

Erosion is the wear produced in the earth's crust by the action of external agents such as wind or water (*English Oxford Living Dictionaries*). Coastal erosion can decrease beach area, thereby potentially impacting the local ecosystem, community, and economy. Throughout the years, Puerto Rico has experienced erosion along its entire coast (Figure 1.1). Changes in the wave regime caused by winter storms or hurricanes; hard stabilizations in properties near to the coasts; upstream damming systems of rivers that reduces inland sediment transport towards the coast; construction of breakwaters; and loss of natural barriers are some of the causes (*Morelock, 2000*). For example, the line of coast from the Rincon Public Beach to the south of Quebrada Los Ramos has experienced 1.1±0.3 meters of erosion per year (*Thieler et al., 2007*). The problem was significantly aggravated with the strong hit of hurricane María in September 2017 (Figure 1.2), with estimated losses of approximately $90 billion throughout the island (*NOAA, 2018*).

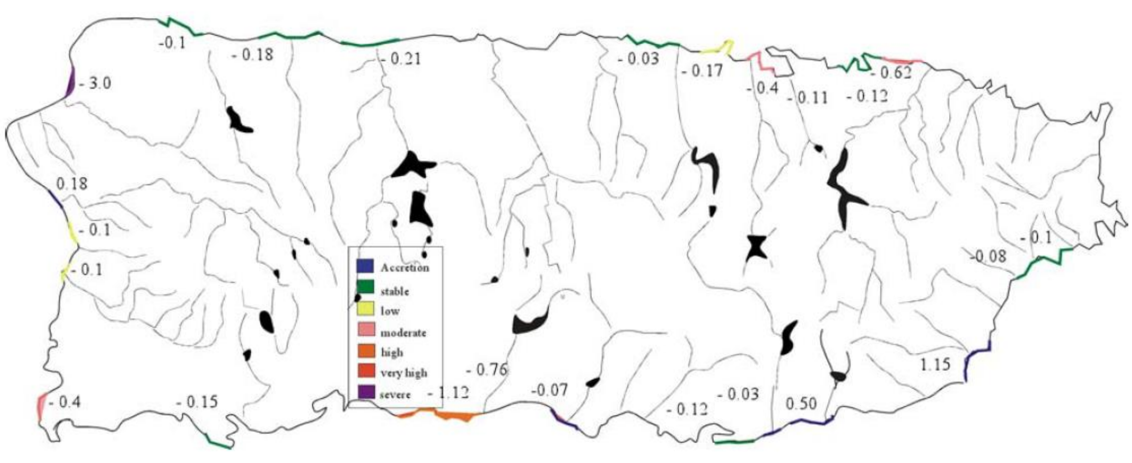

Figure 1.1: Rates of shoreline changes in Puerto Rico for the past 40 years (*Morelock, 2000*). Positive values represent accretion vs. negatives which represent erosion.

Figure 1.2: Photographs illustrating coastal erosion in Rincón, Puerto Rico caused by Hurricane María.

There are several methods to mitigate beach erosion. Hard engineering structures, such as seawalls and breakwaters, are commonly used to reduce the hydrodynamic forcing (i.e., breaking waves) on beaches and/or beach properties. Beach nourishment (a soft engineering measure) generally consists of filling the eroded beach with sand dredged from offshore deposits. Beach nourishment is the only engineering alternative for coastal protection that works directly with the deficit of sand and uses an external source of sediment for mitigating erosion (*Press, 1995*). This method improves natural protection, while providing an extension of the recreational area. Although this measure improves beaches, it must be performed continuously (every 2-3 years); adding a significant amount of maintenance costs to the project. For example, Broward County, Florida, USA spends approximately $80 million in beach restoration every year (*Associated Press, 2007*).

Sediment compatible with the natural beach is the most important parameter for beach nourishment. Recently, there has been growing interest in the possibility of using recycled glass as beach nourishment material. For example, in the island of Curaçao approximately 110 cubic yards of glass cullets were mixed with sand to fill the Hilton Curacao and Zanzibar beaches (*Paardekooper, 2004*). Broward County, Florida, USA has also conducted studies in the City of Hollywood Beach to use this glass cullets as beach nourishment (Figure 1.3). To date, Puerto Rico has not conducted a beach nourishment project in any of its beaches due, in part, to the significant cost of such projects and the lack of available information regarding the location and quantity of available offshore sand deposits. This study is aimed at conducting a preliminary analysis on the feasibility of using recycled glass as an alternative to assess erosion problems along the coast of Rincón, Puerto Rico.

Figure 1.3: A view of tests conducted in 2006 by the City of Hollywood Beach, Broward County, Florida USA demarking varying proportions of glass cullets mixed with native beach sand (*Makowski, et al., 2007*).

1.2 Glass Recycling in Puerto Rico

One ton of glass occupies approximately 1.4 cubic yards of volume in the landfill (*Edge & Magoon, 2002*). Puerto Rico Law 70 of 1992 establishes glass as a recyclable material, which technically prohibits its entry to the landfill (*P.C.1205, 1992*). Up until 2008, Owen Illinois (Vega Alta, PR) was the only glass recycling plant in the island capable of fully recycling glass bottles. Since its closure, glass has been treated as a solid waste, compacted into the garbage truck, and deposited in one of the twenty-seven private landfills operating in the island (*Paulino, 2016*). Today, it accounts for approximately 3% of all solid waste in Puerto Rico landfills; with this percentage rising in the holiday season to approximately 8% (Figure 1.4; *Wehran Puerto Rico, Inc., 2003*). Throughout the island, 251,207 tons of glass were placed in landfills in 2014 (*Romero-Castellano, 2015*), which represents an environmental concern given that such material takes a million years to degrade (*U.S. National Park Service, 2015*). Figure 1.5 shows the distribution of glass disposed in landfills for 2014 (*Appendix A* show this data in more detail).

Glass is composed of metal oxides and silica sand; when small in size it could resemble beach sand very closely. The use of this recycled material as a replacement for sand has taken place in road projects, construction of water filters, insecticides and, more recently, in coastal restoration. In Puerto Rico, it has been used as aggregate for asphalt concrete, ornamental blocks and tiles. Using this new alternative for beach nourishment projects may result in an incentive for glass recycling in the island.

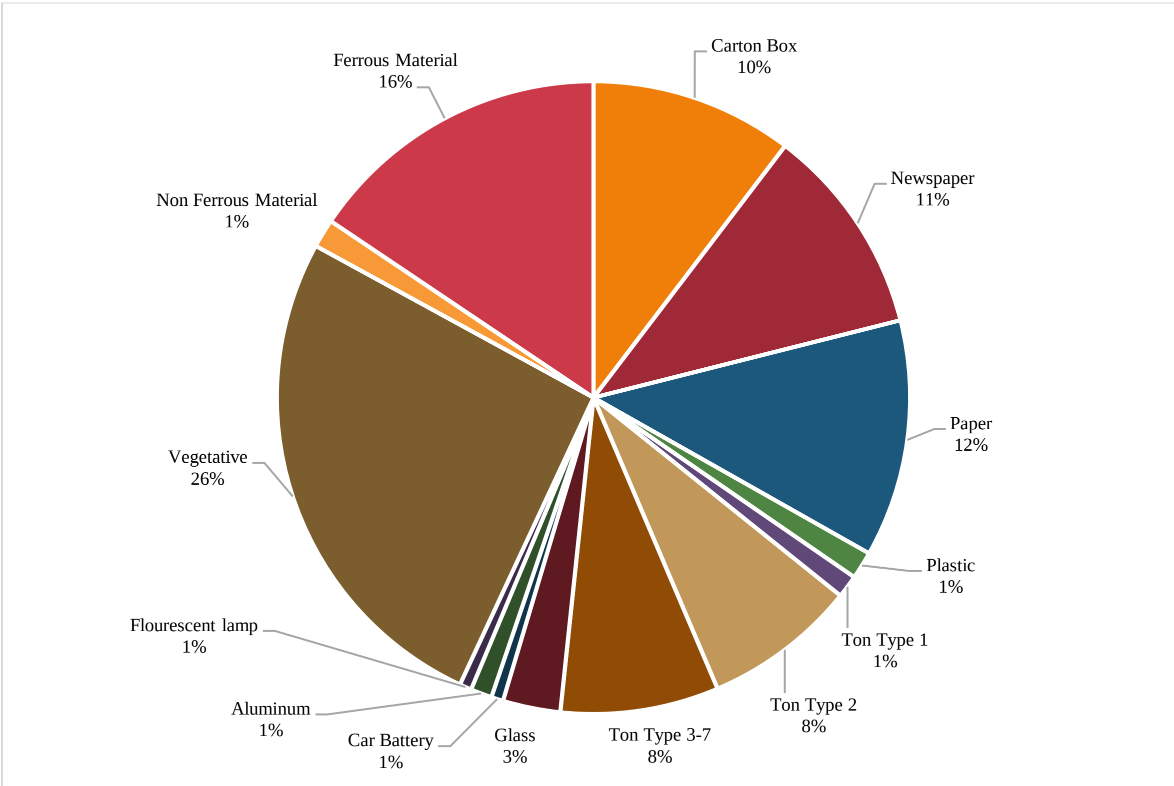

Figure 1.4: Percentage distribution of solid waste disposed in Puerto Rico landfills for 2014 (*Romero-Castellano, 2015*).

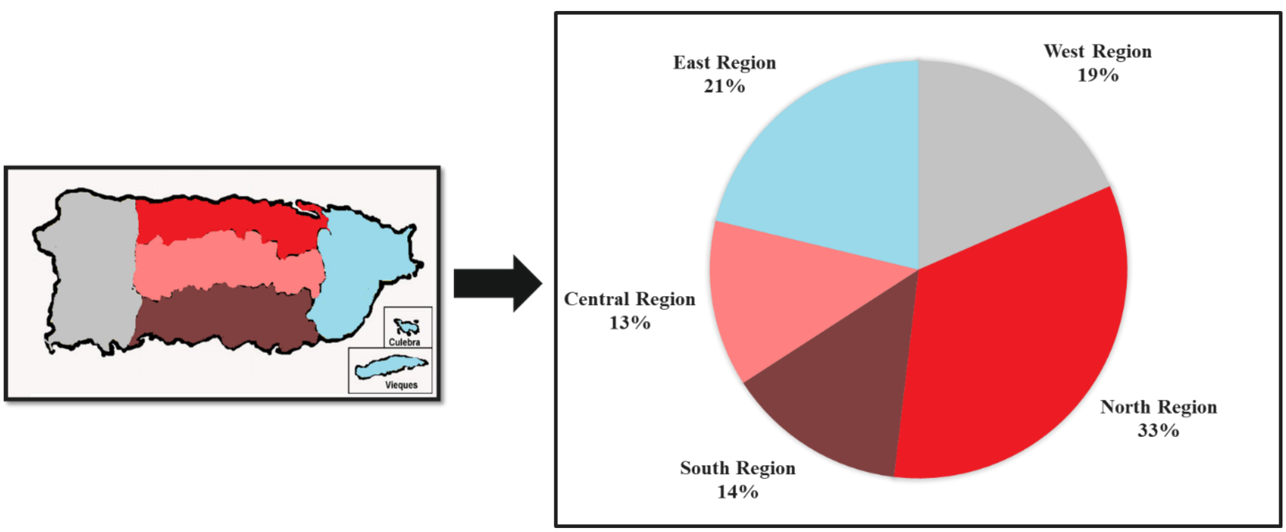

Figure 1.5: Glass disposed in Puerto Rico landfills per region for 2014 (*Romero-Castellano, 2015*).

1.3 Goals and Objectives

The main goal of this project is to assess the feasibility of using recycled glass as a filling material to mitigate erosion problems in coastal areas. The specific objectives are:

- To quantify the amount of crushed glass necessary to fill a specific area of the Rincon's coastline for a variety of sand/glass mixtures.
- Determine the viability of the project in economic, social and energetic terms.

1.4 Literature Review

Sand is a material of high importance in modern society; buildings, bridges, roads, and most manufacturing depend on sand for its construction. It also serves as an important habitat for flora and fauna living in coastal waters and deserts (*Delestrac*, *2012*). The use of sand and its illegal exploitation has resulted in a 70% decrease of this resource in beaches around the world. Such environmental impact has triggered the search for alternative materials for sand replacement in places where native sand is not available. Recycled glass cullets is an example of such materials.

Using crushed glass as an alternative for sand has been considered in Broward County, Florida. Makowski et al. (2013) found that recycled glass cullets can be compatible with the native beach sand based on studies performed on salt-tolerant plants. Their findings suggest that different glass/sand mixtures do not significantly affect plant growth (*Makowski et al., 2013*). Physical modeling experiments were conducted by Edge et al. (2002), where it was found that glass cullet beaches did not significantly differ from sandy beaches in terms of beach profiles and reflected wave energy. Additionally, they did not find significant differences between the rate of mechanical abrasion of sand and glass cullets.

Tests of biological and abiotic stresses with macro and micro-organisms have also been conducted to evaluate the ecological aspects of using glass a replacement for sand in beach environments (*Makowski and Rusenko, 2007*). Different scenarios were studied including invertebrate and vertebrate biotic community assemblage. In all scenarios, the mortality rates for each of the macro and micro-organisms is not increased in glass cullet matrices, proving that glass substrates do not significantly affect this type of biodiversity. Geotechnical tests in the study area, assessments of social perception with different focus groups, and analysis of pollutants also accounted for part of the analysis to study the feasibility of using this material.

1.4.1 Erosion in Rincón, Puerto Rico and potential mitigation alternatives

Historical shoreline changes in Rincón Puerto Rico were thoroughly studied by the United States Geological Survey, *USGS* (*Thieler, 2007*). Although the study was limited to historical georeferenced aerial photographs, results show that the area between Rincón's Public Beach and Córcega is the most affected, with an approximate 1.1 m of shoreline retreat per year (Figure 1.6). This study also suggested that an increase in erosion rate may occur if hard stabilizations measures continue to proliferate. Moreover, high rates of erosion have been observed in this location as a consequence of high-energy wave events generated by storms. Field observations by Chardón-Maldonado (2013) captured the nearshore morphologic change as a result of Tropical Storm Isaac (2012) and Hurricane Sandy (2012). This same effort incorporated numerical simulations of hydrodynamics and sediment transport that suggests a highly dynamic nearshore evolution in response to southwesterly wave events, yet minimal sediment transport resulting from moderate northwesterly events, except for sediment deposition at the Bajo Blanco sand shoal (Figure 1.6).

Considering the importance that this area represents to the town of Rincón, Salas-Sánchez (2014) designed a beach nourishment alternative to alleviate this problem. Topographic and bathymetric data were used to design the equilibrium beach profile for a 0.32 mm median grain diameter (A = 0.129 $m^{1/3}$) in order to estimate the volume of material needed to fill a 36-m wide, 1-m high berm from Rincón Marina to Córcega Beach (Salas-Sánchez, 2014). The proposed design considers a depth of closure of 2.045 m (with respect to MHW) and yields an approximate fill volume of 700,000 m^3.

The possibility of using the Bajo Blanco sand shoal as a beach nourishment borrow site was studied by Rojas-Vázquez (2016), who found the shoal sediment to be slightly smaller than the native beach sand. To mitigate this, Rojas-Vázquez (2016) suggested an overfill factor ranging from 1.5-1.7 (Badges 2006), which yielded a total fill volume of approximately 1,000,000 m^3. Moreover, this study suggests that utilizing the Bajo Blanco sand shoal as a borrowing site can potentially impact the local wave climate and subsequently beach morphology.

Figure 1.6: Rincón coastline considered for replenishment between Rincón Marina and Corcéga Beach (Created with Google Earth 2018).

CHAPTER 2. ECONOMIC FEASIBILITY

2.1 Identification of Potential Recycled Glass Sources

To help mitigate glass as a solid waste problem in Puerto Rico, an effort has been put forward to open a recycling glass plant in Bayamón, Puerto Rico. Cay Clean Glass Plant, initially said to open in late 2017, operates with Sioneers technology. This technology is said to be the best technique to refine recycled glass, regardless of its color and size, and the only one to remove impurities and achieve a 100% recycling (*DG Authority, 2016*). This plant would be able to processes all types of glasses including windshields, house glass and bottles. The crushing process is carried out by means of rollers where the more it shreds the material, the thinner and granulated it becomes.

This project evaluates the use of crushed glass provided by Cay Clean Glass (CCG) Plant and an additional manufacturer (Ballotini, BL). Figure 2.1 shows the types of crushed glass from both manufacturers. Different compositions of sand/glass mixtures for beach nourishment were considered, as described in the economic feasibility analysis (see *Section 2.2*). As a first assessment, a characterization of four different types of crushed glass was conducted following ASTM C136-01, C128-04a, C1444-00. Properties such as median grain diameter (d_{50}), specific gravity, angle of repose, and bulk density were estimated and compared to Rincón's native sand (RNS) (Table 2.1 and Figure 2.2). These measurements suggest that BL-25-40 and CCG-20-40 are the glass types that most closely resemble Rincón's native sand. This project will consider CCG-20-40 as the glass type to be used in the potential nourishment scenario.

Figure 2.1: Types of crushed glass from Cay Clean Glass Plant (CGG), Ballotini (BL) and Rincón Native Sand (RNS); from left to right: CCG-10-20, CCG-20-40, BL-25-40, BL-50-70 and RNS.

The amount of glass bottles needed to nourish a beach (considering 50% glass/sand mixture) was computed in order to evaluate the feasibility of having such amounts of raw material available in the island. Based on Salas-Sánchez (2014), nourishing Rincón beach (*Rincón Marina – Córcega*) with a berm width of 36 m and height of 1 m above MHW would require roughly 675,000 m^3 of sand-glass mixture. To translate this volume into mass, a bulk density analysis was performed following ASTM C29/C29M -17a. The volume of a known mass of crushed glass (CCG-20-40) was quantified in 5 trials, resulting in an average bulk density of 1.28 $g/cm^3 \pm 2\%$. As a rough approximation we estimate the sand-glass mixture to also be 1.28 g/cm^3, which implies that 476,000 tons (337,500 m^3) of crushed glass are needed to fulfill this beach nourishment design. This accounts to 2.3 billion of glass bottles (1 bottle = 190.24 g). If the tendencies presented by Romero-Castellano (2015) hold (see Section 1.2), it would require almost two years of glass recycling in Puerto Rico to achieve the full amount of raw material. Moreover, if CCG glass plant is able to achieve a maximum of 120,000 tons of crushed glass per year (*CCG Director, Mr. Rubén González, personal communication, October 17, 2016*), it would require four years of processing time, assuming all crushed glass available for the project is generated by CCG.

Table 2.1: Properties of different glass types and Rincón's Native Sand (RNS).

Particle Type	d_{50} (mm)	Specific Gravity	Angle of repose (°)	Bulk Density (g/cm^3)	ASTM Classification
CCG-10-20	0.98	2.50±0.04	~32.6	1.49±0.02	Medium Sand
CCG-20-40	0.68	2.51±0.06	~34.20	1.28±0.03	Medium Sand
BL-25-40	0.64	2.44±0.03	~31.4	1.44±0.01	Medium Sand
BL-50-70	0.24	2.37±0.10	~16.7	1.50±0.01	Fine Sand
RNS	0.40	2.65±0.07	~30.4	~1.6	Medium Sand

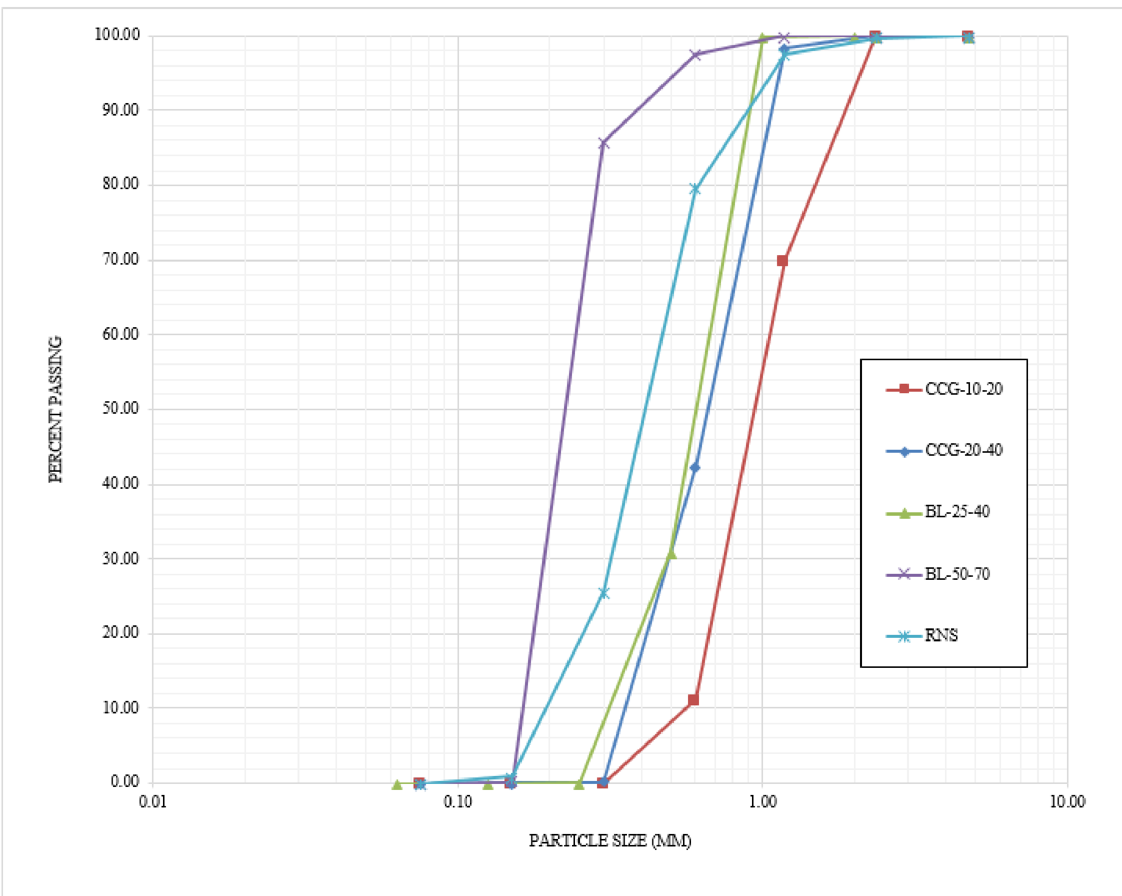

Figure 2.2: Grain size distribution for different types of crushed glass from Cay Clean Glass Plant (CGG), Ballotini (BL) and Rincón's Native Sand (RNS).

2.2 Potential Scenarios

The analysis of economic feasibility was evaluated with three scenarios. This analysis was performed to decide whether or not the use of crushed glass is a cost-effective way to mitigate erosion problems at the study area. The scenarios are as follow:

1. Fill with sand dredged within 1 mile from shore;
2. Fill with sand dredged within 4 miles from shore;
3. Fill with a 50/50 mixture of crushed glass from the Cay Clean Glass Plant installed in Rincón, Puerto Rico and sand dredged within 1 mile from shore;

The three scenarios contained an important part of the cost estimate analysis: filling the beach with sand from Bajo Blanco sand shoal. To perform this cost estimate, the production rate of the dredge, i.e. the rate at which a dredge moves soil in a given period of time, was determined.

A trailing suction hopper dredge was considered for the project based on the distance needed for dredging and the type of material (*Vlasblom, 2007*). This type of dredge is a self-propelled vessel equipped with a suction pipe and other advanced components (*Bray, 1979*). Figure 2.3 shows the arrangement of this type of dredge. The suction pipe contains a drag head that draws bed material at dredging depths of 10 – 30 m and average speed of 3.5 – 5 knots.

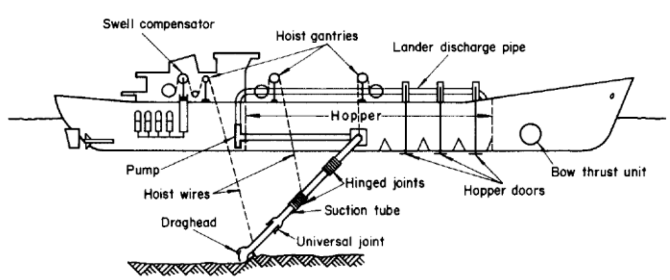

Figure 2.3: Trailing suction hopper dredger components (*Bray, 1979*).

For a trailing suction hopper, Bray (1979) defines the total load of material dredged during a time cycle as:

$$P_{max} = \frac{H\, f_e}{B\, (t_{loading} + t_{turning} + t_{sailing} + t_d)} \qquad (2.1)$$

where P_{max} is the maximum potential total production rate in m^3/hr; H is the hopper capacity as specified by the dredger type in m^3; f_e is the proportion of hopper filled with settled material (unitless); B is the bulking factor (unitless); $t_{loading}$ represents the total loading time in hours; $t_{turning}$ is the total turning time in hours; $t_{sailing}$ is the total time in hours the dredge takes to sail to the dump ground and turn back; and t_d is the time taken to dump the soil at the dump ground, assumed to be 0.083 hours as specified by Bray (1979). For medium sand, f_e and $t_{loading}$ were estimated from Figure B.1 in *Section B.1* from *Appendix B*, while B taken from Table B.1 in the same Appendix.

The total turning time, $t_{turning}$, can be computed as

$$t_{turning} = \frac{V_l t_{loading} t_t}{l} \qquad (2.2)$$

where V_l is the loading speed, assumed 3.5 knots (Bray, 1979); t_t is the time taken to perform an individual turn, assumed 0.066 hours (Bray, 1979); and l is the length of the dredging area estimated to be 1.48 km.

The sailing time, $t_{sailing}$, can be expressed as:

$$t_{sailing} = \frac{2\, g}{V_g} \qquad (2.3)$$

where g represents the distance to the dumping ground estimated to be 1.61 km and 6.44 km for scenarios 1) and 2), respectively; and V_g represents the fully laden sailing speed, assumed 9.5 knots following Figure B.2 from *Appendix B.*

The total production rate, P_{max} must then be adjusted using three reduction factors to obtain the actual total production rate of the dredge. The three-reduction factor are: (1) f_d, a delay factor accounting for bad weather and marine interruptions, (2) f_o, an operational factor taking into account inefficiencies in the dredging crew, among others; and (3), f_b, mechanical factors accounting for breakdown of the dredger. The actual total production rate can then be calculated as:

$$P_{avg} = f_d f_o f_b P_{max}. \qquad (2.4)$$

For this analysis, a 70% efficiency was considered to account for the three reduction factors combined (*dredging specialist, Federico García, personal communication, February 22, 2017*). The analysis was based assuming the specifications of the Sugar Island trailing suction dredge owned by Great Lakes Dredge & Dock Company (Figure 2.4 and *Table B-2* from the appendices).

Figure 2.4: Sugar Island trailing suction hopper dredge (*Great Lakes Dredge & Dock Company, LLC*).

2.2.1 Fill with sand dredged within 1 mile from shore

This scenario considered that sand will be dredged from an offshore sand shoal within 1 mile, potentially the Bajo Blanco sand shoal. Analysis of sand compatibility evaluated the similarities between this borrow site and the area to be nourished; results show that the d_{50} at Bajo Banco ranges between 0.22 mm – 0.25 mm (Rojas-Vázquez, 2016). For the cost estimate analysis, the d_{50} of the beach site (0.40 mm) was assumed, as more information is still needed regarding the vertical variability of d_{50} at Bajo Blanco. The reader is cautioned that nourishing with a d_{50} smaller than the native beach sand can have significant implications to the success of the project and its total cost (*Woods Hole Group, Inc., Louis Berger Group,Inc., 2010*); and referred to Rojas-Vázquez (2016) for a detailed analysis on the overfilling considerations that must be taken into account in such case (see *Section 1.4.1*).

Table 2.2: Production rate and duration for scenarios 1, 2, and 3.

Variables considered	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total volume of filling material (m^3, yd^3)	743k, 972k	743k, 972k	371.5k, 486k
Hopper Capacity, H (m^3)	2754	2754	2754
Laden Speed, V_g (kn)	9.5	9.5	9.5
Bulking Factor, B (Sand, medium soft to hard)	1.2	1.2	1.2
Turning time, t_t (hr)	0.066	0.066	0.066
Dumping time, t_d (hr)	0.083	0.083	0.083
Loading time, t_l (hr)	0.75	0.75	0.75
Proportion of hopper filled with settled material, f_e	0.7	0.7	0.7
Distance to the dumping ground, g (km)	1.61	6.44	1.61
Length of the dredging area, l (km)	1.48	1.48	1.48
Loading Speed, V_l (kn)	3.5	3.5	3.5
P_{max}(m^3/hr, yd^3/hr)	**1314, 1719**	**923,1207**	**1314, 1719**
Efficiency, $f_d f_o f_b$	0.70	0.70	0.70
P_{avg}(m^3/hr, yd^3/hr)	**920, 1203**	**646,845**	**920, 1203**
Project duration (days)	**48**	**68**	**24**

Considering an extraction volume of 675,000 m^3 (*Rojas-Vázquez, 2016*), and a 10% of extra material recommended for every dredging project (*dredging specialist, Federico García, personal communication, February 22, 2017*), the total volume considered to for the first two scenarios was 743,000 m^3 (972,000 yd^3). Given that operations are highly dependent on weather, the beach nourishment project was considered to take place between the months of April and August, where high swells or tropical storms are less likely in the area. Dredging operations are usually performed in a 24/7 schedule and 70% efficiency. Considering this efficiency and the theoretical production rate computed with Equation 2.1-2.4, the effective production rate of the dredger was computed as 920 m^3/hr, yielding a total of 48 days of project duration (assuming 17 hours of production time, 6 hours of maneuvers, and 1 hour of maintenance). *Section B.2* from *Appendix B* shows the specifications and calculations in more detail; *Section 2.3* shows the complete cost estimate for this scenario.

2.2.2 Fill with sand dredged within 4 miles from shore

This scenario was conducted as the previous one but considering the sand source to be located 4 miles from shore. This is approximately equal to the distance between the dumping site and a sand deposit located near the Rincón Lighthouse. This has a significant impact on the cost estimate given the increase in distance from the dumping site, which increases the length of pipeline and requires the use of booster units. Please note that even though trailing suction dredge hoppers normally travel to the dumping ground, this cost estimate considers, in a conservative approach, to install pipeline and booster units from the loading area to the dump area. Since the dredging design is out of the scope of this project, further refinement and details are left for future efforts.

Using the same approach as the previous scenario, Equation (2.1) suggested an effective production rate of 646 m^3/hr. This increased the duration of the project to 68 days. Table 2.2, Figure B.1 – Figure B.2 and Table B.1 - Table B.4 from *Appendix B* show in more detail the specifications and calculations conducted; *Section 2.3* shows the complete cost estimate for the project.

2.2.3 Fill with a 50/50 mixture of crushed glass from the Cay Clean Glass Plant installed in Rincón, Puerto Rico and sand dredged within 1 mile from shore

This scenario considered beach nourishment with a mixture of 50% crushed glass (CCG 20-40) and 50% sand dredged within 1 mile from shore. The estimated costs for the dredging part were calculated as the first two scenarios. The dredged volume needed to complete half of the project with sand considering the 10% of extra material was 371,500 m^3. As in the first scenario, the effective production rate of the dredge was computed at 920 m^3/hr. The total project duration to complete the first half of this scenario resulted in 24 days. Table 2.2, Figure B.1 – Figure B.2 and Table B.1 - Table B.4 from *Appendix B* shows in more detail the specifications and calculations conducted; *Section 2.3* shows the complete cost estimate for the project.

The second half of the glass/sand mixture scenario consisted in obtaining the crushed glass from the Cay Clean Glass Plant installed in Rincón, Puerto Rico. The price of crushed glass with the same characteristics as the native beach sand ranges from \$74/yd^3 - \$79/yd^3 (*CCG Director, Mr. Rubén González, personal communication, October 17, 2016*). This price has a significant impact on the total project cost compared with the price of solely dredging the material. For this scenario, other costs were also included such as transportation of the material at the site, and a bulldozer to dump the material into the beach. Assuming 300 ft of dozing distance and a D10R-

10U Caterpillar Bulldozer (Caterpillar, Inc., 2011), the estimated dozing production based on Figure 2.5 was estimated as 700 yd^3/hr. This amounts to a total of 58 extra days to complete the nourishment with the additional 371,500 m^3 of crushed glass. Table 2.3 and *Section B.3* from *Appendix B* show in more detail the specifications of the bulldozer selected.

Table 2.3: Bulldozer labor production to complete half of the project with crushed glass, CCG-20-40 (Caterpillar Inc., 2011).

Variables considered	**Scenario 3**
Caterpillar Bulldozer Model:	D10R
Type	10U
Est. Dozing Production	700 Lyd^3/hr
Labor Production	12 hr
Total project size (m^3, yd^3)	**743000, 971844**
Half project size (m^3, yd^3)	**371500, 485922**
Project duration (hrs, days)	690, 58

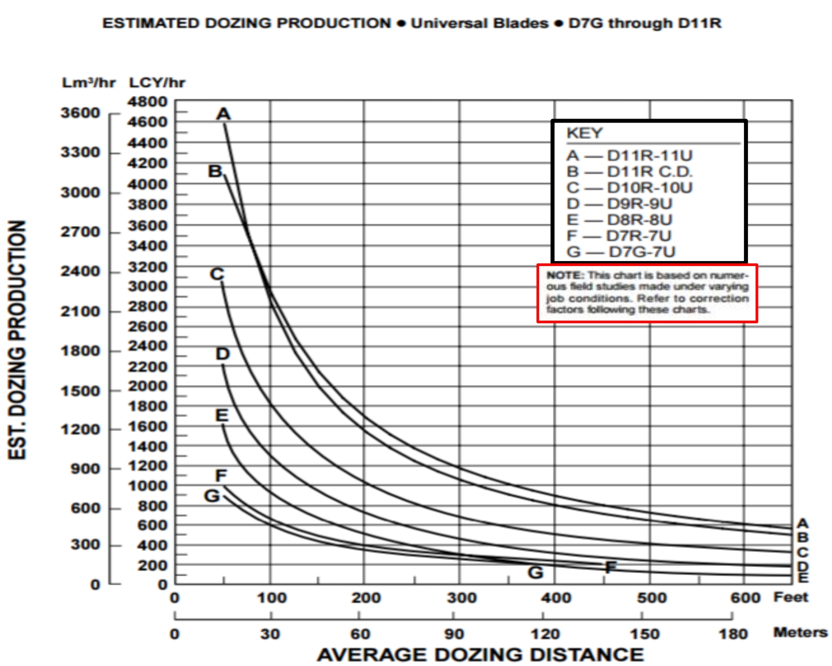

Figure 2.5: Caterpillar Bulldozer Estimating Production (Caterpillar Inc., 2011).

2.3 Cost Estimates

The total cost estimate of a beach nourishment project is determined using a combination of various costs and the total production rate of the dredge (*dredging specialist, Federico García, personal communication, February 22, 2017)*. This analysis was divided into five categories: operational costs, rent and mobilization costs, fuel costs, salaries and fringe, and other costs including taxes, insurances, contingencies, etc. Table 2.4 provides details for each category. Cost estimates were all computed with standard costs based on local costs and hourly rates, the Heavy Construction Manual (RS Means, 2017), and a previous project using the same dredge (USACE, 2011). Also, professional expertise guidance from dredging engineer Federico García and construction management specialist Francisco Rodriguez were considered in the cost estimate analysis.

Table 2.4: Cost category considered in the cost estimate for the first three scenarios.

Operations	Dredger, dozer and pipeline maintenance and depreciation costs; booster costs; replanting, localization and bathymetry costs; lubricating costs; oils, fats, and consumable costs
Mobilization	From Louisiana, USA.
Fuel Cost	Dredge operation and maneuvering
Salary & Fringe	Operators salaries and benefits
Other	Previous studies, general requirements, sales taxes, construction permits, patents, contingency, insurances, CIAPR stamps, performance bonds, and location adjustment factor

Operational costs are highly dependent on the total duration of the project, as it includes activities directly involving the dredging and dumping processes. As such, it depends on the total volume needed for replenishment and the production rate of the dredger (Equation 2.1). Additional assumptions and relevant variables used to estimate costs in this category were taken from *Bray et al., (2009), and* are detailed in Appendix B.

Mobilization costs assume the dredge is being transported from Louisiana, USA, where several of this type of dredges are located. Mobilizing the dredge was estimated to have a cost of $2M (*dredging specialist, Federico García, personal communication, February 22, 2017*). For this beach nourishment project only mobilization costs were considered, as it was assumed that other projects will be using the dredge after this project ends. Other mobilization costs, such as those of heavy equipment and crew members, were not considered for the present cost estimate.

Fuel costs include fuel consumption of the dredge and its operating components (maneuvering). For this cost estimate, the diesel price was computed by averaging the monthly average price of diesel during the months April-August of 2017 (*DACO, 2017*), yielding a value of $2.71/gal. The average fuel consumption per unit time was then estimated as:

$$F_c = TIP\ x\ ACE \quad (2.5)$$

where TIP is the total installed power, taken as 9,395 HP following specifications of dredge; and ACE is the average consumption of engines, assumed as 0.0481 gal/HP-hr after *Wowtschuk (2016*). Fuel prices of the bulldozers were not considered in this category, as they were included in the average operating costs of the dozers.

For the salaries and fringe category, two different crews were considered: the hopper crew at the dredge, and the beach crew at the dump site. The hopper crew operated on a 24-hours per day schedule, while the second crew operated on a 12-hours per day schedule (*USACE, 2011*). Table 2.5 shows the average salary for each crew member, taken from the ranges specified in Glassdoor, Inc., (2017). Fringe benefits were computed at the 60% rate.

Table 2.5: Hopper and beach crew average salary (Glassdoor, Inc., 2017).

Hopper Crew Salary (12 labor hours each)	
Crew	**Average Salary, $**
1 Captain	45
2 Deck Cap	35
2 Eng.	17
4 Deck Hand	11
2 Dredge Operators	32.5
Beach Crew Salary (12 labor hours each)	
Crew	**Average Salary, $**
1 Foreman	27.5
1 Aux Foreman	22
4 Dozer Operators	22
2 Laborer	11
Daily Labor Costs ($/day):	**6,259.00**

Other costs such as general requirements, taxes, overhead and profit, permits, patents, contingencies, insurance, performance bonds, stamps, and adjustment factors are provided in Table 2.6. These costs vary depending on the project's location and specifications (*Wowtschuk, 2016*), and were assessed using the Heavy Construction Manual, RS Means (2017), and personal communications with construction management specialist Francisco Rodriguez, April 24, 2018. Details regarding which parts of the project these percentages are adjudicated to are provided in Section 2.3 and in the detailed cost estimate shown in *Section B.5* from *Appendix B.*

Table 2.6: Percentages adjusted to the project (construction management specialist, Francisco Rodriguez, personal communication, April 24, 2018 and Data, 2017).

General Requirements	10%
General Requirements (Sales Tax)	11%
General Contractors O&P	15%
Construction Permits (Expenses)	2%
Patent	1%
Contingency	5%
Insurances ($8/$1000)	0.008%
CIAPR Stamps ($1/$1000)	0.001%
Performance Bond	1%
Location Adjustment Factor	121.2

2.3.1 Fill with sand dredged within 1 mile from shore

This scenario shows the total cost estimate for the project when the nourishment is performed with sand dredged within 1 mile from shore. Figure 2.6 shows the total cost for each category. The total cost resulted in approximately $10.5 M. The highest cost is represented by the operations, mobilization and other costs, $3.9 M, $2 M and $3.3 M, respectively. In the dredging and beach nourishment industry, it is not uncommon to express the cost of the project in terms of the cost per cubic yard of material mobilized ($\$/yd^3$). As shown above, this varies depending on dredging mobilization, distance and method of transporting the sand to the replenish area (Dobkowski, 2008). For this scenario, the cost of dredging sand within 1 mile from shore is $\$10.86/yd^3$ ($\$14.20/m^3$). *Section B.5* from *Appendix B* shows in detail the calculations for this estimate.

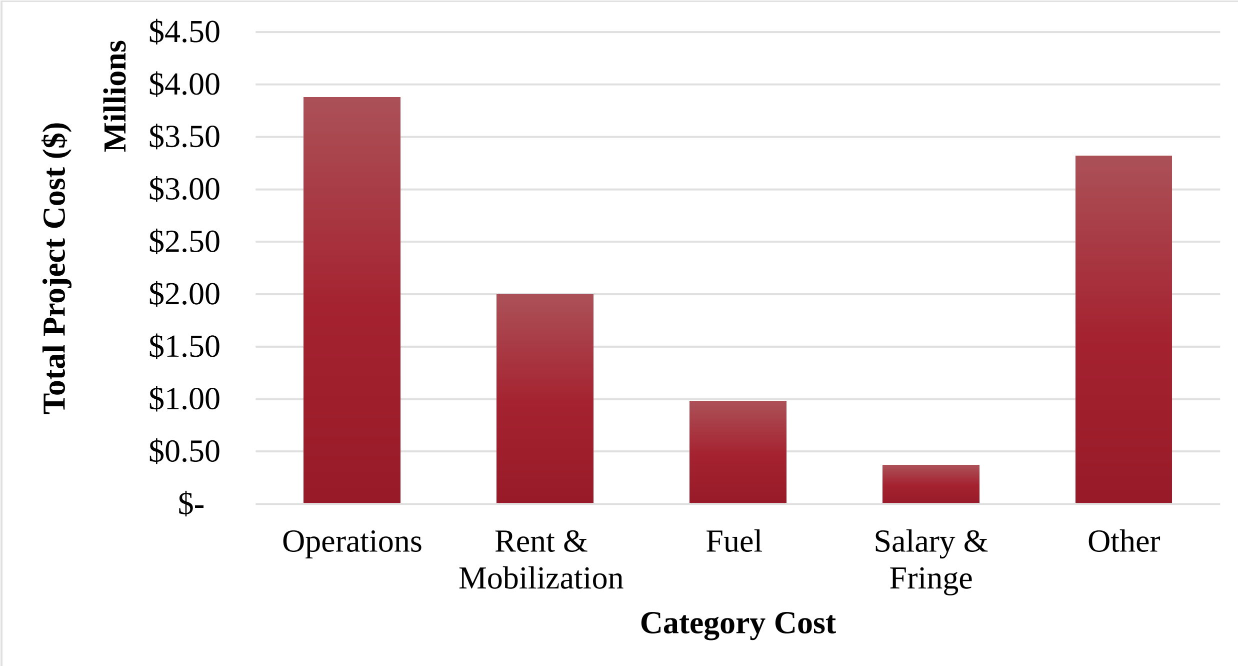

Figure 2.6: Cost estimate for beach fill using sand dredged within 1 mile from shore.

2.3.2 Fill with sand dredged within 4 miles from shore

This scenario shows the total cost estimate for the project when the nourishment is performed with sand dredged within 4 miles from shore. Figure 2.7 shows the total cost for each category. The total cost results in approximately $15.8 M. The highest costs are attributed to operations and other costs, with $6.8 M and $4.8 M, respectively. For this scenario, the cost of nourishing the beach with sand dredged within 4 miles from shore is $16.02/yd^3 ($20.95/m^3). *Section B.5* from *Appendix B* shows in detail the calculations for this estimate.

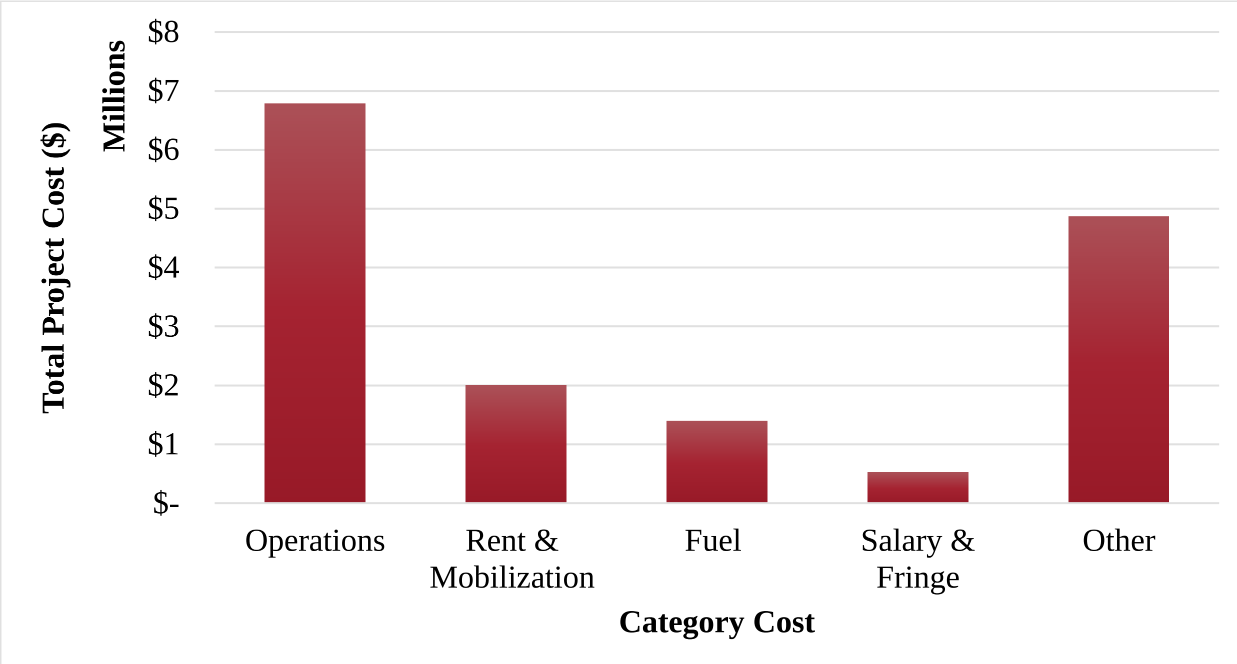

Figure 2.7: Cost estimate for beach fill using sand dredged within 4 miles from shore.

2.3.3 Fill with a 50/50 mixture of crushed glass from the Cay Clean Glass Plant installed in Rincón, Puerto Rico and sand dredged within 1 mile from shore

This scenario shows the total cost estimate for the project when the nourishment is performed with a 50/50 mixture of crushed glass (CCG 20-40) and sand dredged within 1 mile from shore. For the whole scenario, the total cost results in approximately $70.5M. Figure 2.8 shows the total cost for each category. The highest cost corresponds to the glass crushing process, $35.9M. For this scenario, the total cost per cubic yard increases to $72.54/yd^3 ($94.89/m^3). *Section B.5* from *Appendix B* shows in detail the calculations for this estimate.

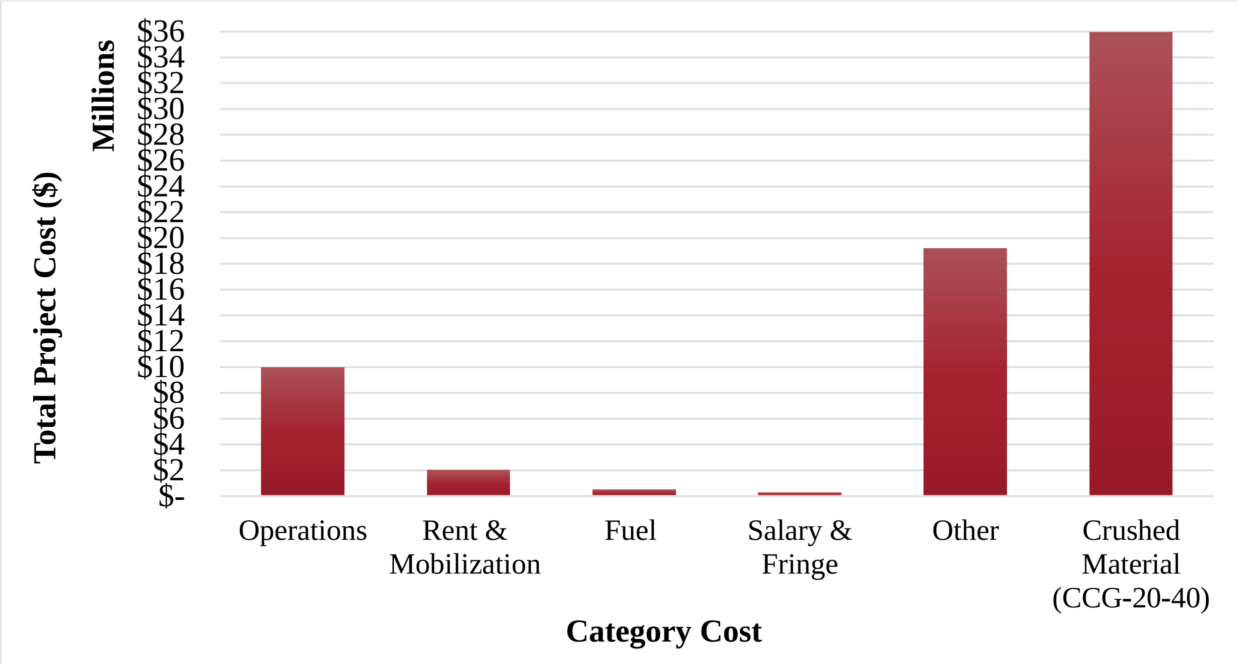

Figure 2.8: Cost estimate for beach fill using a 50/50 mixture of crushed glass and sand dredged within 1 mile from shore.

2.4 Cost Estimates Discussion

A summary of the three cost scenarios can be found in Figure 2.9, while a detailed breakdown of each category is depicted in Table 2.7. From the analysis previously shown, it can be seen that the two main variables affecting the total cost of the project are: 1) distance from the dredging area to the dumping ground (beach site), and 2) the cost of crushing glass. While mobilization costs remain the same for all the scenarios, operation costs carry most of the difference, as they are strongly related to the production rate of the dredge and, consequently, to the distance between the dredging site and the dumping ground (Table 2.2). For example, it can be seen that dredging within 4 miles (Scenario 2) as opposed to dredging within 1 mile (Scenario 1) increases the total costs by roughly $5 M (Table 2.7 and Figure 2.9), $3 M of which are operations costs. Additionally, the project duration is increased by approximately 20 days. For the case of filling the beach with the sand/glass mixture (Scenario 3), total project costs increase dramatically to $70 M, roughly 7 times more expensive than the first scenario. The reason for such a high number lies on the crushed glass, which carries a cost of $35 M to produce, and an increase of roughly $15 M of additional costs in the "Other" category. This analysis suggests that, from a purely economic perspective, using recycled glass as beach nourishment material is not the most feasible alternative.

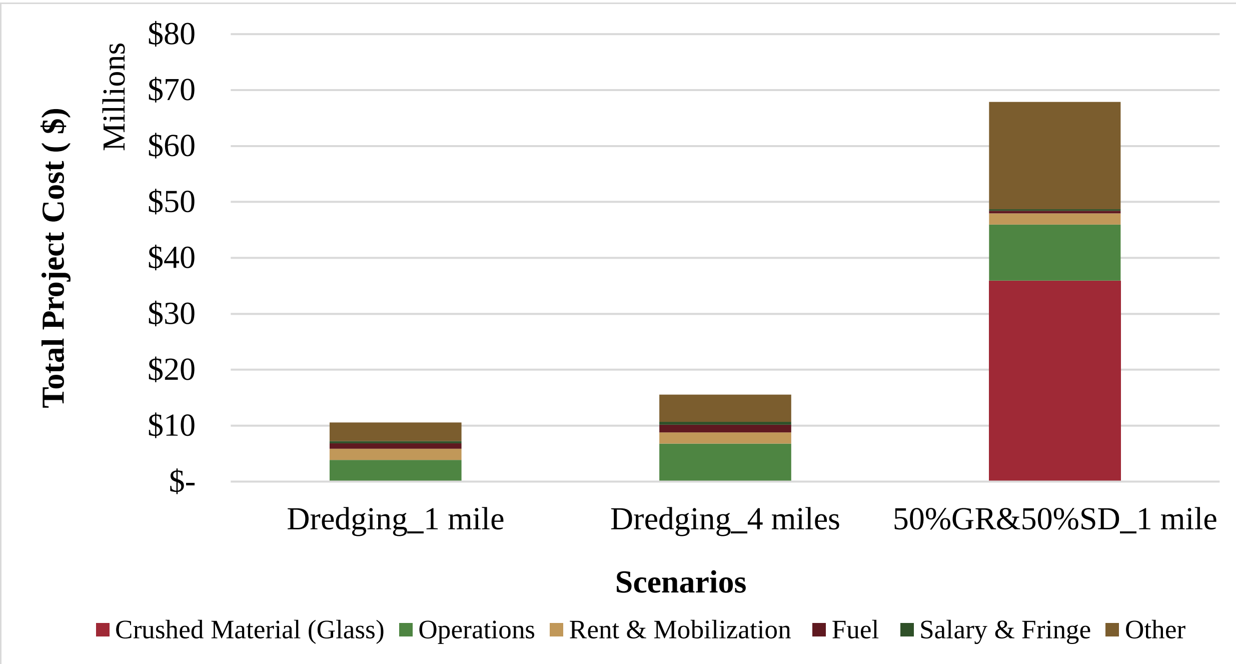

Figure 2.9: Cost estimate comparison for the three scenarios.

Table 2.7: Cost estimates and project duration for scenarios 1, 2, and 3.

Category Costs	**Scenarios**		
	1 (Dredging 1 mile)	**2 (Dredging 4 miles)**	**3 (50%GR&50%SD 1 mile)**
Crushed Glass			$ 35,958,228.00
Operations	$ 3,879,480.71	$ 6,779,624.28	$ 9,982,297.23
Rent & Mobilization	$ 2,000,000.00	$ 2,000,000.00	$ 2,000,000.00
Fuel	$ 981,303.26	$ 1,397,630.38	$ 490,681.79
Salary & Fringe	$ 370,026.03	$ 527,013.05	$ 267,663.39
Other	$ 3,318,620.91	$ 4,866,854.56	$ 19,194,698.35
Total	**$ 10,549,730.90**	**$ 15,571,422.27**	**$ 70,501,461.48**
Project Duration (days)	**48**	**68**	**24**
Cost per yd^3	$ 10.86	$ 16.02	$ 72.54

In light of the potential increase in beach fill volume resulting from the significant erosion caused by the 2017 hurricane season, a sensitivity analysis for increased project sizes was performed (Table 2.8, Table 2.9 and Figure 2.10). The analysis suggests that the behavior previously discussed remains, i.e. project costs increase with increased distance between the dredging and filling area, as well as with an increased use of crushed glass. Comparisons between the original project size (743K m^3) and the other project sizes suggests an increment in costs roughly proportional to the increment in project size. However, due to the fixed costs of mobilization, permits and others, the cost per cubic yard decreases as project size increases (Table 2.9 and Figure 2.11), with Scenario 1 at 5 M m^3 yielding the best rate ($7.68/$yd^3$).

Table 2.8: Total cost comparison for different project sizes.

Project Size, m^3 (yd^3)	**Scenarios**		
	1 (Dredging 1 mile)	**2 (Dredging 4 miles)**	**3 (50%GR&50%SD 1 mile)**
743K (972K)	$ 10,549,730.90	$ 15,571,422.27	$ 70,501,461.48
1M (1.3M)	$ 12,947,020.82	$ 19,705,116.89	$ 93,638,513.44
2M (2.6M)	$ 22,273,339.63	$ 35,789,531.79	$ 183,656,324.88
5M (6.5M)	$ 50,252,296.07	$ 84,042,776.46	$ 453,709,759.20

Table 2.9: Cost per cubic yard for different project sizes.

Project Size, m^3 (yd^3)	**Estimated Cost ($/$yd^3$)**		
	1 (Dredging 1 mile)	**2 (Dredging 4 miles)**	**3 (50%GR&50%SD 1 mile)**
743K (972K)	$ 10.86	$ 16.02	$ 72.54
1M (1.3M)	$ 9.90	$ 15.07	$ 71.59
2M (2.6M)	$ 8.51	$ 13.68	$ 70.21
5M (6.5M)	$ 7.68	$ 12.85	$ 69.37

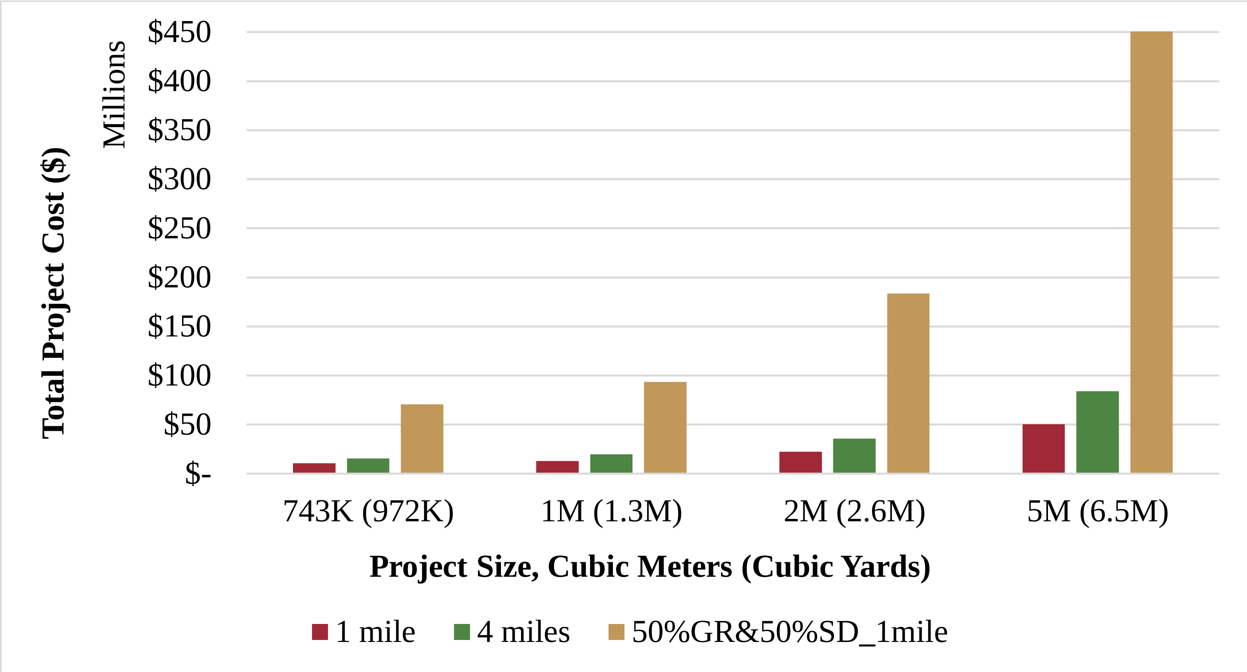

Figure 2.10: Total cost comparison for different project sizes.

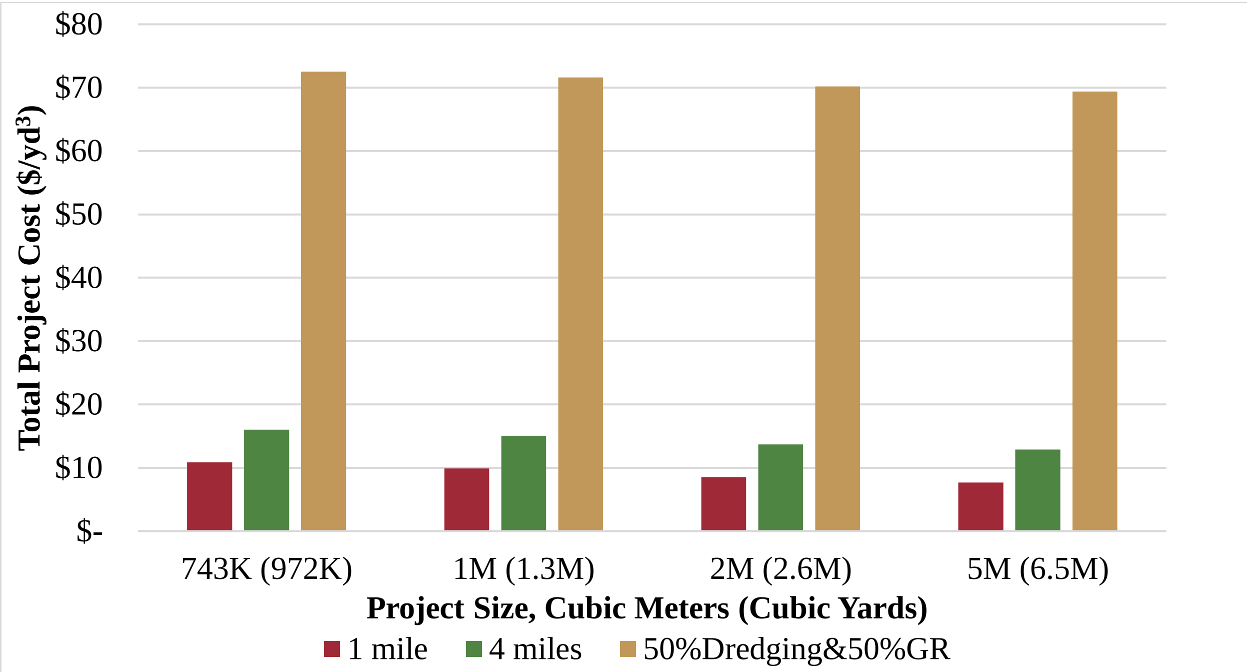

Figure 2.11: Cost per cubic yard for different project sizes

Given the uncertainty regarding the amount of sand locally available at the Bajo Blanco sand shoal and other potential borrow sites, additional cost estimates were computed for the 743k m^3 scenario assuming distances between the dredging site and the dumping site of 10 and 20 miles. It was found that the project cost is almost doubled and tripled when the distance between the dredging site and the dumping site is increased from 1 mile to 10 and 20 miles, respectively (Figure 2.12). Please note that the same hydraulic conditions were assumed in this extrapolation, and that further analysis is required in order to conclude the best engineering practices for a project with such long distances. Additionally, cost estimates for the same scenario were computed for the distance between the dredging site and the end of the dumping site (2.5 miles); it was found that the project cost increased approximately $2 M (Figure 2.12).

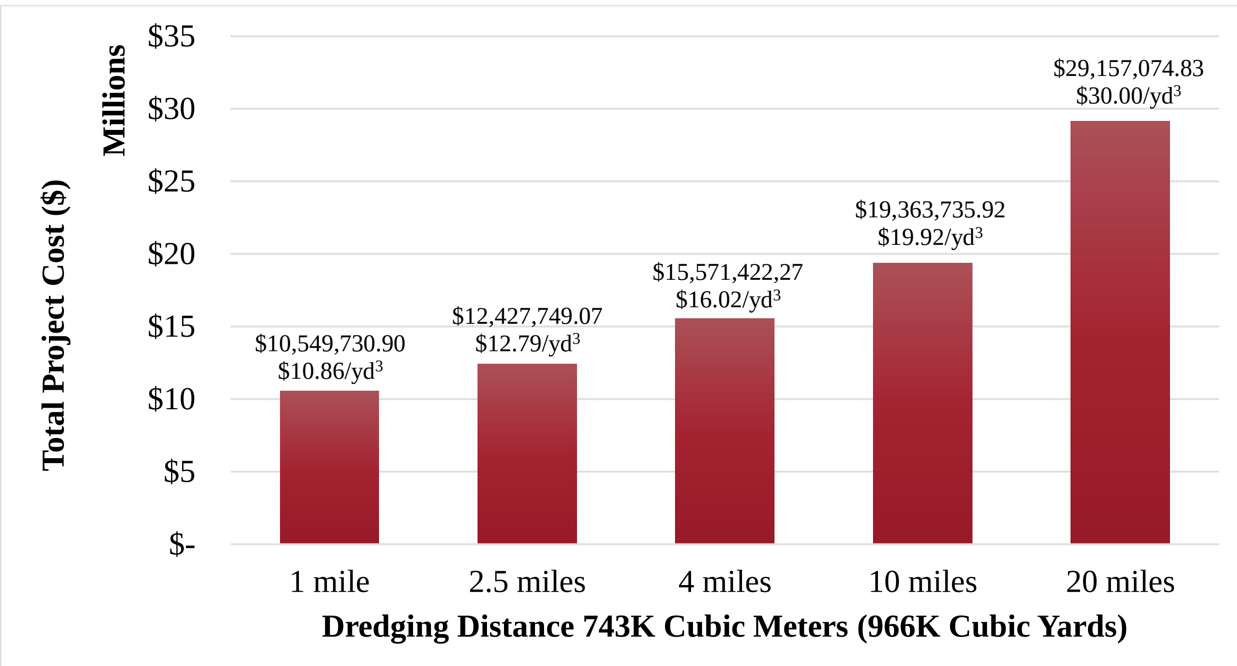

Figure 2.12: Total project cost comparison for a 743K m3 project size at different dredging distances.

Even though a beach nourishment project has never taken place in Puerto Rico, this cost analysis was performed to the best of our knowledge, following guidance from dredging experts, project managers and available literature. As shown above, the total cost estimate for this beach nourishment project could vary depending on the size of the project, location of the sand source, type of dredger used, and mobilization/demobilization cost. Moreover, the cost of crushing glass significantly increases project costs by almost one order of magnitude. It is worth noting that after 40 years, Cay Clean Glass Plant may become a public-private company in Puerto Rico, which could result in a reduction of municipal taxes (*CCG Director, Mr. Rubén González, personal communication, April 27, 2018),* thereby reducing the cost of crushing glass. However, a possible increase in price may also take place as a result of inflation and/or increased of energy costs.

2.5 Summary

This chapter describes the economic feasibility analysis of using recycled glass as beach nourishment material to mitigate erosion problems in Rincón, PR. Three scenarios were considered: 1) using sand dredged within 1 mile from the beach site; 2) using sand dredged within 4 miles from the beach site; and 3) using a 50/50 mixture of crushed glass and sand dredged within 1 mile from the beach site. The main results are as follows:

- Project costs increase with increased distance between the dredging and filling area, as well as with an increased use of crushed glass.
- Project costs increment is roughly proportional to the increment in project size. However, the cost per cubic yard ($\$/yd^3$) decreases as project size increases.
- Using recycled glass as beach nourishment material is not the most economically feasible alternative.

CHAPTER 3. SOCIAL FEASIBILITY

The social feasibility analysis is of utmost importance for this type of project as it directly affects the public. For the social assessment, two types of surveys were conducted. The first survey was focused on recycling in order to evaluate the current recycling practices in the area. The second survey considered the social perception regarding the beach nourishment portion of the project. These surveys were carried out at various activities with the nearby community. Some of these activities included wave flume demonstrations, posters presentations, and other forums that helped inform the community about this study and its importance.

3.1 Recycling Practices in PR

Surveys about current recycling practices were conducted to evaluate the recycling potential in the study area. To evaluate the possibility of implementing glass recycling in the area in order to use this material as a beach nourishment alternative, questions regarding recycling items, frequency and volume were made. The survey was divided in two parts; the first was focused on recycling practices at the household level; while the second part was focused on bars and restaurants near the study area in Rincón, Puerto Rico (see section 3.2). Surveys focused on household recycling practices were made to seventy legal age individuals of different municipalities throughout the island. The survey included a series of approximately nine questions. Questions were slightly different for individuals that recycle versus those who do not, as presented in Figure 3.1. *Appendix C* – Table C.1 and Table C.2 shows in detail each one of the questions along with their response.

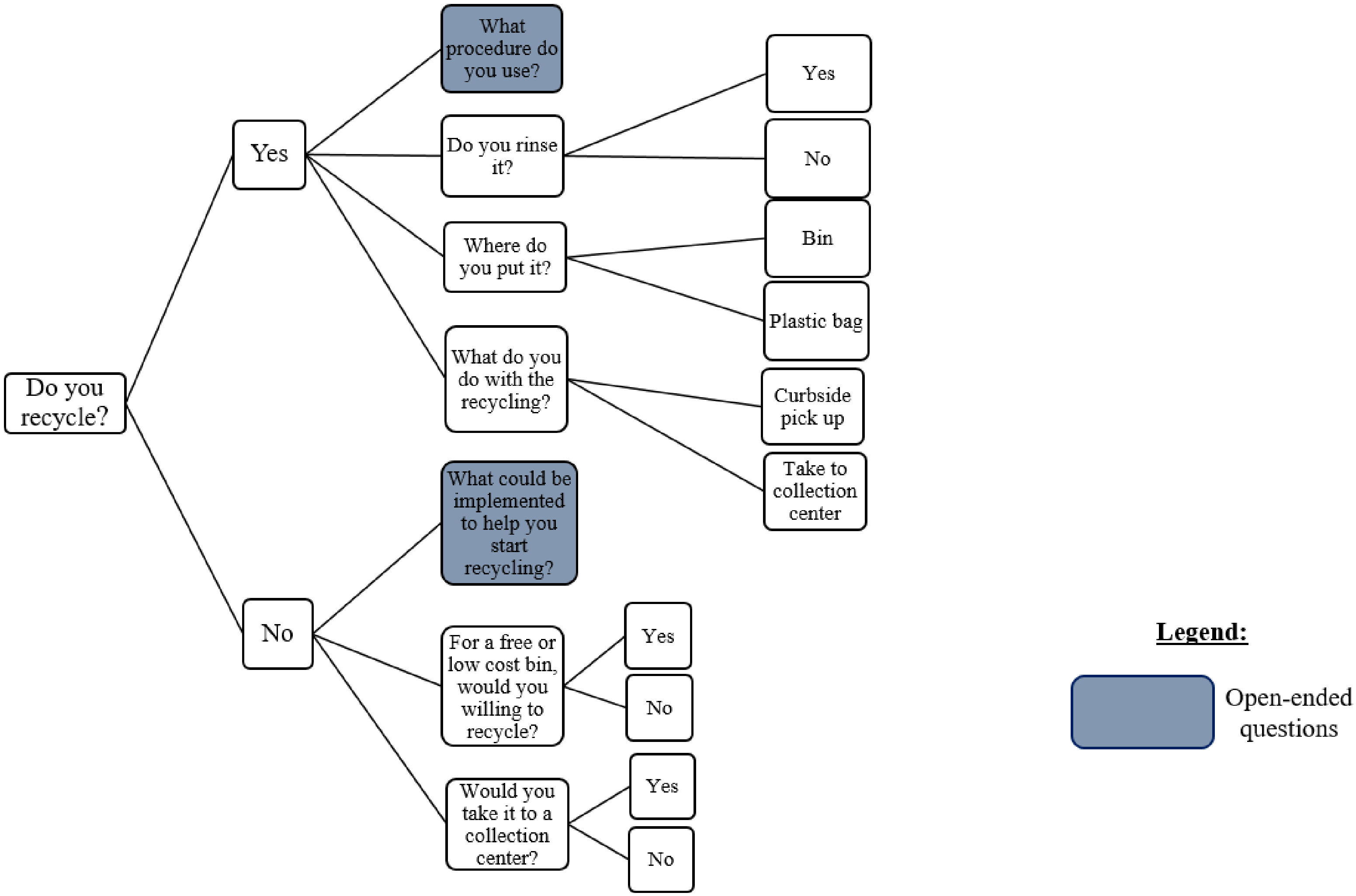

Figure 3.1: Recycling survey questions. Three Decision Diagram shows the different type of questions for individuals that recycle vs. those who do not.

This survey was conducted at *Cinco Días con Nuestra Tierra*, an annual agricultural fair, carried out at the facilities of the University of Puerto Rico, Mayagüez Campus on March 16, 2017. Each year this fair includes educational demonstrations and workshops; students from campus, neighbors and individuals from all parts of the island attend. The process of choosing individuals for the survey was aleatory, person-to-person; after answering the surveys, individuals were given brochures with information about the investigation (*Appendix C*: Figure C.1-Figure C.2). North and West region of Puerto Rico represent the areas with the greatest number of individuals who answered the survey (Figure 3.2).

In general, the survey shows that 63% of the individuals recycle while the other 37% does not. Specifically, in the East region it was found that all individual interviewed engage in recycling practices (Figure 3.2). The results obtained also shows that 52% of the people that recycle are not provided with a container to place their recycling; with the North and West region reporting the most and least amount of individuals provided with a recycling bin by their township, respectively (Figure 3.3). Of those surveyed, 61% reported that their municipality collects the recycling material, 30% delivered the materials to a collection center, and the other 9% engaged in re-using practices; here the North and West region represents the highest number of individuals whose township collects the material at their homes (Figure 3.4).

The survey also showed that 81% of individuals would take the recycled material to a collection center if necessary (Figure 3.5). Even though all individuals from the East region reported to engage in recycling practices, they were not willing to take their recycling to a collection center. The North and West regions show the highest number of individuals willing to take their recycled materials to nearby collection centers.

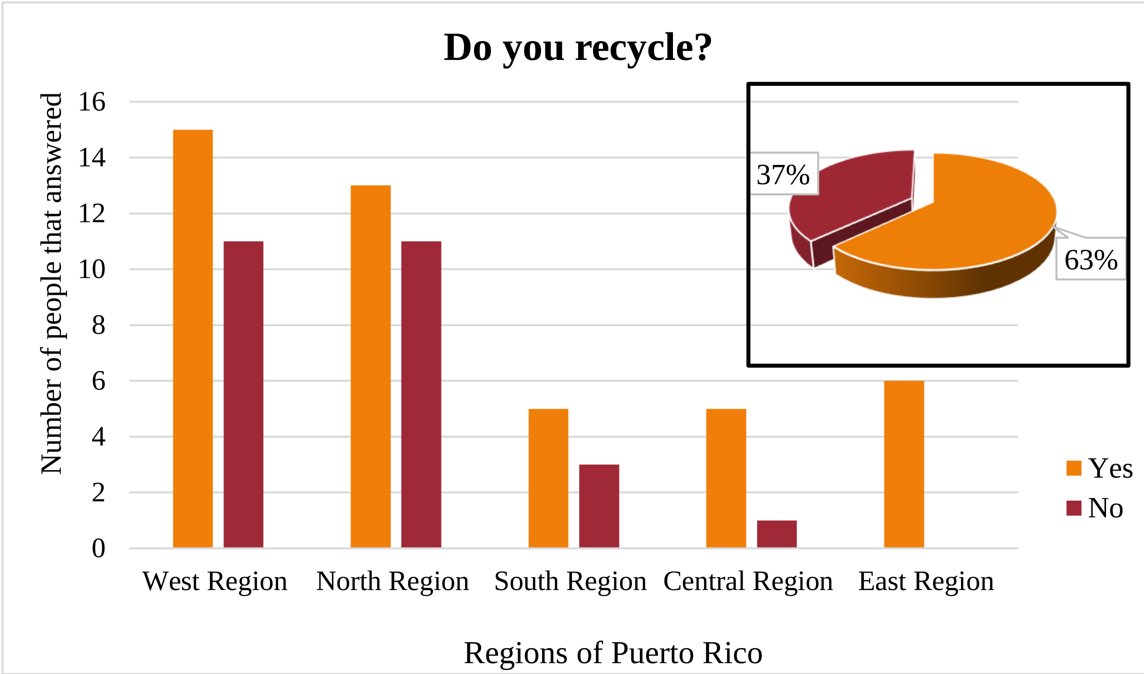

Figure 3.2: Individuals that answer the recycling survey. Pie chart shows the percent of individuals that recycled vs. those who do not recycle; while the bar graph shows the distribution by region (N=70 individuals interviewed).

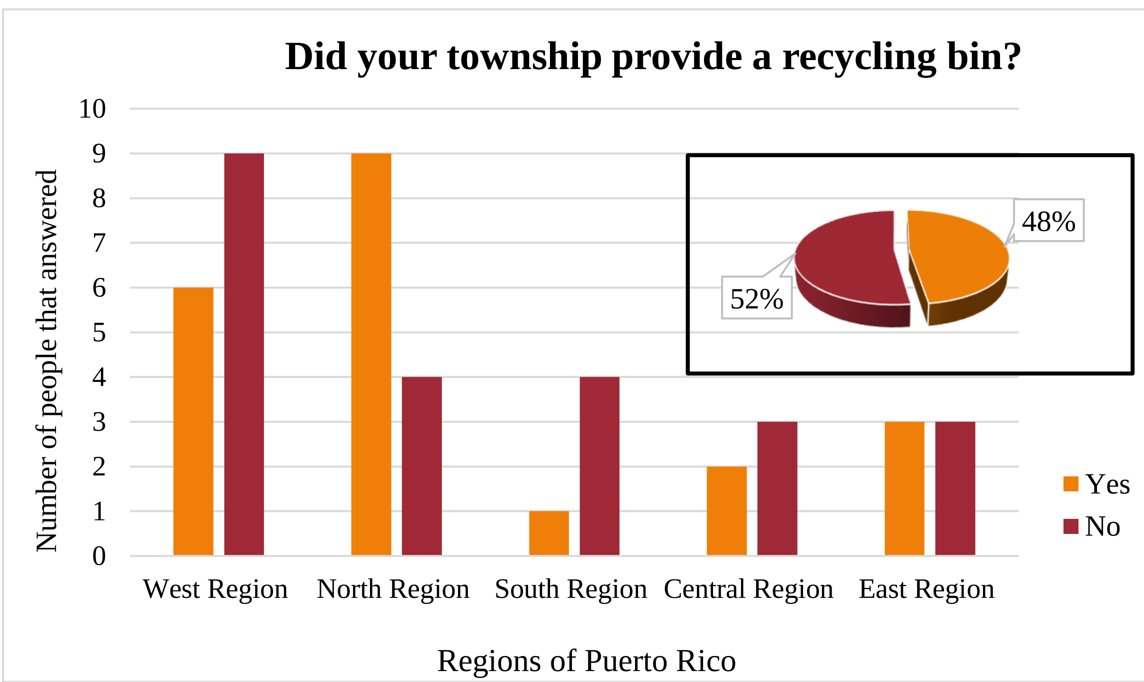

Figure 3.3: Individuals whose township provided a recycling bin. Pie chart shows the percent of individuals whose township provided the recycling bin vs. those who were not provided with one; while the bar graph shows the distribution by region (N=70 individuals interviewed).

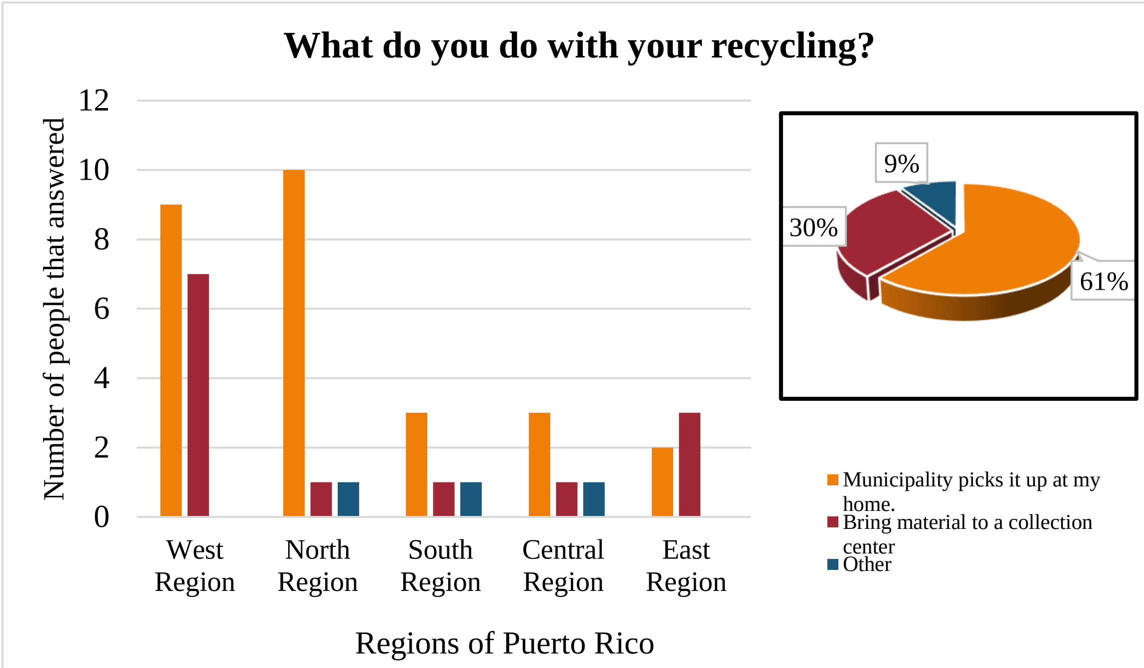

Figure 3.4: Curbside pickup vs. dropping off at collection center. Pie chart shows the percent of individuals whose township picks the recycling material vs. those who take the recycling material to a collection center; while the bar graphs show the distribution by region (N=70 individuals interviewed).

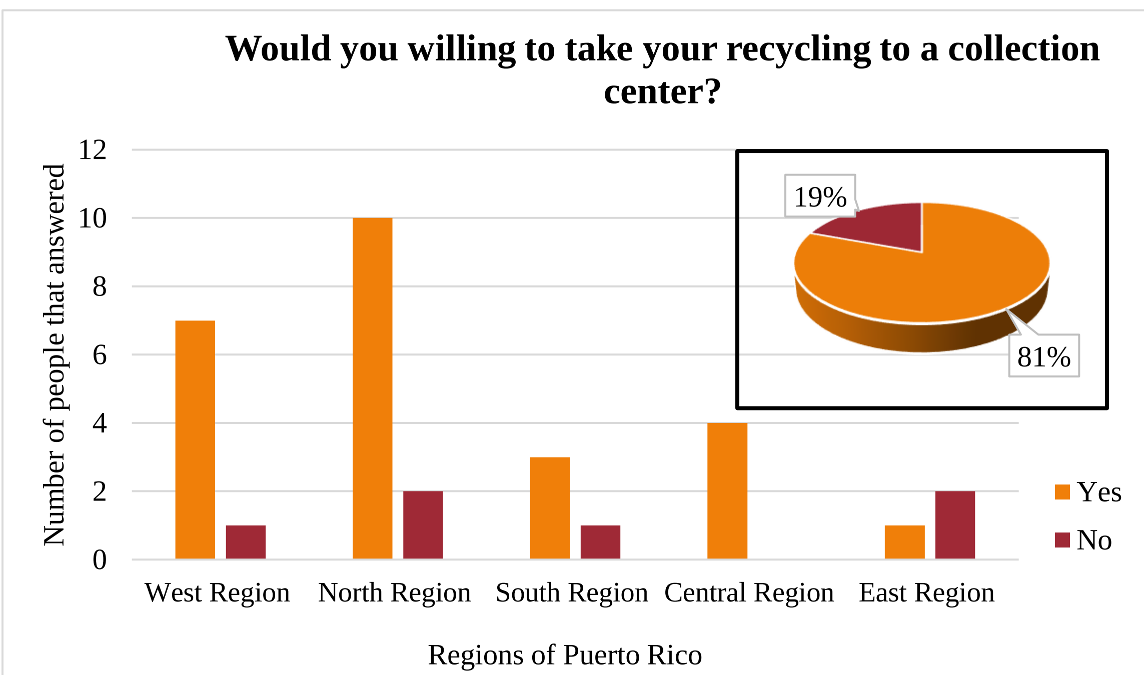

Figure 3.5: Individuals willing to take their recycling to a collection center. Pie chart shows the percent of individuals willing to take their recycling to the collection center vs. those who are not; while the bar graphs show the distribution by region (N=70 individuals interviewed).

Our survey also assessed some of the knowledge and current recycling practices of each individual. Figure 3.6 shows that 75% of those surveyed clean their recycling. Furthermore, during the interview process, the majority of those surveyed expressed that plastic was the most common, if not the only material they recycled (*Appendix C*-Table C.1). Additionally, the way in which the individuals dispose of recycling was also considered. Figure 3.7 shows that 57% of individuals place their recycling in bins provided by the municipality or purchased by themselves; while the remaining 43% uses plastic bags. This action suggests that many individuals who do not have a recycling bin are still, willing to recycle; with the North and West regions having the highest number of individuals placing their recycling in plastic bags. *Section C.2* from *Appendix C* shows these results in more detail.

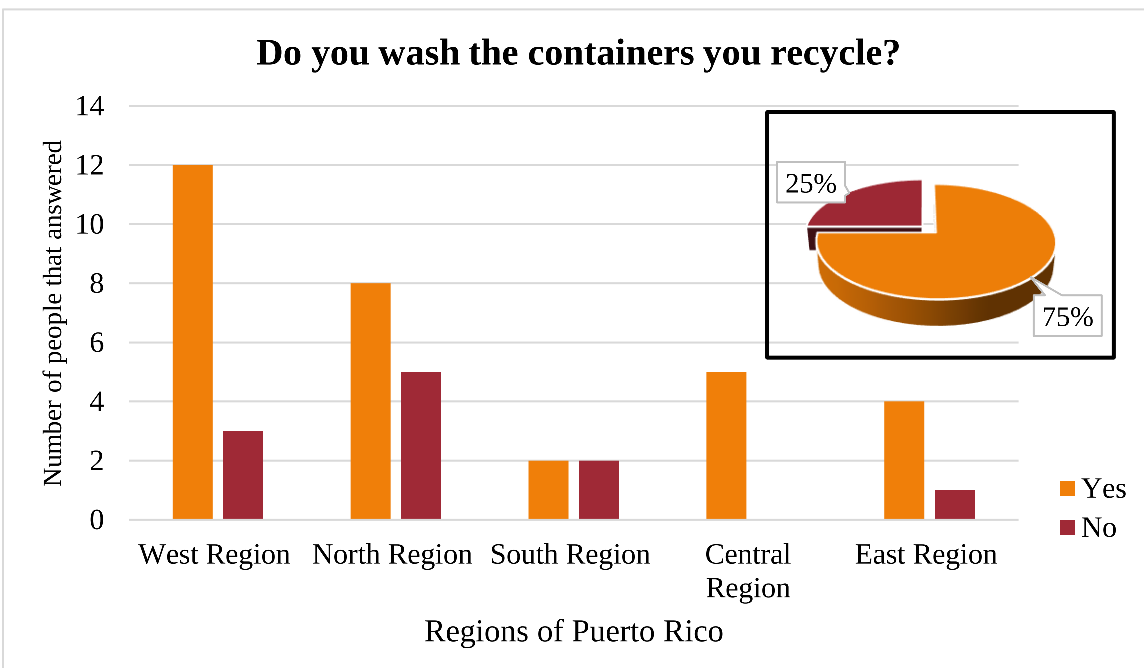

Figure 3.6: Individuals washing their recycling before disposing. Pie chart shows the percent of individuals that wash the recycling vs. those who do not; while the bar graphs show the distribution by region (N=70 individuals interviewed).

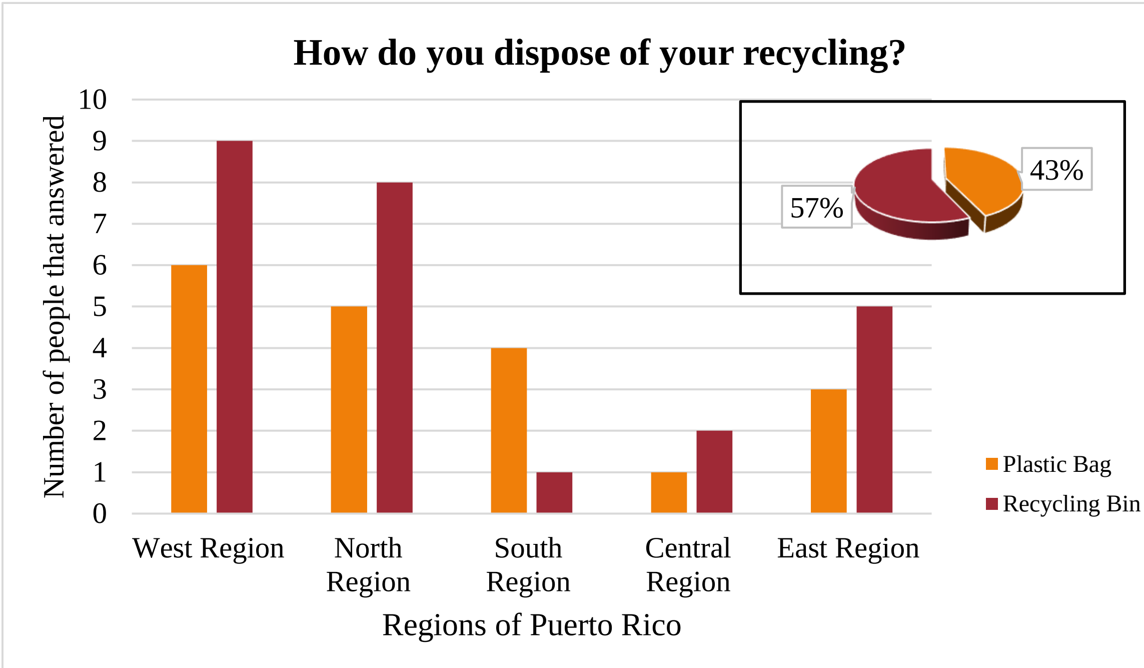

Figure 3.7: Individuals disposing of their recycling in plastic bags or bins. Pie chart shows the percent of individuals using plastic bags vs. those using recycling bins; while the bar graphs show the distribution by region (N=70 individuals interviewed).

A different set of questions was developed for individuals that did not recycle (*Appendix C* - Table C.2). The idea was to better understand what type of actions could be implemented in order to promote recycling within this population. From the surveyed individuals, 54% overwhelmingly agree that more recycling bins are needed to promote recycling (Figure 3.8). In fact, 100% of the participants agreed that if the township provides a recycling bin for free or at a low cost they would be willing to recycle (*Appendix C* - Table C.2). Moreover, 65% of the individuals agreed to transport their recycling to a collection center (Figure 3.9). This suggests that an active role of the township is necessary for further implementing a recycling culture in the island.

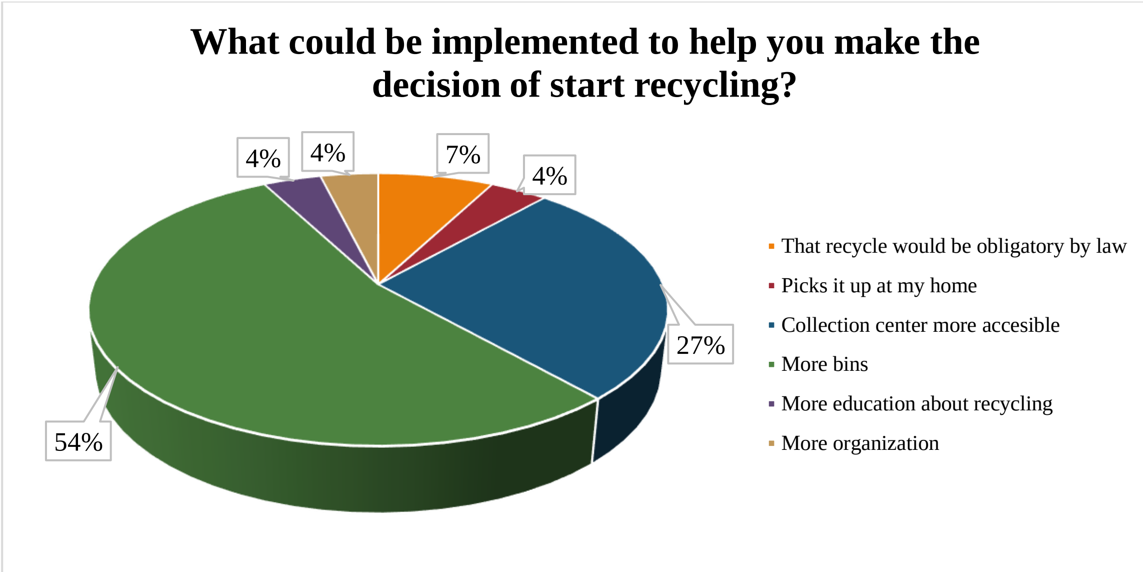

Figure 3.8: State or municipal actions that could be implemented in order to increase the number of households engaging in recycling practices (N=70 individuals interviewed).

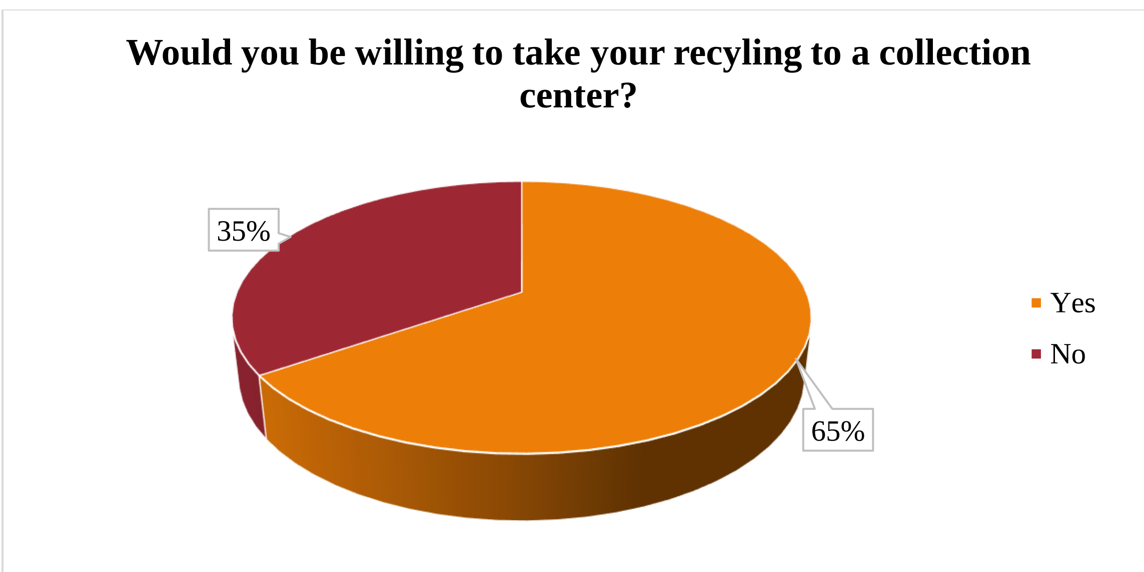

Figure 3.9: Individuals willing to take their recycling to a collection center. Pie chart shows the percent of individuals willing to take their recycling to the collection center vs. those who's not (N=70 individuals interviewed).

3.2 Recycling Practices in Rincón's Bars and Restaurants

The second part of the recycling survey was conducted near the study area in Rincón, Puerto Rico. The same type of questions as S*ection 3.1*, were made for this part of the assessment with a total of nine bars and restaurants. Surveys were conducted to the owners and managers of the bars and restaurants in two neighborhoods: *Barrio Puntas* and *Barrio Pueblo*. The process of the interviews was conducted with the help of Steve Tamar (vice-chair *Surfrider Foundation Rincón*), interviews were made in person as described in *Section 3.1*. Also, brochures with information about the investigation were provided after the interview (*Appendix C*: Figure C.1 – Figure C.2). From the bars and restaurants interviewed, 89% responded that they carried out the practice of recycling in their businesses (Figure 3.10a). Materials currently being recycled include aluminum, plastic and cardboard. However, owners and managers suggested that the municipality should improve the collection of material, since only 50% responded that the pick-up program works well (Figure 3.10b).

Business owners/managers indicated the difficulty of carrying out recycling due to limited space. Most of the surveyed showed an interest and concern with this practice; suggesting that the township must provide greater accessibility to collection centers or curbside pick-up. Fifty percent of those interviewed reported that they would be willing to take their recycling to a collection center, Figure 3.10c; *Appendix C* - Table C.3 shows the responses obtained in greater details. These results underline the importance of improving recycling practices and policy in the island. Moreover, it stresses the importance of improving accessibility to recycling infrastructure at bars and restaurants given that these produce much more material than a common household.

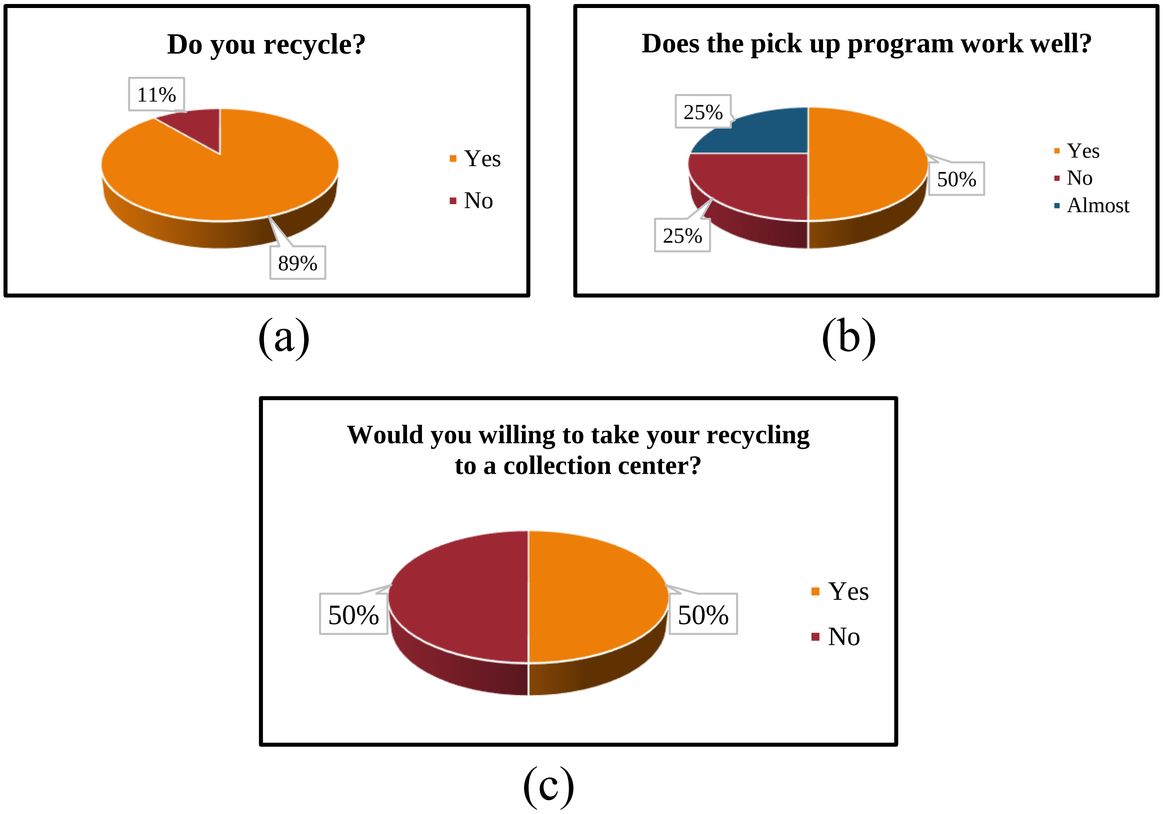

Figure 3.10: Bars and restaurants that answer the recycling survey in Rincón, Puerto Rico. (a) Percent of businesses that recycled vs. those that do not recycle. (b) Opinions regarding how they pick-up program works. (c) Willingness to take the recycling to a collection center (N=9 owners/managers interviewed).

3.3 Public Perception Survey

Surveys regarding community approval of using glass as beach nourishment material were also conducted for this project. A series of approximately five questions were made; questions about how interesting the project was and how appealing this new technique were included; *Appendix C* – Table C.4 presents in more detail the questions with the results obtained. With a total of 72 legal age individuals interviewed, the survey process involved the presentation of the project in different activities. The scientific exhibition as part of an Open House at the facilities of the University of Puerto Rico, Mayagüez Campus in March 2017 was the first activity where this perception survey was carried out. Wave flume demonstrations, brochures, posters demonstrations and glass samples were part of the presentation conducted to inform the community of the project approach (Figure 3.11). After given a short description of the project, individuals were interviewed in person; students, professors and community members participated in the survey.

Figure 3.11: Open house activity and public perception survey conducted at the University of Puerto Rico, Mayaguez Campus on March 2017.

The second activity where the social perception survey took place was in Rincón, Puerto Rico at *Reserva Marina Tres Palmas* festival in May 2017. Here, a video with the wave flume demonstration was shown, as well as a poster and glass sample. The survey was also conducted in *Pensemos en un Rincón más resiliente a eventos naturales costeros* conference in December 2017 at Villa Confresí, Rincón. This conference was a local forum to discuss the effects of Hurricane María in the coast of Rincón along with potential solutions for beach erosion in the area. A total of ten individuals including professionals, locals and students were interviewed after given a description of the project.

In general, this public perception survey shows that individuals are interested and motivated with this initiative. Fifty-four percent of the individuals surveyed fully approved of the project, while 43% somewhat approved and the other 3% do not approved (Figure 3.12). The main concern about the project was the environmental damages that this new method could represent; however, none of the individuals disapprove of the project. When crushed glass samples, individuals found that this material was very similar to Rincón's native sand (*Appendix C* – Table C.4). Those surveyed expressed that the texture and color of crushed glass are very similar to those of sand and that they would not have been able to notice a difference. Moreover, 94% of the individuals interviewed agreed that they will visit a crushed glass beach (*Appendix C* – Table C.4).

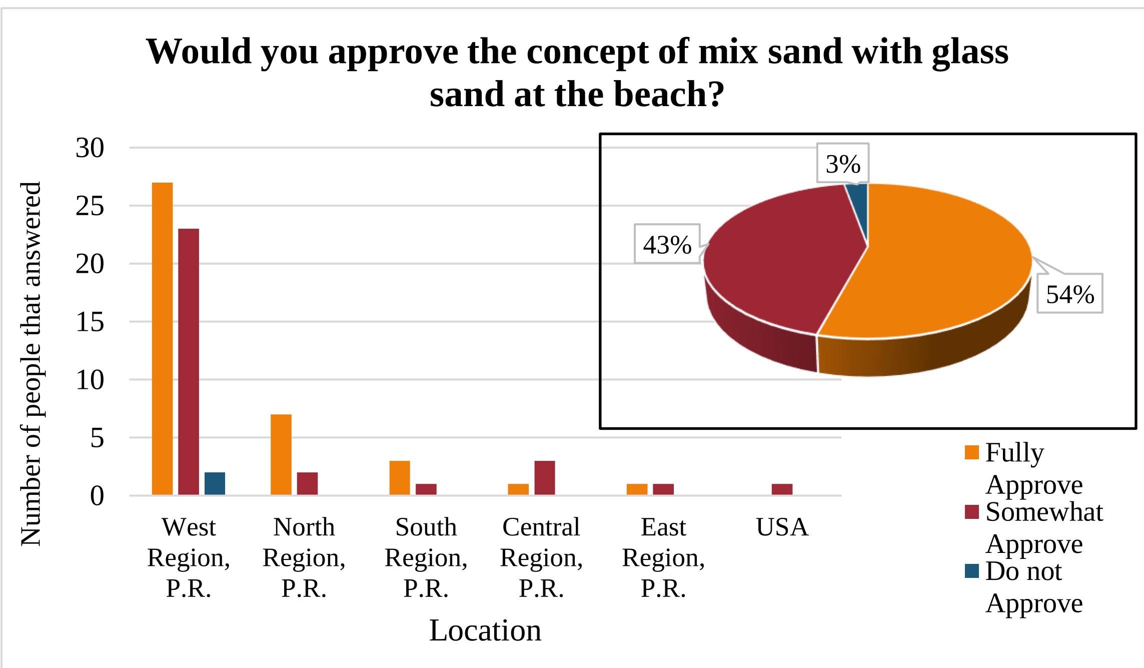

Figure 3.12: Individual perception about the beach nourishment project. Pie charts shows the percent of individuals that fully approve the project vs. those that not; while bar graph show the distribution by region in Puerto Rico and USA (N= 72 individuals interviewed).

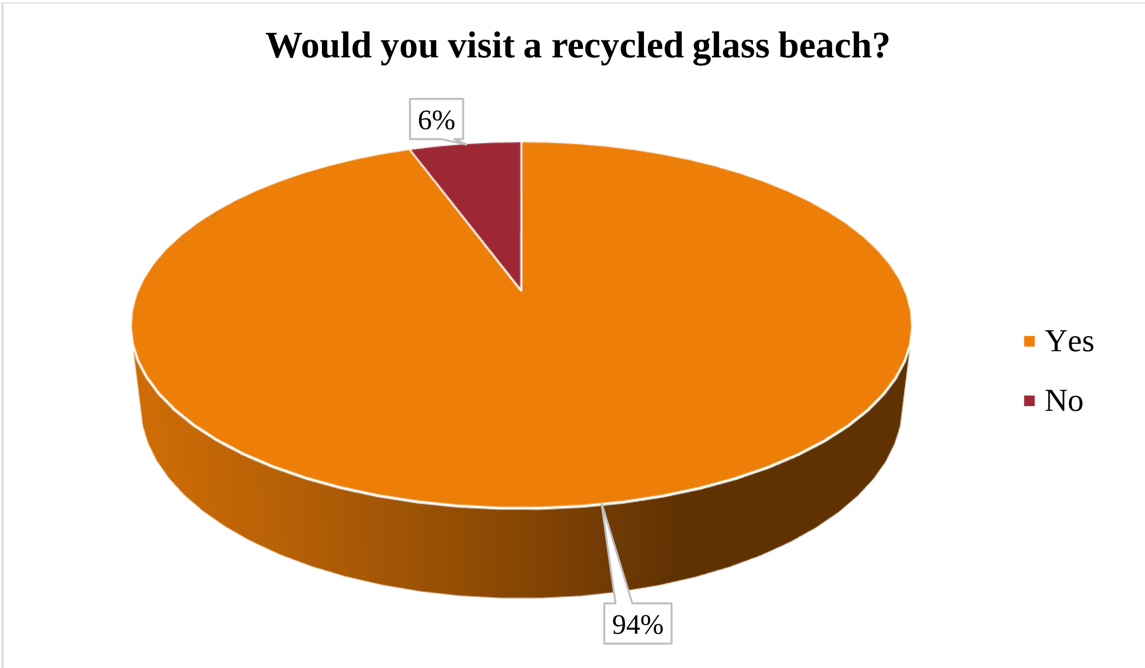

Figure 3.13: Individuals willing to visit a beach with a mixture of sand and crushed glass (N=72 individuals interviewed).

3.4 Social Feasibility Discussion

The results of the first survey convey that 63% of individuals are involved in recycling practices. Assuming those individuals will also be willing to recycle glass, they will contribute to saving landfill space around Puerto Rico. To estimate the percent reduction of landfill space, it was considered that one person disposes 1.77 kg of trash per day (ADS, 2014), representing 646 kg/yr. Assuming 3% of this is glass (*Section 1.2)*, then one person disposes of approximately 19.4 kg of glass per year. Given that one ton of glass occupies roughly 1.4 yd^3 of landfill space (847 kg/m^3, *Edge & Magoon, 2002*) then each person can potentially save 0.0229 m^3 of landfill volume per year. Extrapolating to the current Puerto Rican population, roughly 50k m^3 of landfill space could be saved every year, if 63% of the population embarked in glass recycling. To put this into perspective, 50k m^3 is almost two-fifths of the total volume of El Cuartel de Ballajá historic building in Old San Juan (*Lombera, 2013*), therefore if 63% of the Puerto Rican population practice glass recycling, a landfill volume close to El Cuartel de Ballajá building would be saved every 2.5 years. Please note that the 63% assumption is an extrapolation to the entire island, and that the survey results are biased towards the North and West regions where most of the individuals surveyed reside (Figure 3.2).

3.5 Summary

This chapter involves the social feasibility aspect of the project. Two surveys were conducted: the first assessed recycling practices of the general public and owners/managers of Rincón's bars and restaurants. The second survey considered the social perception regarding using crushed glass as beach nourishment material. The main results are as follows:

- The recycling survey shows that 63% of the individuals surveyed engage in recycling practices, with the North and West regions reporting the highest number of surveyed individuals. As a rough approximation it was estimated that glass recycling in the island could save up to 50K m^3/yr of landfill space.
- The most common suggestions regarding implementation of practices and policy to promote recycling within the non-recycling population included: more availability of recycling bins, and more accessible collection centers.
- Surveys at Rincón's bars and restaurants indicated that 89% of owners/managers carried out recycling practices in their businesses. However, concerns about the difficulty of limited space and poor curbside collection practices were reported.
- The public perception survey shows that 54% of the individuals fully approve of the project while 43% somewhat approve. However, 94% of the individuals interviewed agreed that they will visit a crushed glass beach.

CHAPTER 4. LIFE CYCLE ASSESSMENT

4.1 Introduction

Glass recycling and reusing can reduce the carbon footprint of manufacturing processes involving glass. Studies have shown that achieving a 10% of glass recycling could represent a reduction in carbon emissions of 5% and energy savings of 3% (*Owen Illinois, 2010*). Furthermore, 1 kg of recycled glass cullets can replace up to 1.2 kg of the raw materials used in the fabrication of glass bottles. In order to evaluate some of the environmental implications of dumping used glass in Rincón's coastline, as opposed to taking it to the landfill, this part of the project consisted in performing a life cycle assessment of glass bottles.

A Life Cycle Assessment (LCA) is an analytical tool that measures the environmental consumption and emissions associated with a product process from the raw materials through the final disposition (*Hogan, L et al., 1997*). This planning tool is used by environmental professionals in three separated elements: life cycle inventory, life cycle impact assessment, and life cycle improvement assessment. LCA is often use by industries for planning environmental strategies and legislation, marketing and comparisons of different alternative products, and product development and improvement (*GaBi, 2018*). In the conduction of a LCA, the International Organization for Standardization (ISO) defines the subdivisions of a life cycle assessment to be performed in four stages: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment and (4) interpretation (ISO, 2006).

The first phase defines all general reasons and decisions for the study. This includes the analysis of the general boundary system: the most important part to determine is whether the system will consider the entire life cycle (cradle to grave) or part of the system's life cycle (cradle to gate, gate to gate, or gate to grave). The second phase consist on a step-by-step modelling of all system processes to calculate the life cycle inventory. The third phase evaluates the significant amount of environmental impact of the product in the system; while the last phase includes the interpretation of the environmental impact data.

4.2 Methodology

To perform the LCA of glass bottles we used a streamlining method consisting of two alternatives: (1) taking the glass bottles to the landfill, as currently done in Puerto Rico; and (2) crushing the glass bottles for subsequent use as beach nourishment material. The analysis was performed using GaBi (www.thinkstep.com), a modelling and reporting software used by professionals and industries to conduct LCA on their products. For this LCA, the system boundary was considered from gate to grave: taking the used glass bottles as the *gate*, and the two above-mentioned alternatives as the *grave*. Each of the alternatives provides for estimates of carbon emissions, human toxicity, among others.

GaBi software evaluates the potential environmental impact using "plans" representing the system boundary where processes take place. The software includes default processes such as disposal and transportation, while other processes can be created depending of the system boundary. For this analysis, two plans were created in order to analyze the two alternatives. As previously discussed, the system boundary for this LCA was considered from gate to grave, and its location specified as the United States.

The first process in the system boundary was taken as the main product, i.e. the glass bottles. Here, 2.5 billion of glass bottles (524k tons, 371.5k m^3) were considered following the 50/50 sand/glass mixture discussed in Section 2.2.3. The second process considered was the transportation of the main product to the final destination. A 12-14 tons gross weight truck powered by Diesel fuel was assumed. Parameters such as CO_2 emissions, utilization, among others were considered as the software's default. For the transportation distance, the software also provided 10 km as the default parameter.

The final step of the system boundary (grave) was different for each scenario. For the first scenario a municipal solid waste landfill was considered; while a crushing glass plant (CCG Plant) was considered for the second scenario. The latter was manually created in the software with input parameters being the total amount of bottles to process and the associated power required for crushing (2 kWh per ton of glass; Lassesson, 2008). The output was specified as glass waste (external cullets), approximately 524k tons.

4.3 First scenario: Bring glass bottles to landfill

This scenario considered that glass bottles were taken to the municipal landfill as part of the current waste management practices in Puerto Rico. Only the west region of Puerto Rico was considered. A transportation distance of 10 km from the collection point to the dumpsite was assumed in the LCA simulation. Figure 4.1 shows the process diagram. Two routes were specified assuming two main regional landfills. The simulation computed the amount of diesel necessary for the complete disposal of the 524k tons of glass bottles.

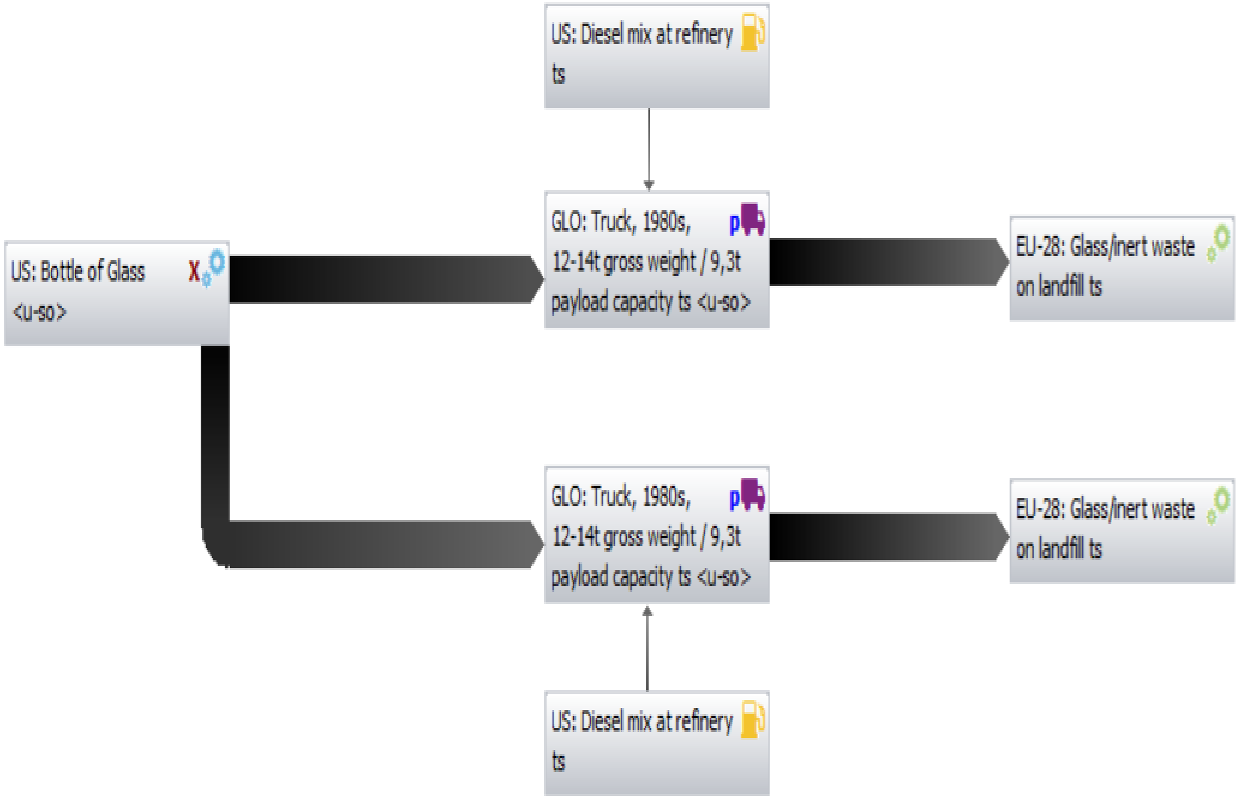

Figure 4.1: LCA process diagram for the first scenario: bring glass bottles to landfill.

The results of the simulation provides for the assessment of potential environmental and health impacts. Figure 4.2-4.5 shows estimates of global warming potential (GWP), ozone depletion potential (ODP), ecotoxicity in air (Ecotox Air) and ecotoxicity in water (Ecotox Water). GWP considers emissions that contribute to global warming: CO_2, CO, CH_4, among others. The GWP results show that bringing the glass bottles to the municipal landfill contributes to a total of 9.11 M kg CO_2-equivalent units (Figure 4.2). For this scenario, the grave process (Glass/inert waste on landfill) represents the process that most contributes to the GWP (4.19 M kg CO_2-equivalent units per landfill). Contributions of the transportation and fuel consumption processes were almost negligible in this impact category. This trend is consistent with all different potential impacts considered (Figures 4.3-4.5).

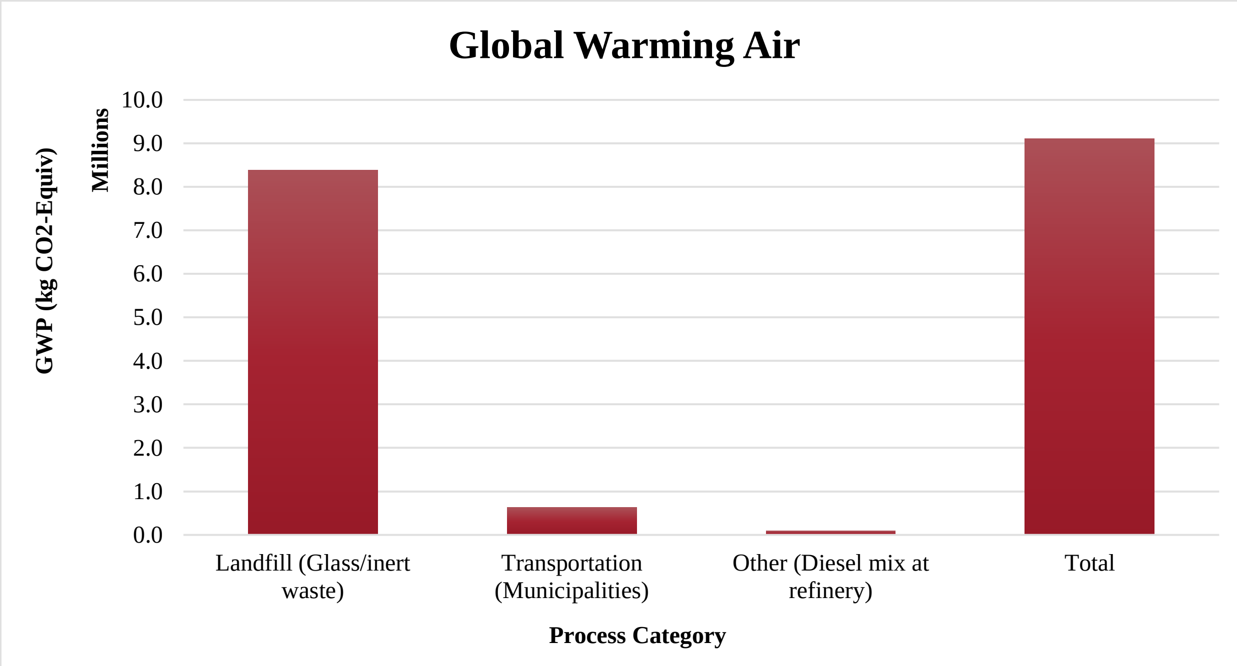

Figure 4.2: Global warming potential for the first scenario: bring glass bottles to landfill. The x-axis represents the processes depicted in Figure 4.1.

ODP considers several gas compounds contributing to depletion of the ozone layer. These are reported in terms of chlorofluorocarbons (CFCs). For the gate to grave simulation, ODP results show a total contribution of 2.32 mg CFC 11-equivalent units (Figure 4.3). The volume of glass bottles placed in each municipal solid waste landfill contributes with 1.15 mg CFC 11-equivalent units.

Ecotoxicity represents the chemicals that interact with organisms in the environment (The National Academies of Science, Engineering Medicine, 2014). Ecotox Air results show a total contribution of 0.138 M CTUeco (PAF m^3 day/kg); with each municipal landfill contributing with 0.07 M CTUeco (Figure 4.4). For the case of Ecotox Water, the total contribution is 0.8 M CTUeco; with each landfill contributing with 0.357 M CTUeco (Figure 4.5).

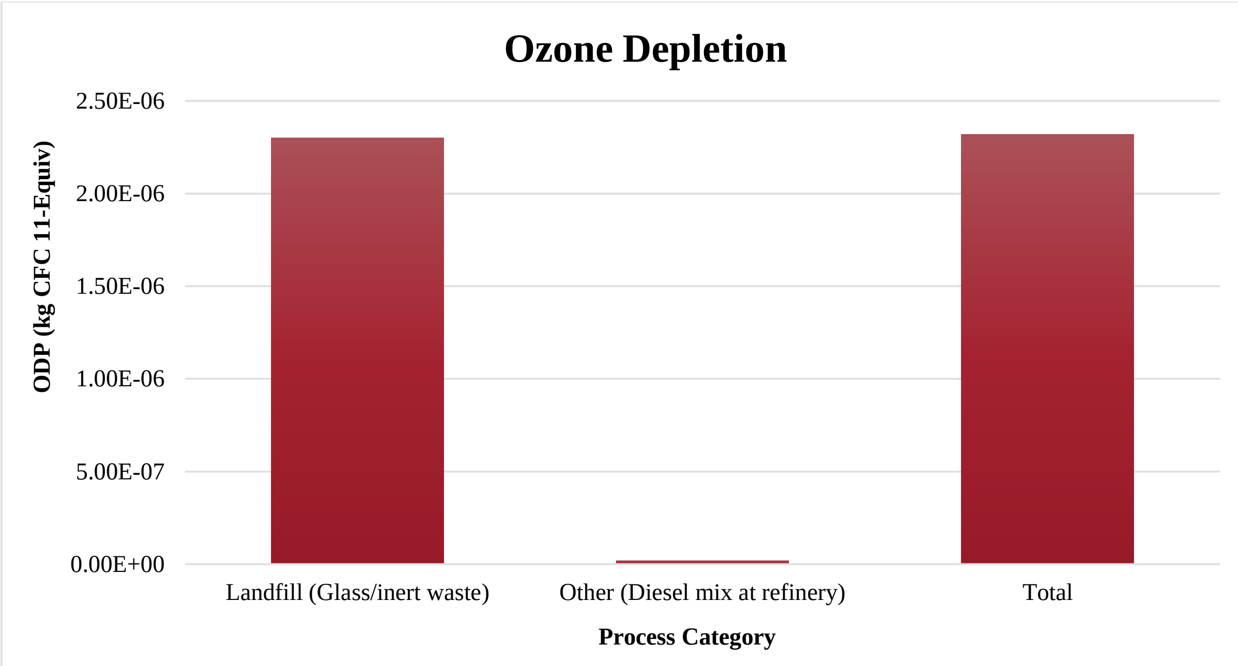

Figure 4.3: Ozone depletion potential for the first scenario: bring glass bottles to landfill. The x-axis represents the processes depicted in Figure 4.1.

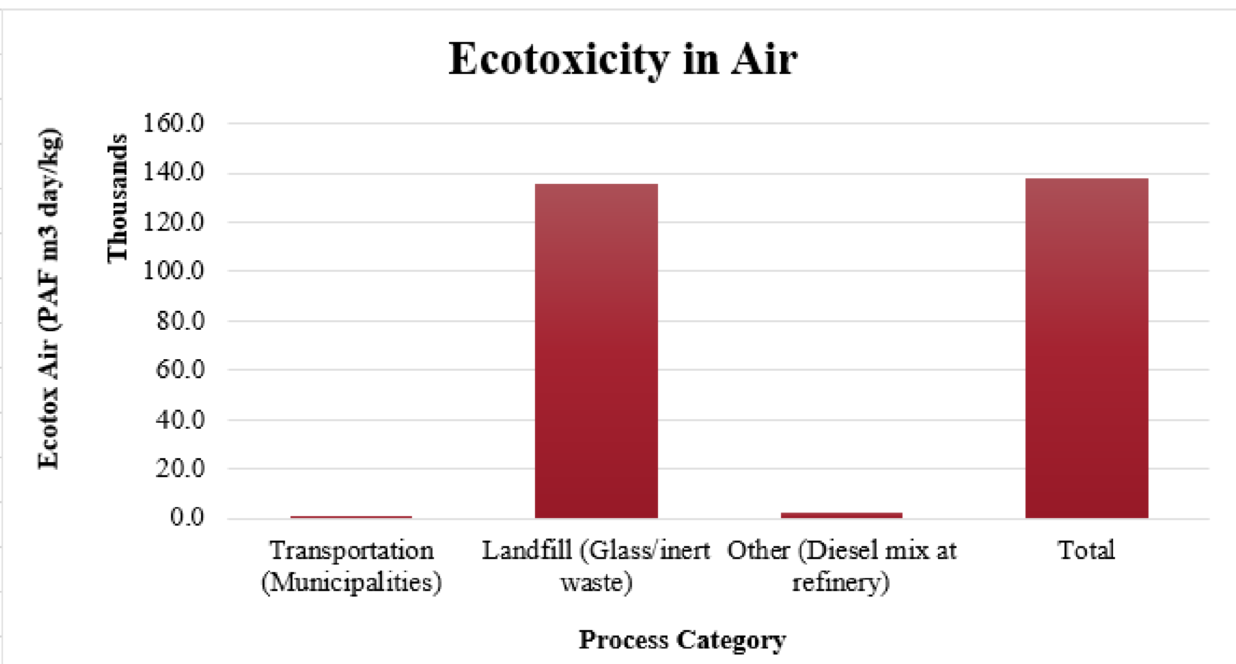

Figure 4.4: Ecotoxicity in air for the first scenario: bring glass bottles to landfill. The x-axis represents the processes depicted in Figure 4.1.

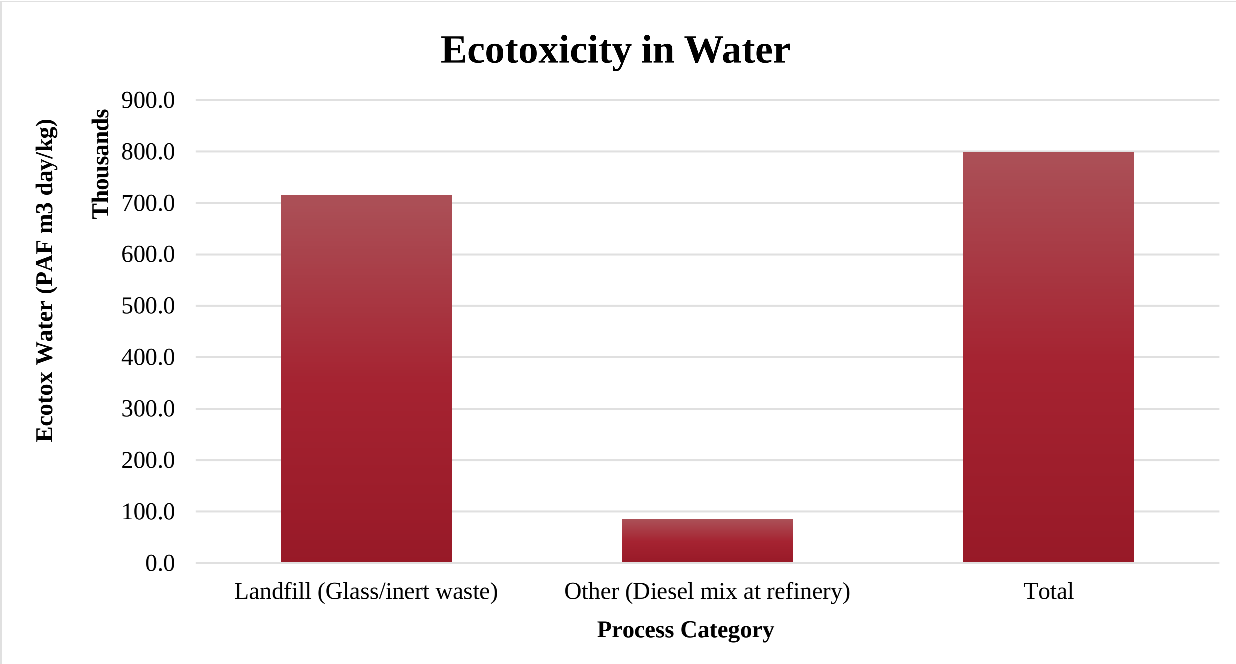

Figure 4.5: Ecotoxicity in water for the first scenario: bring glass bottles to landfill. The x-axis represents the processes depicted in Figure 4.1.

4.4 Second scenario: Use glass bottles for beach replenishment

This scenario considered that glass bottles were picked-up in each township in the west region of Puerto Rico and taken to a crushing glass plant located in Rincón, Puerto Rico (CCG Plant). Two different transportation routes were considered, the first included the distance between the recollection point and the dumpsite (10 km) where glass would have been sorted; while the second included the distance between the dumpsite to the CCG Plant. As with the first streamlining method, the total volume of glass bottles was divided equitably into two routes. For this alternative the municipalities considered were Mayagūez and Añasco, with a total transportation distance of 23.5 km and 16.5 km, respectively. Figure 4.6 shows the process diagram used in this second simulation.

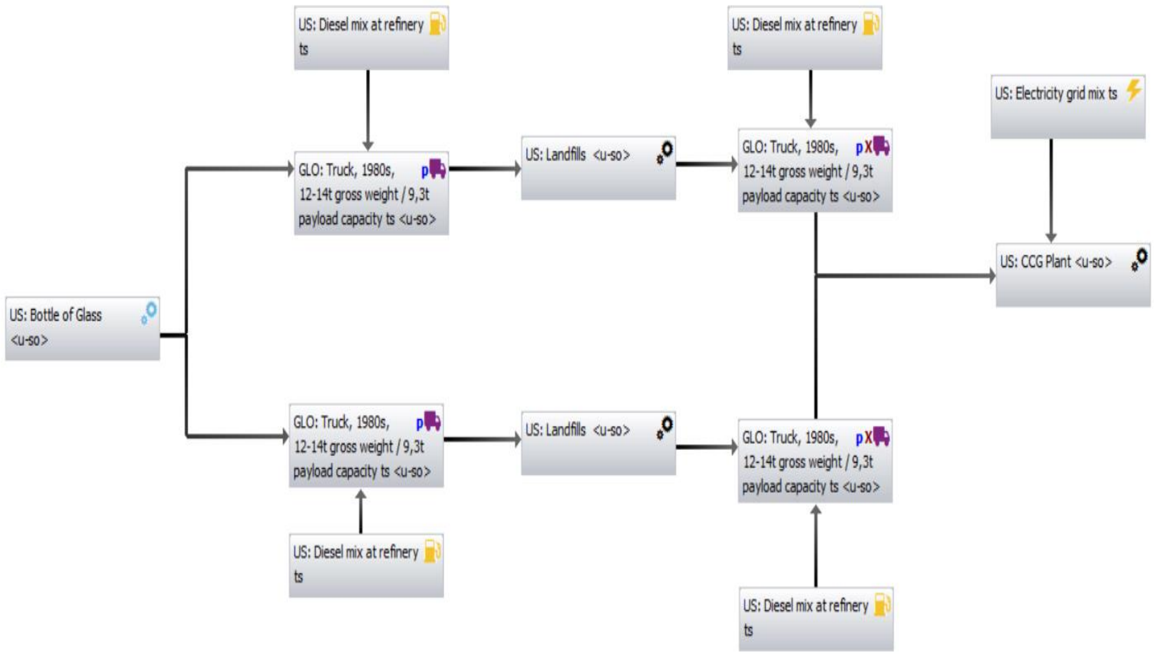

Figure 4.6: LCA process diagram for the second scenario: Use glass bottles for beach replenishment.

Results show that this scenario contributes to GWP roughly four times less than the first scenario (2.38 M kg CO_2-equivalent units, Figure 4.7). Here, the processes that contribute the most are the transportation distance to the CCG Plant and the energy used to crush the glass bottles. From Mayagūez to Rincón and Añasco to Rincón, GWP contribution resulted in 0.75 M kg CO_2-equivalent units and 0.527 M kg CO_2-equivalent units, respectively. The energy used in the crushing process shows a contribution of 0.64 M kg CO_2-equivalent units. For the case of ODP, results show a total contribution of 0.98 mg CFC 11-equivalent units (Figure 4.8), one order of magnitude less than the first scenario. Most of the contribution to ODP are associated with the energy used in the crushing process (0.918 mg CFC 11-equivalent units).

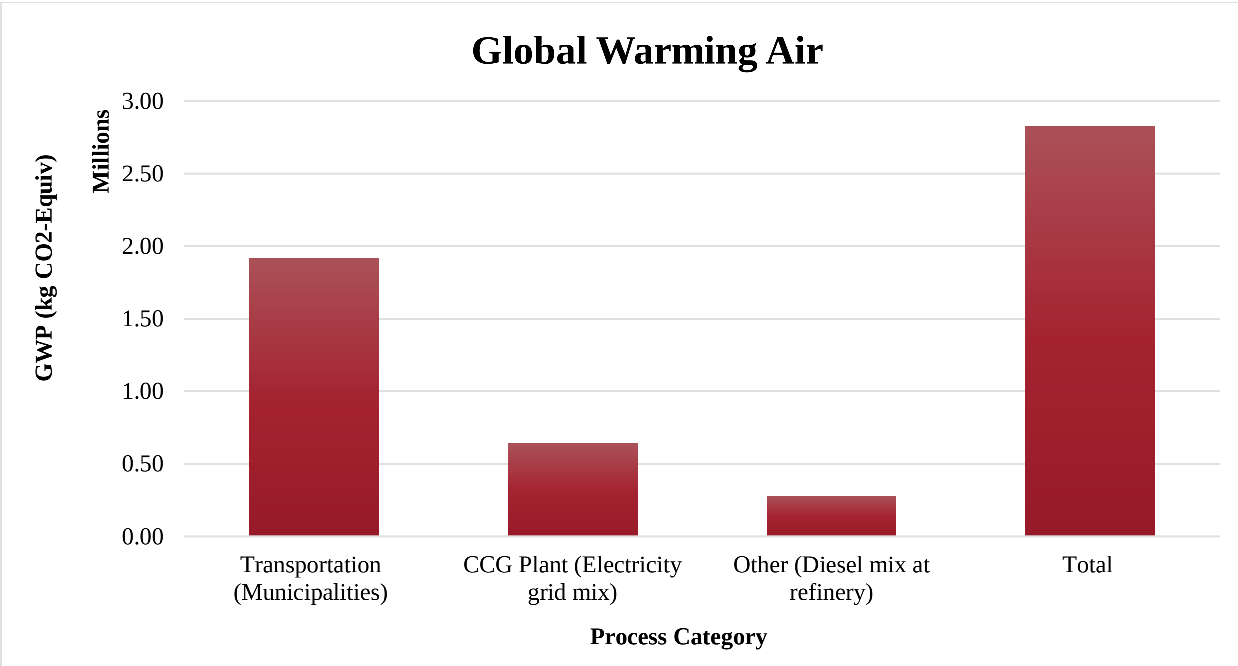

Figure 4.7: Global warming potential for the second scenario: Use glass bottles for beach replenishment. The x-axis represents the processes depicted in Figure 4.6.

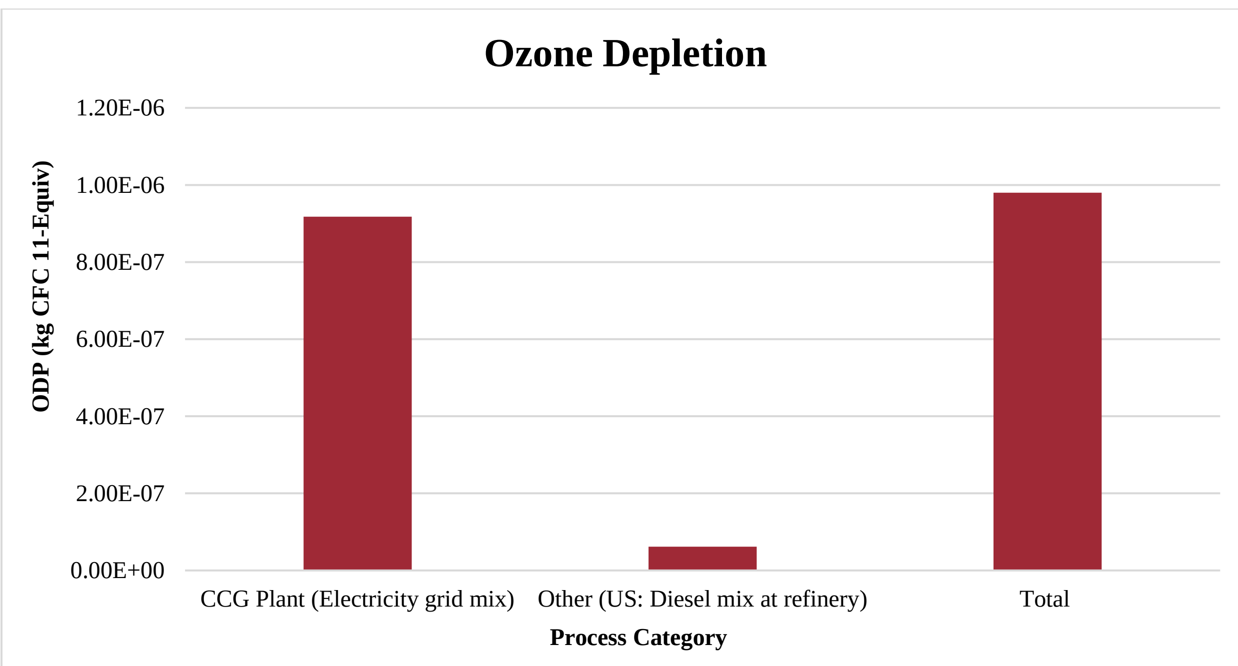

Figure 4.8: Ozone depletion potential for the second scenario: Use glass bottles for beach replenishment. The x-axis represents the processes depicted in Figure 4.6.

Ecotox Air results shows a total contribution of 0.01 M CTUeco (PAF m^3 day/kg). As GWP, the processes that represented the most contribution to the Ecotox Air were transportation distance to the CCG Plant and the energy used to crush the bottles (Figure 4.9). From Mayagūez to Rincón and Añasco to Rincón, Ecotox Air contributions resulted in 3.02K CTUeco and 2.12K CTUeco, respectively. The crushing process shows a contribution of 5.23K CTUeco. These are all about two orders of magnitude less than the first scenario. For the case of Ecotox Water, results show a total contribution of 0.27 M CTUeco (Figure 4.10). Transportation distance to the CCG Plant was the processes with most of the contributions: 0.1 M CTUeco from Mayagūez to Rincón, and 0.07 M CTUeco from Añasco to Rincón. In general, results of Ecotox Water for this scenario are about half of those for the first scenario

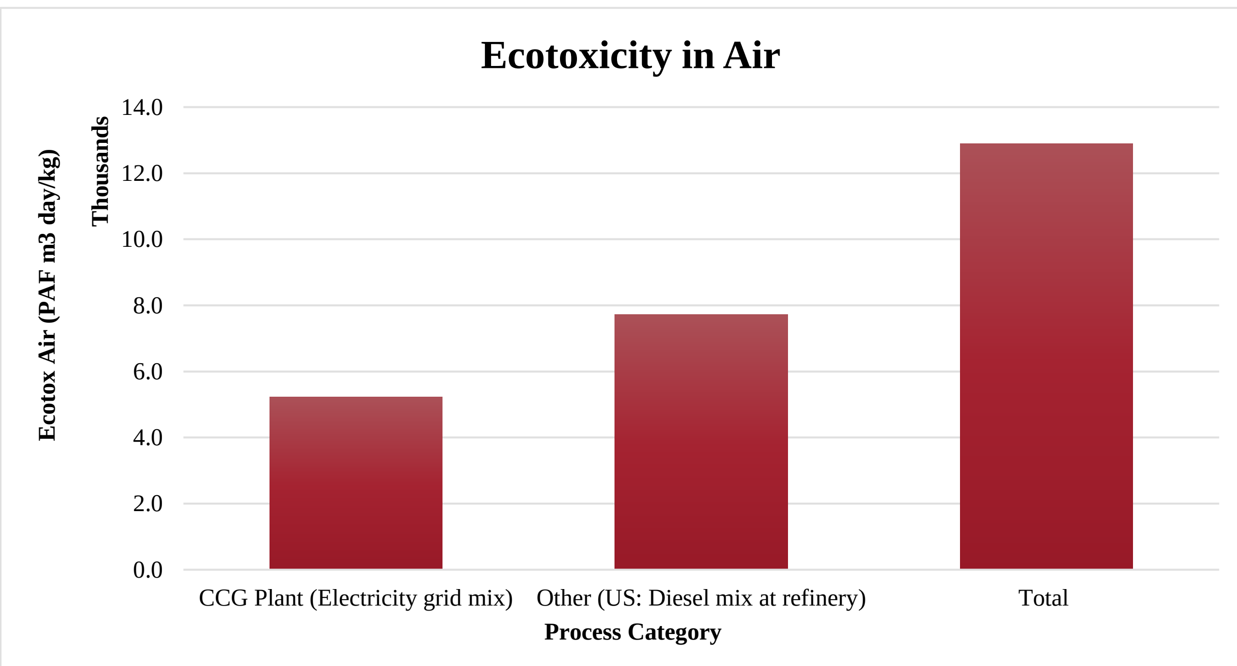

Figure 4.9: Ecotoxicity in air for the second scenario: Use glass bottles for beach replenishment. The x-axis represents the processes depicted in Figure 4.6.

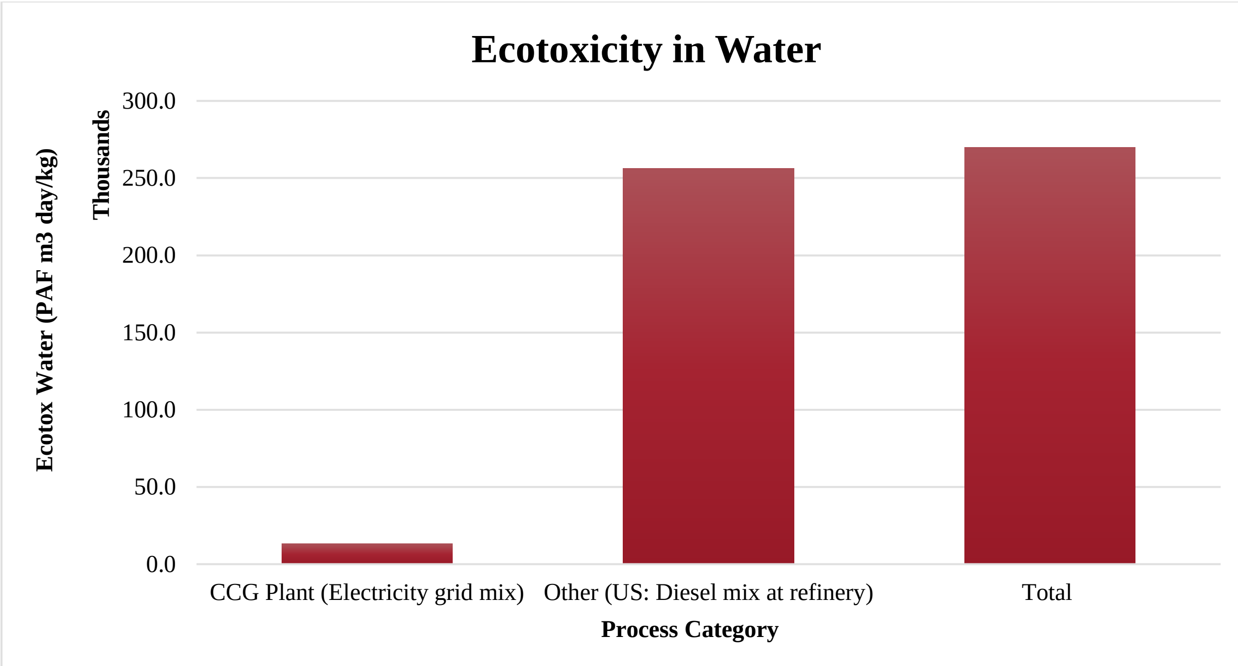

Figure 4.10: Ecotoxicity in water for the second scenario: Use glass bottles for beach replenishment. The x-axis represents the processes depicted in Figure 4.6.

4.5 LCA Discussion

From the analysis shown above, the main variables affecting the LCA of the project are: 1) disposing of the glass bottles at the landfill, 2) the transportation distance, and 3) energy used to crush the material (CCG Plant). Comparisons between the two alternatives show that the potential impacts are higher for the first scenario: Bring glass bottles to landfill. Glass bottles in the landfill represent a total GWP contribution of 9.11 M kg CO_2-equivalent units versus 2.38 M kg CO_2-equivalent units if bottles are crushed in CCG Plant (Figure 4.11). This represents a difference of 6.73 M kg CO_2-equivalent units. Similar differences were found with ODP and ecotoxicity in air and water, thereby suggestion the second scenario as the one with the lowest impact (Figures 4.12 – 4.14). The reason for such a high difference may be attributed to the grave process (end-life landfill), which would be saved if the second scenario takes place.

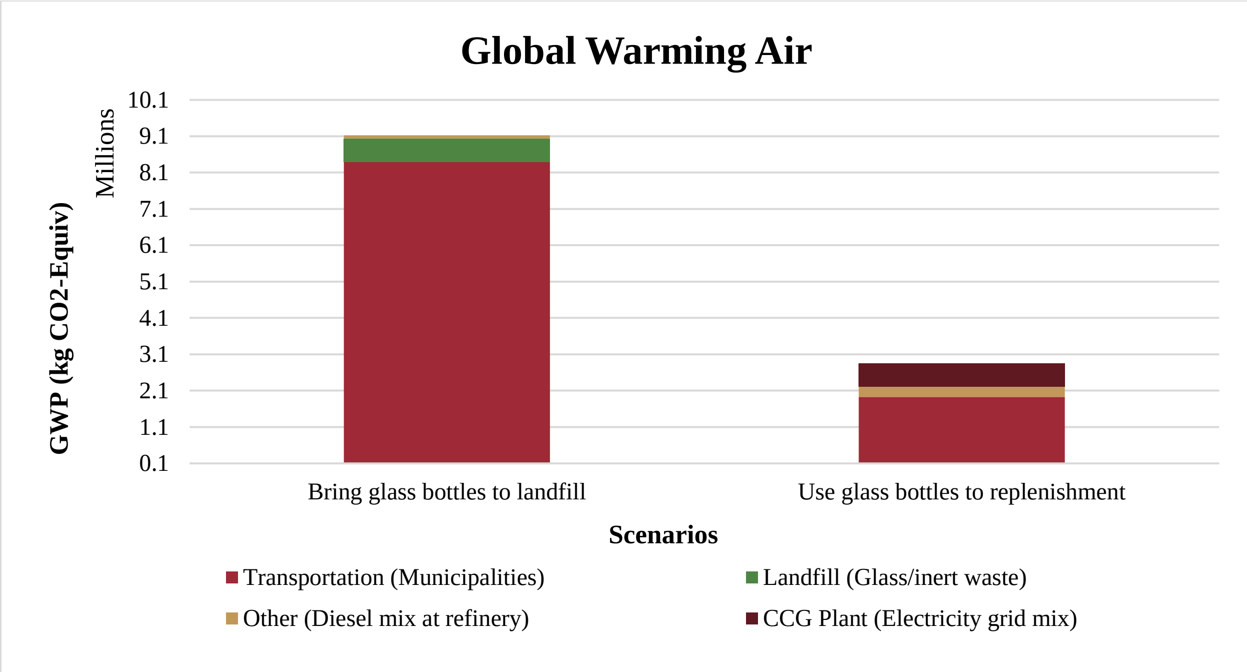

Figure 4.11: Global Warming Air comparison for the two scenarios.

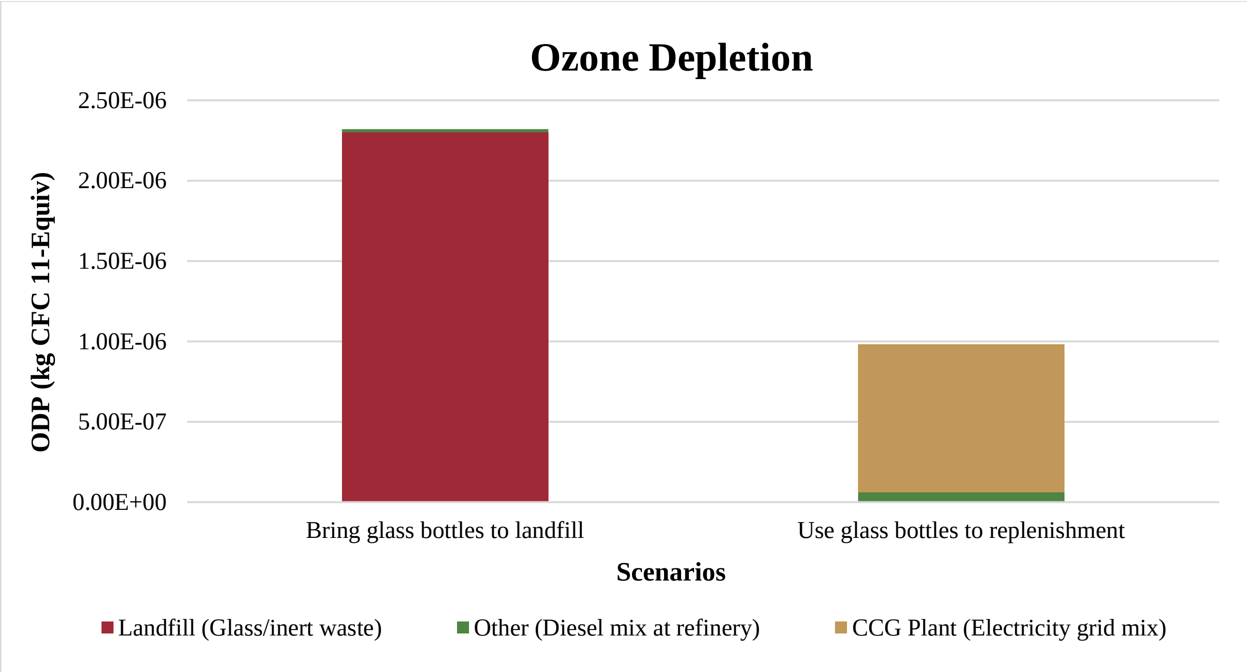

Figure 4.12: Ozone depletion comparison for the two scenarios.

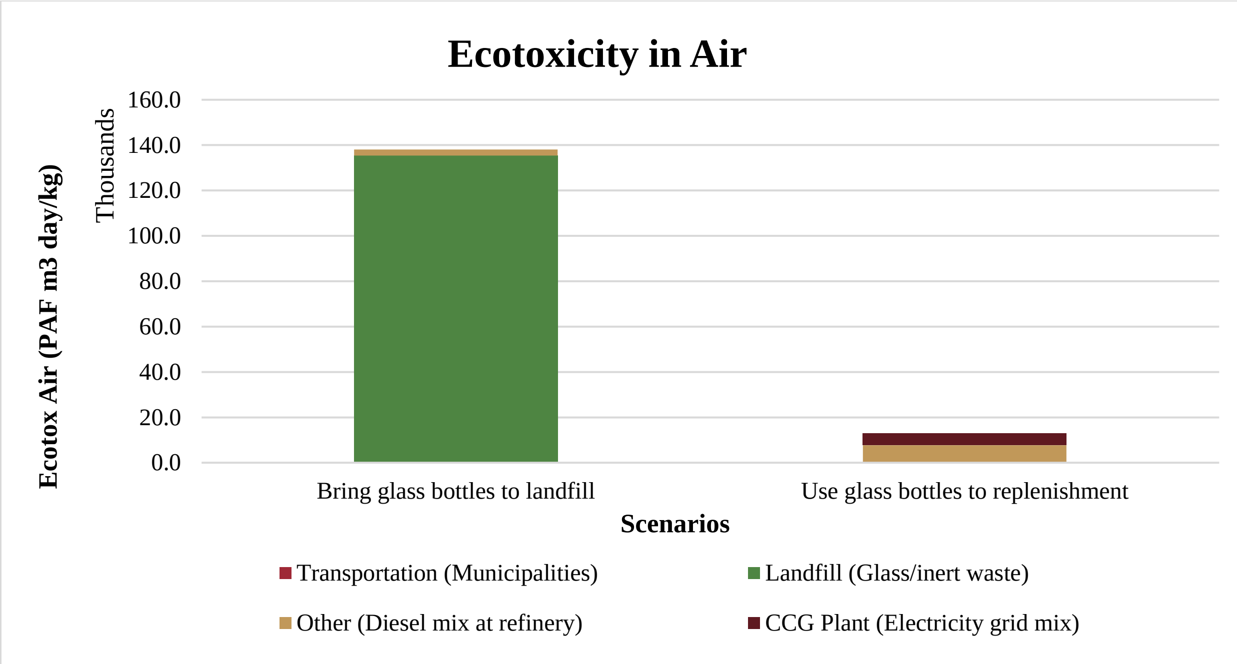

Figure 4.13: Ecotoxicity in air comparison for the two scenarios.

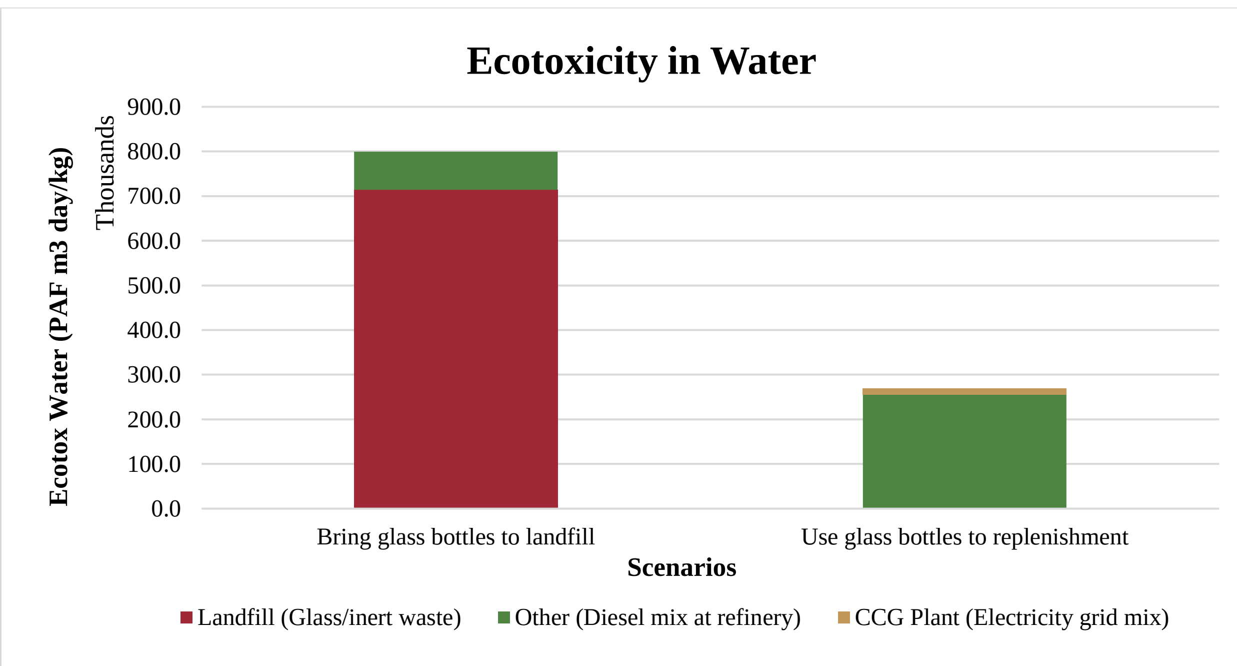

Figure 4.14: Ecotoxicity in water comparison for the two scenarios.

4.5.1 Sensitivity Analysis

A sensitivity analysis was conducted to evaluate the effect of transportation distance on the second scenario. A range of 5 miles to 45 miles (8 km to 72 km) were considered in the west region of Puerto Rico; with Aguada and Añasco as the nearest municipalities to Rincón, and Guánica and Yauco as the furthest municipalities from Rincón. Figure 4.11 shows the system process diagram used in the simulation; only one route was considered.

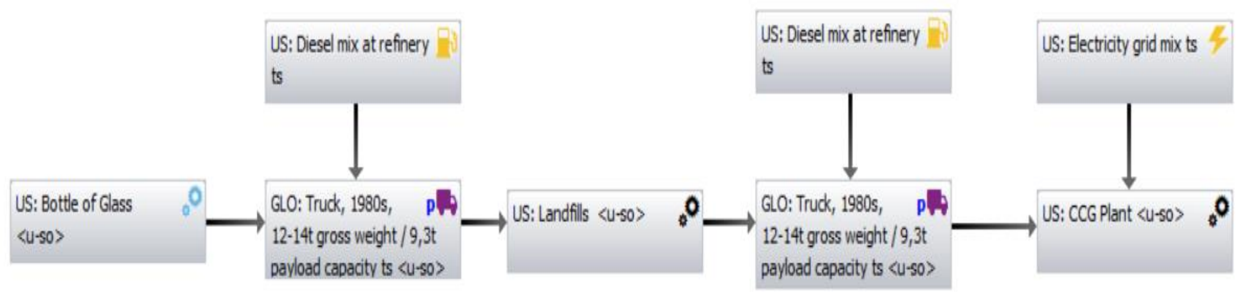

Figure 4.15: LCA process diagram for the sensitivity analysis.

Results for all categories show that increased potential impacts are proportional to the transportation distance (Figure 4.16-4.19). GPW contribution from the farthest municipality (45 miles) is 6.64 M kg CO_2-equivalent units vs. a 9.11 M kg CO_2-equivalent unit resulting from the first scenario. However, when transportation distances increase (e.g. 125 miles, 200.5 km), total GWP contributions resulted in 16.1 M kg CO_2-equivalent units, suggesting that this second scenario is suitable only if the glass waste origin is close to the CCG Plant. The same holds for ODP, Ecotox Air and Ecotox Water impact categories. Within the west region (45 miles) the second scenario is still the best choice. ODP, Ecotox Air, and Ecotox Water show a total contribution of 1.09 mg CFC 11-equivalent units, 0.03 M CTUeco, and 0.715 M CTUeco, respectively; as opposed to 2.32 mg CFC 11-equivalent units, 0.138 M CTUeco, and 0.799 M CTUeco corresponding to the first scenario.

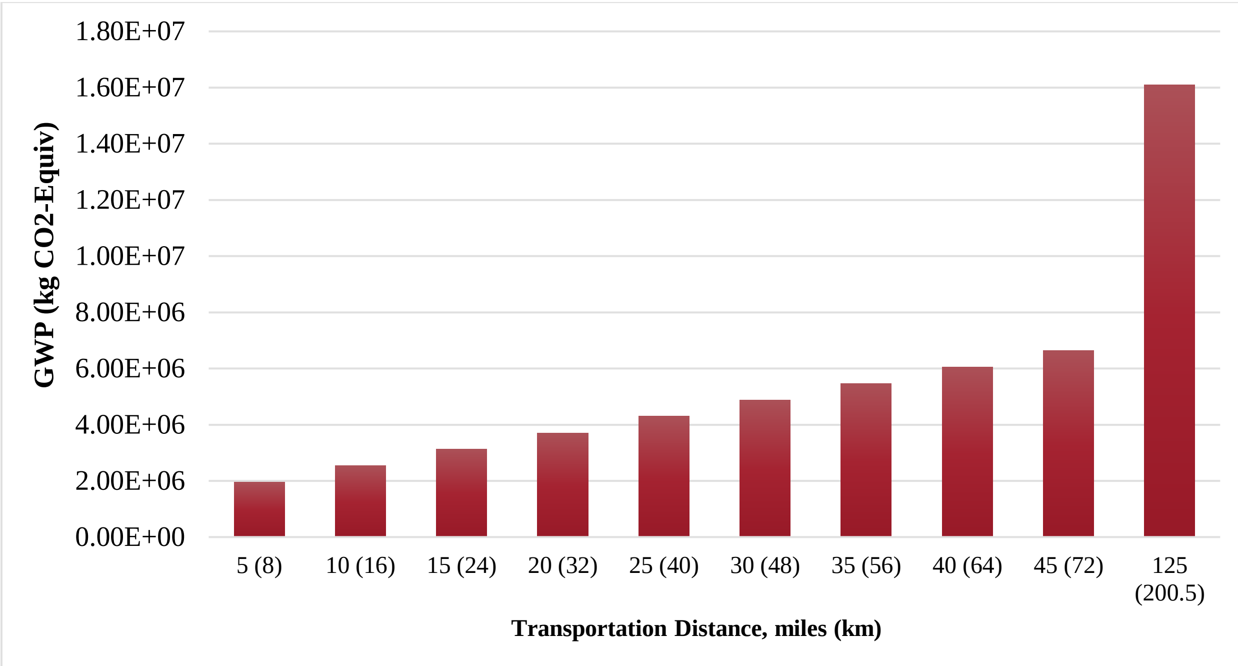

Figure 4.16: Sensitivity analysis for the second scenario in terms of global warming potential.

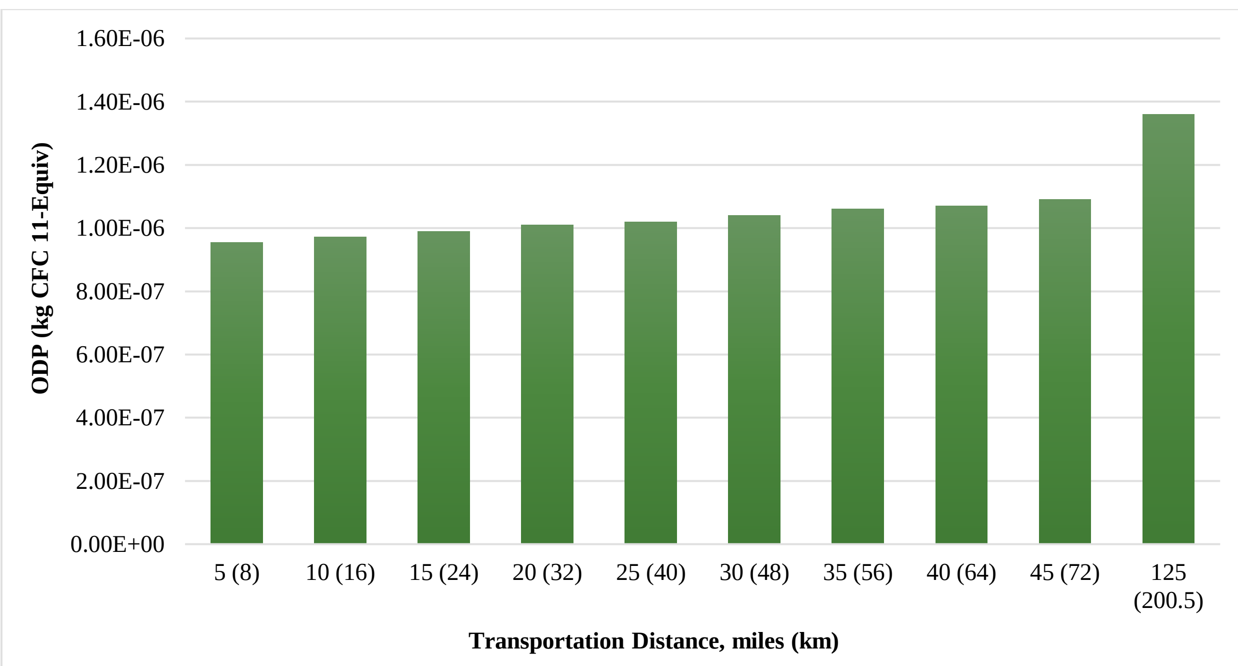

Figure 4.17: Sensitivity analysis for the second scenario in terms of ozone depletion potential.

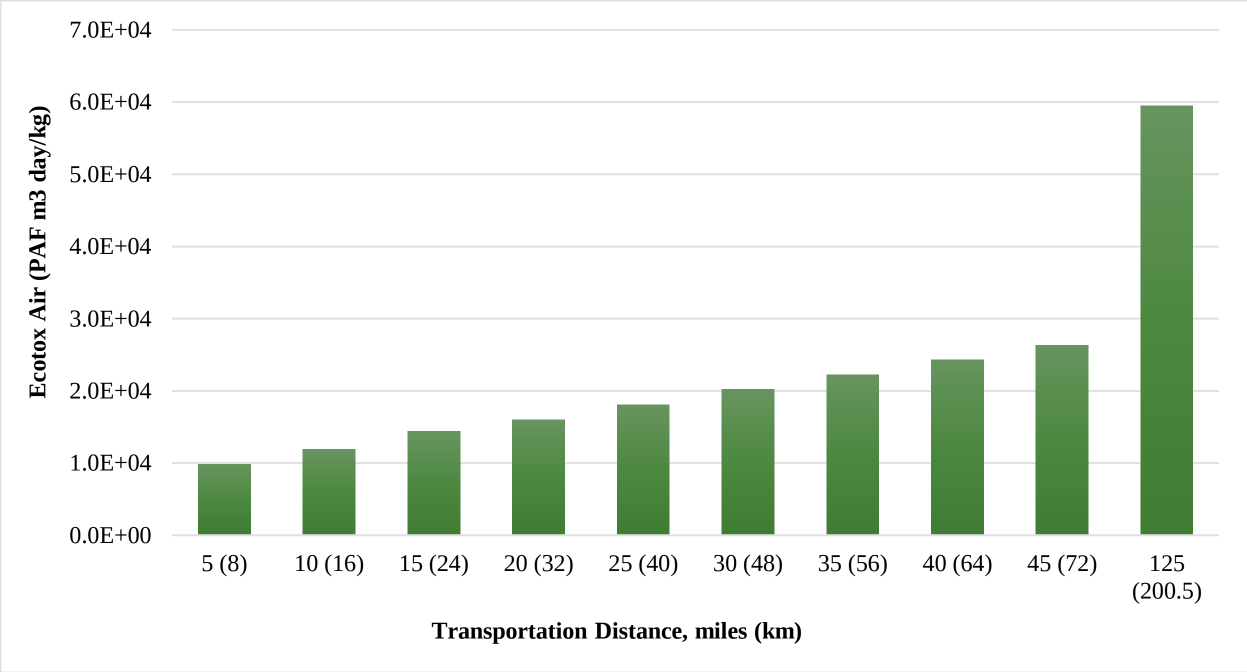

Figure 4.18: Sensitivity analysis for the second scenario in terms of ecotoxicity in air.

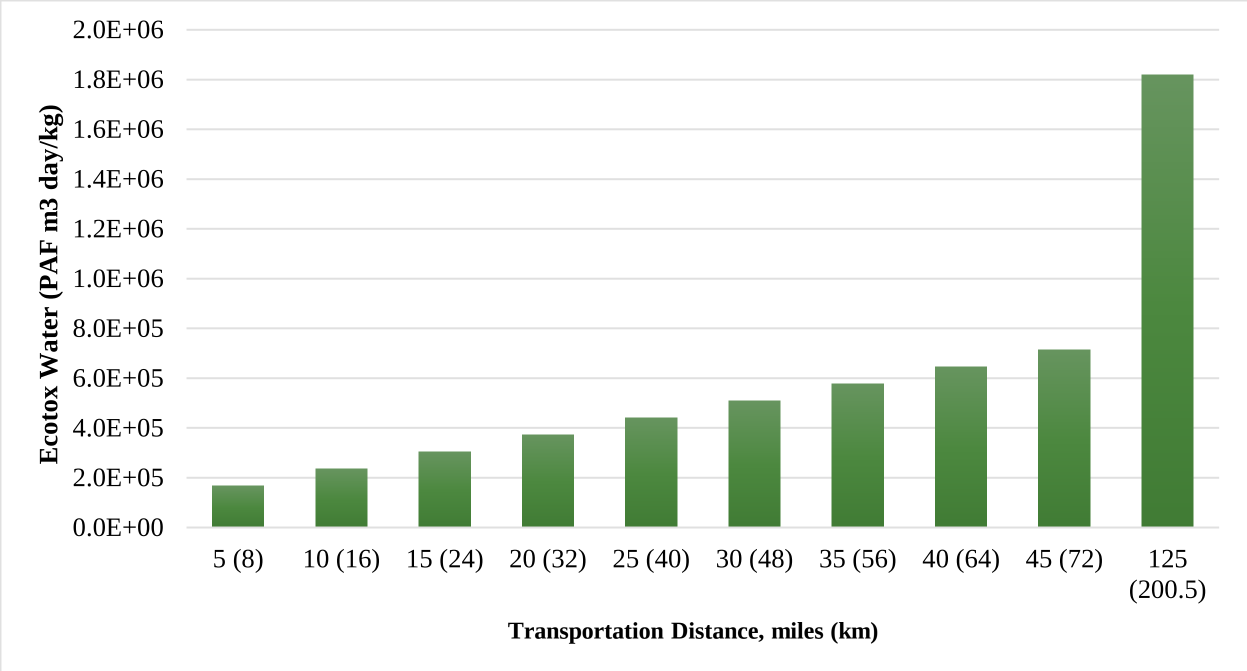

Figure 4.19: Sensitivity analysis for the second scenario in terms of ecotoxicity in water.

4.6 Summary

This chapter involves the life cycle assessment of glass bottles in a system boundary from gate to grave. GaBi simulations for two alternatives: (1) bring glass bottles to landfill and (2) use glass bottles for beach replenishment were conducted. The initial process (gate) evaluated in both alternatives was the amount of glass needed for nourishment, while the final processes (grave) was taken as the landfill (scenario 1) or crushing plant (scenario 2). Assessment of global warming potential, ozone depletion potential, and ecotoxicity in air and water suggests that bringing glass bottles to the landfill represents a higher concern in terms of environmental and public health impacts. However, crushing glass bottles for beach nourishment represents the best alternative as long as the distance between the origin of the glass waste and the crushing plant remains reasonable (less than 45 miles).

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The main goal of this study was to assess the feasibility of using recycled glass as a filling material to mitigate erosion problems in Rincón, PR. To achieve this, economic and social feasibility analyses were conducted in conjunction with a life cycle assessment of glass bottles. Quantification of the amount of crushed glass necessary to fill a specific area of the Rincon's coastline was also conducted.

An economic feasibility analysis was conducted considering three scenarios: 1) using sand dredged within 1 mile from the beach site; 2) using sand dredged within 4 miles from the beach site; and 3) using a 50/50 mixture of crushed glass and sand dredged within 1 mile from the beach site. The analysis shows that the total project costs increases proportionally with increased distance between the dredging and filling areas, increased replenishment volume, as well as an increased use of crushed glass. However, an increased replenishment volume decreases the cost per cubic yard. Given the cost of glass crushing, the total cost of replenishing the beach with a 50/50 sand/glass mixture results excessive. Therefore, using recycled glass as beach nourishment material is not the most economically feasible alternative. For the improvement of such economic viability study, it is highly recommended that future efforts consider the maintenance costs of replenishment, costs of potential ecological damages and cost benefit analyses regarding performing (or not performing) the project.

The social feasibility aspect of the project indicates that 63% of individuals in the survey area engage in recycling practices. Extrapolating into the entire population of Puerto Rico suggests, as a rough estimate, that 50k m^3 of landfill space could be saved every year. Although suggestions regarding implementation of practices and policy to promote recycling by the non-recycling population were noted, public perception of the project was overwhelmingly favorable. In order to better assess recycling practices throughout the whole island, it is recommended that a broader characterization of the Puerto Rican population must be considered.

To evaluate the potential environmental benefits of using crushed glass as a beach nourishment material, a life cycle assessment (LCA) was conducted using the GaBi software tool. The simulations allowed for estimates of potential environmental and health impacts resulting from two scenarios: bringing glass bottles to the landfill versus using glass bottles as beach nourishment material. In general, disposing of glass bottles in landfills presented a higher potential for global warming, ozone depletion and ecotoxicity in air and water. This is possibly due to the potential landfill space saved. However, as distance between the origin of the glass waste and the location of the crushing plant increases, so does the potentially negative impacts to the environment and human health. Future work may include a life cycle assessment of the dredging process; a sensitivity analysis considering different energy sources for the crushing process; and a cost analysis considering the monetary value of the potential impacts to the environment and human health, including the cost of landfill space.

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Appendix A – Glass Sources

A.1 Solid waste disposed of landfills in Puerto Rico in 2014

Table A. 1: Solid waste disposed in landfills per region in Puerto Rico in 2014 (Romero-Castellano, 2015).

En esta tabla se presenta la data por región de los 78 municipios de Puerto Rico. La misma contiene la cantidad de material que se recupera y la que se dispone en los sistemas de relleno sanitario. La unidad de peso es en toneladas (Sin Recuperar - Annual)

Regions in Puerto Rico	Carton Box	Newspaper	Paper	Plastic	Ton Type 1	Ton Type 2	Ton Type 3-7	Glass	Car Battery	Aluminum	Flourescent lamp	Vegetative	Non Ferrous Material	Ferrous Material
West Region	163192	168984	191192	22208	18348	56972	127464	46352	9656	17380	9656	410392	23028	245620
North Region	295692	306188	346432	40240	33244	103228	230956	83984	17496	31492	17496	743600	41724	445048
South Region	123744	128136	144976	16840	13912	43200	96652	35144	7324	13180	7324	311188	17460	186244
Central Region	114116	118168	133700	15532	12828	399840	89132	32412	6752	12156	6752	286980	16104	171760
East Region	187716	194380	219928	25548	21104	65536	146620	53316	11108	19036	11108	472068	26488	282532
Total	884460	915856	1036228	120368	99436	668776	690824	251208	52336	93244	52336	2224228	124804	1331204

A.2 Glass disposed on landfills in Puerto Rico in 2014

Table A. 2: Glass disposed in the municipalities of a quarter in Puerto Rico in 2014 (Romero-Castellano, 2015).

En esta tabla se presenta la data por región de los 78 municipios de Puerto Rico. La misma contiene la cantidad de material que se recupera y la que se dispone en los sistemas de relleno sanitario. La unidad de peso es en toneladas.

	Municipality	Region	Glass (Tons)	
			Recovered	Disposed
West Region	Aguada	O	109	710
	Aguadilla	O	2	1,017
	Añasco	O	36	499
	Cabo Rojo	O	11	875
	Camuy	O	5	595
	Guanica	O	-	322
	Hormigueros	O	9	294
	Isabela	O	-	777
	Lajas	O	26	433

En esta tabla se presenta la data por región de los 78 municipios de Puerto Rico. La misma contiene la cantidad de material que se recupera y la que se dispone en los sistemas de relleno sanitario. La unidad de peso es en toneladas.

	Municipality	Region	Glass (Tons)	
			Recovered	Disposed
	Lares	O	-	508
	Las Marías	O	-	164
	Maricao	O	-	106
	Mayagüez	O	-	1,473
	Moca	O	-	681
	Quebradillas	O	-	441
	Rincón	O	26	259
	Sabana Grande	O	-	426
	San German	O	-	597
	San Sebastián	O	28	711
	Yauco	O	-	696

	Municipality	Region	Glass (Tons)	
			Recovered	Disposed
North Region	Arecibo	N	-	1,621
	Barceloneta	N	6	430
	Bayamón	N	-	3,465
	Cataño	N	9	469
	Dorado	N	23	662
	Florida	N	-	216
	Guaynabo	N	-	1,648
	Hatillo	N	-	723
	Manatí	N	10	741
	San Juan	N	-	6,547
	Toa Alta	N	-	1,292
	Toa Baja	N	-	1,500
	Vega Alta	N	-	684
	Vega Baja	N	3	999

	Municipality	Region	Glass (Tons)	
			Recovered	Disposed
South Region	Aibonito	S	-	436
	Arroyo	S	-	333
	Cayey	S	-	816
	Coamo	S	-	701
	Guayama	S	0	770
	Guayanilla	S	-	359
	Juana Díaz	S	-	862
	Peñuelas	S	32	402

En esta tabla se presenta la data por región de los 78 municipios de Puerto Rico. La misma contiene la cantidad de material que se recupera y la que se dispone en los sistemas de relleno sanitario. La unidad de peso es en toneladas.

	Ponce	S	-	2,746
	Salinas	S	-	526
	Santa Isabel	S	-	400
	Villalba	S	-	435
	Municipality	**Region**	**Glass (Tons)**	
			Recovered	**Disposed**
Central Region	Adjuntas	C	18	331
	Aguas Buenas	C	-	484
	Barranquitas	C	-	520
	Caguas	C	-	2,421
	Ciales	C	-	314
	Cidra	C	-	739
	Comerío	C	-	354
	Corozal	C	-	630
	Jayuya	C	-	280
	Morovis	C	-	562
	Naranjito	C	-	519
	Orocovis	C	-	395
	Utuado	C	6	554
	Municipality	**Region**	**Glass (Tons)**	
			Recovered	**Disposed**
East Region	Canóvanas	E	-	824
	Carolina	E	-	2,958
	Ceiba	E	-	226
	Culebra	E	-	31
	Fajardo	E	-	614
	Gurabo	E	-	804
	Humacao	E	-	988
	Juncos	E	23	696
	Las Piedras	E	7	670
	Loiza	E	-	502
	Luquillo	E	-	342
	Maunabo	E	-	205
	Naguabo	E	-	465
	Patillas	E	-	324
	Rió Grande	E	-	925
	San Lorenzo	E	6	696

En esta tabla se presenta la data por región de los 78 municipios de Puerto Rico. La misma contiene la cantidad de material que se recupera y la que se dispone en los sistemas de relleno sanitario. La unidad de peso es en toneladas.

	Trujillo Alto	E	-	1,262
	Vieques	E	-	159
	Yabucoa	E	-	637
	Total		394	62,802

Table A.3: Glass disposed per region in Puerto Rico landfills in 2014 (Romero-Castellano, 2015).

Regions in Puerto Rico	Glass disposed on landfill (tons)
West Region	46350
North Region	83983
South Region	35146
Central Region	32412
East Region	53316
Total	**251207**

Appendix B – Equipment Specifications

B.1 Trailing Suction Hopper Specifications

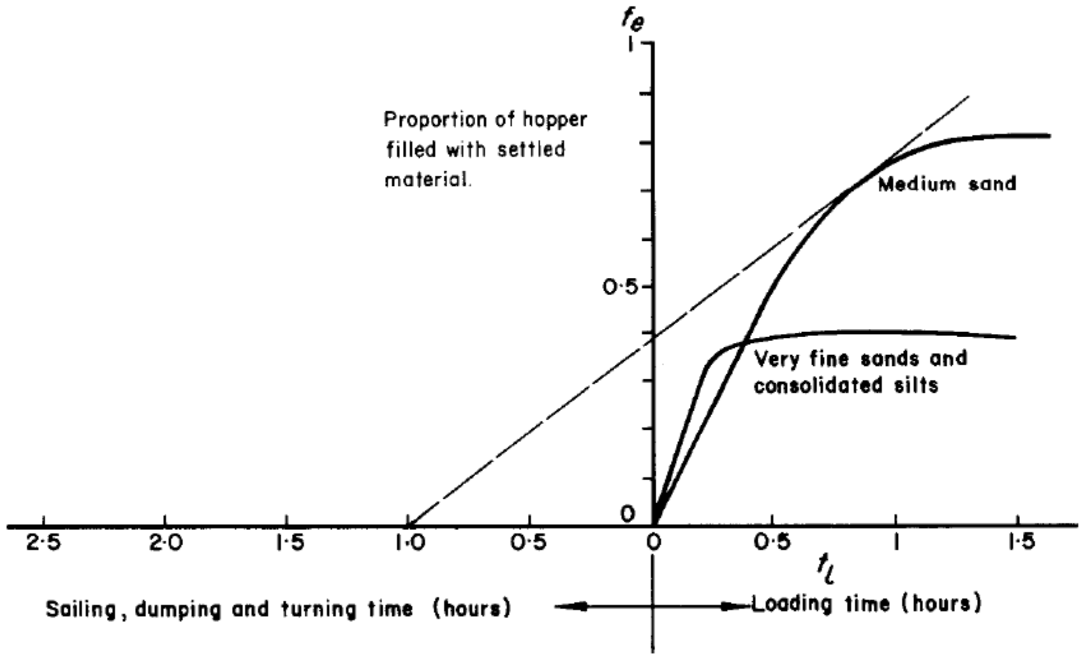

Figure B.1: Trailing suction hopper dredger: loading graphs for medium sand / very fine sands and consolidated silts (Bray, 1979).

Table B.1: Bulking factor, B, for various soil types when excavated by mechanical dredger (Bray, 1979).

Soil type	Bulking factor, *B*,
Hard rock (blasted)	1.50–2.00
Medium rock (blasted)	1.40–1.80
Soft rock (unblasted)	1.25–1.40
Gravel, hardpacked	1.35
Gravel, loose	1.10
Sand, hardpacked	1.25–1.35
Sand, medium soft to hard	1.15–1.25
Sand, soft	1.05–1.15
Silts, freshly deposited	1.00–1.10
Silts, consolidated	1.10–1.40
Clay, very hard	1.15–1.25
Clay, medium soft to hard	1.10–1.15
Clay, soft	1.00–1.10
Sand/gravel/clay mixtures	1.15–1.35

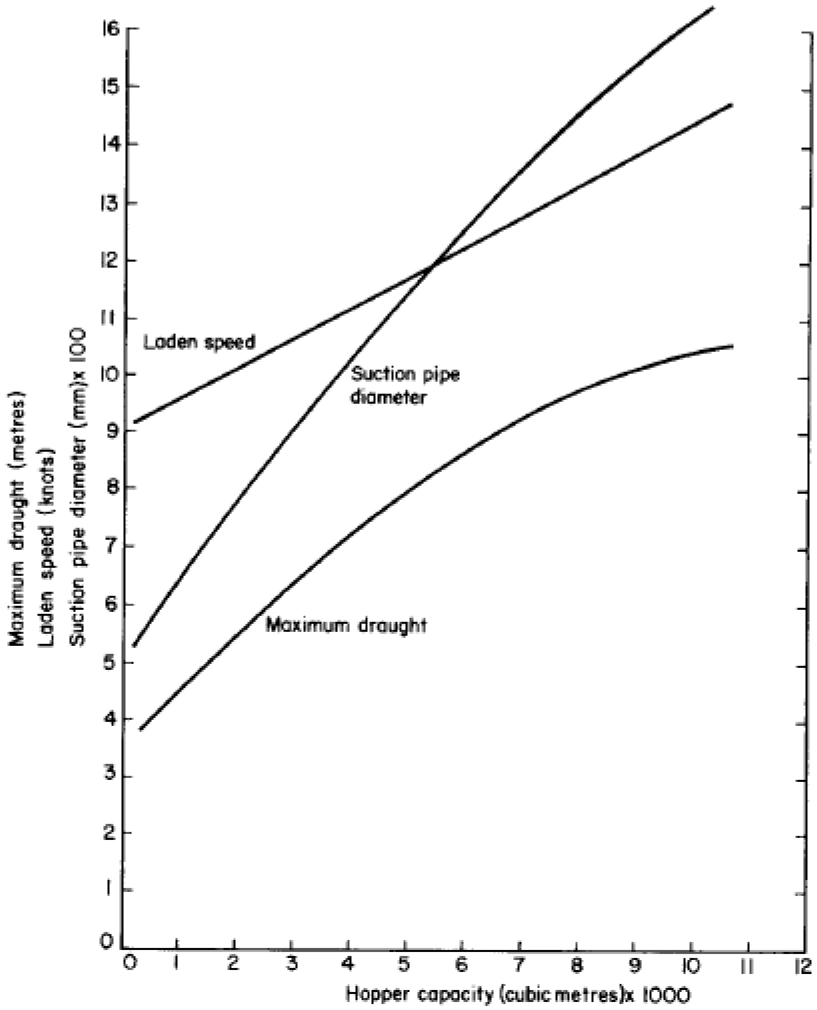

Figure B.2: Trailing suction hopper dredger: laden speed, maximum draught and suction pipe diameter (Bray, 1979).

B.2 Sugar Island -Trailing Suction Hopper Specifications

Table B.2: Trailing Suction Hopper Dredge specification (Great Lakes Dredge & Dock Company, LLC, 2018).

Dimensions	
Length:	281 ft (85.6m)
Breadth:	53 ft (16.2m)
Depth:	21.5 ft (6.6 m)
Draft Light:	9.5 ft (2.9m)
Draft Loaded:	19.65 ft (6.0m)
Operating Parameters	
Dredging Depth:	70ft (21.3m)
Suction Diameter:	2 @ 27 in (686 mm)

Discharge Diameter:	24 in (610 mm)
Hopper Capacity:	3,600 yd3 (2,754 m^3)
Machinery & Power	
Propulsion Power:	4,350 hp (3,245 kW)
Dredge Pump Power:	1,700 hp (1,268 kW)
Total Installed Power:	9,395 hp (7,009 kW)

Table B.3: Theoretical dredging capacity with the borrow site at 1 mile (Bray, 1979).

Theoretical Dredging Capacity			
Using: Trailing Suction Hopper Dredger			**Source**
Hopper Capacity, H (m^3)	2754		Specified by the dredger type
Number of Dredger needed	1		
Max. dredger depth (meters)	21.3		
Dredging Pump horsepower (hp)	1700		
Propulsion Power (hp)	4350		
Total Installed Power (hp)	9395		
Laden Speed, Vg (Knots)	9.5		
Suction pipe diameter	2@27 in		
Discharger Diameter (mm)	610		
Bulking Factor, B (Sand, medium soft to hard)	1.2		
Time taken to dump spoil, Tt(hours)	0.066		
Time taken to turn the dredger at each end of the dredging area, Td (hours)	0.083		
Loading time, Tl (hours)	0.75		
Proportion of hopper filled with settled material, fe	0.7		
D50 (mm)	0.40		
Distance to the dumping ground, g (kilometers)	1.6093		
Length of the dredging area, l (kilometers)	1.48		
Number of turns	3.284	approx.	4
Turning time (hours)	0.21673		
Sailing Time (hours)	0.172788		
Unproductive cycle time (hours)	0.473		
P_{max}(m^3/hr)	**1314**	**P_{max}(yd^3/hr)**	**1719**
P_{avg}(m^3/hr)	**919.864**	**P_{avg}(yd^3/hr)**	**1203.18206**

Table B.4: Theoretical dredging capacity with the borrow site at 4 miles (Bray, 1979).

Theoretical Dredging Capacity			
Using: Trailing Suction Hopper Dredger			**Source**
Hopper Capacity, H (m^3)	2754		Specified by the dredger type
Number of Dredger needed	1		
Max. dredger depth (meters)	21.3		
Dredging Pump horsepower (hp)	1700		
Propulsion Power (hp)	4350		
Total Installed Power (hp)	9395		
Laden Speed (Knots)	9.5		
Suction pipe diameter	2@27 in		
Discharger Diameter (mm)	610		
Bulking Factor, B (Sand, medium soft to hard)	1.2		
Time taken to dump spoil, Tt(hours)	0.066		
Time taken to turn the dredger at each end of the dredging area, Td (hours)	0.083		
Loading time, Tl (hours)	0.75		
Proportion of hopper filled with settled material, fe	0.7		
D50 (mm)	0.40		
Distance to the dumping ground, g (kilometers)	6.44		
Length of the dredging area, l (kilometers)	1.48		
Number of turns	3.284	approx.	3.000
Turning time (hours)	0.21673		
Sailing Time (hours)	0.691453		
Unproductive cycle time (hours)	0.991		
P_{max}(m^3/hr)	**923**	**P_{max}(yd^3/hr)**	**1207**
P_{avg}(m^3/hr)	**646**	**P_{avg}(yd^3/hr)**	**845**

B.3 Caterpillar bulldozer specifications

MODEL	D9R WHA				D10R WHA	
Type	9SU		9U		10U	
Blade Capacities*	28.8 m^3	**37.6 yd^3**	33.5 m^3	**43.8 yd^3**	48.9 m^3	**63.9 yd^3**
Dozer Weight**	6964 kg	**15,353 lb**	7662 kg	**16,891 lb**	—	
Tractor & Dozer Dimensions						
Length Blade Straight	6.84 m	**22'5"**	7.18 m	**23'7"**	8.01 m	**26'3"**
Length Blade Angled	—		—		—	
Width Blade Angled	—		—		—	
Width C Frame Only	—		—		—	
Blade Dimensions						
Width including std. end bits	4314 mm	**14'2"**	4645 mm	**15'3"**	5260 mm	**17'3"**
Height	2845 mm	**9'4"**	2845 mm	**9'4"**	3174 mm	**10'5"**
Maximum Dig Depth	606 mm	**1'11.9"**	606 mm	**1'11.9"**	679 mm	**2'2.5"**
Ground Clearance at full raise	1422 mm	**4'8"**	1422 mm	**4'8"**	1497 mm	**4'10.9"**
Maximum Manual Tilt	—		—		—	
Maximum Pitch	—		—		—	
Maximum Hydraulic Tilt	940 mm	**3'1"**	1014 mm	**3'3.9"**	1074 mm	**3'6.3"**
Blade Angle	—		—		—	

*Blade capacities, weights and heights include 762 mm (2'6") trash rack on D8R blades, 914 mm (3'0") trash rack on D9R blades, and 1067 mm (3'6") trash rack on D10R blades.
**Total bulldozer arrangement includes blade with trash rack, pusharms, braces, cylinders, lines, trunnions and lift cylinder mountings.

Figure B.3: D10R-10U Caterpillar Bulldozer Specification (Caterpillar, Inc., 2011).

MODEL	D8R		D9R		D10R	
Mounting Point	**Under Operators Platform**		**Under Operators Platform**		**Under Operators Platform**	
Number of Valves	**3**		**4**		**2**	
	Ripper◀ Requires optional electronic diverter		**+ Dual Tilt (Attach.) Radiator Guard**		**At Rear Under Fuel Tank 2◀ + Dual Tilt (Attach.) Radiator Guard**	
Flow at 6890 kPa **(1000 psi)**	239 L/min	**63 gpm**	235 L/min	**62.1 gpm**	408 L/min	**107.8 gpm**
	@ 2100 RPM		**@ 1900 RPM**		**@ 1900 RPM**	
Tank Capacity (Oil)	72 L	**19 U.S. gal**	77.2 L	**20.4 U.S. gal**	108 L	**28.6 U.S. gal**
Lift Relief Valve Setting	24 100 kPa	**3500 psi**	26 200 kPa	**3800 psi**	18 616 kPa	**2700 psi**
Weight Installed (Two Valves)	**Included in Std. Tractor**		**Included in Std. Tractor**		**Included in Std. Tractor**	

Figure B.4: D10R-10U Hydraulic Controls Caterpillar Bulldozer Specification (Caterpillar, Inc., 2011).

	CATERPILLAR BLADES							SPECIAL ATTACHMENTS													
MODEL	S	U	SU	A	FS	LFS	P	RC	WC	CL	HU	LF	TW	CU	CPB	CB	VR	WCB	CS	WCS	W
D3C Series III							●						●								
D4C Series III							●						●								
D3C LGP Series III							●						●								
D4C LGP Series III							●						●								
D4E SR				●									●								
D5C Series III							●						●								
D5C LGP Series III							●						●								
D5M XL							●						●								
D5M LGP							●						●								
D5E				●									●								
D6M XL			●				●						●								
D6M LGP							●						●								
D6R	●		●	●			●		●	●	●	●	●				●				
D6R XL			●	●									●								
D6R LGP	●								●	●		●	●								
D6R IG			●	●									●								
D6G	●			●						●		●	●				●				
D7R	●	●	●	●					●	●	●	●	●				●				
D7R LGP	●											●	●				●				
D7G	●	●		●					●	●	●	●	●	●	●		●				
D8R		●	●	●				●	●	●	●	●		●	●	●	●				
D8R LGP																					
D9R		●	●						●	●		●		●	●		●	●			
D10R		●	●					●	●	●				●	●	●	●				
D11R		●	●					●		●							●				
814F	●								●	●	●								●	●	
815F					●																
816F						●						●									●
824G	●								●	●	●								●	●	
825G					●																
826G						●						●									●
834B	●	●							●	●									●	●	
836												●									●

CATERPILLAR SUPPLIED
S — Straight
U — Universal
SU — Semi-Universal
A — Angling
FS — Fill Spreading
LFS — Landfill Spreading
P — Power Angle Tilt

SPECIAL ATTACHMENTS SUPPLIED
RC — Reclamation U
WC — Woodchips
CL — Coal
HU — Heavy U
LF — Landfill
TW — Two-Way Dozer
CU — Cushion Dozer
CPB — Cushion Push Block
CB — Coal Bowldozer
VR — Variable Radius
WCB — Wood Chip Bowldozer
CS — Coal Scoop
WCS — Wood Chip Scoop
W — W-Blade

NOTE: This chart suggests a range of blade options for Caterpillar built machines. It is not totally inclusive of all blades available. For additional information consult Caterpillar Attachment Products and Services.

Figure B.5: Summary Blade Options for Caterpillar Built Machine (Caterpillar, Inc., 2011).

MODEL	D10R				D11R					
	10SU		10U		11SU		11U		11 C.D.	
Type	Semi-U		Universal		Semi-U		Universal		Universal	
Blade Capacities*	18.5 m^3	**24.2 yd^3**	22.0 m^3	**28.7 yd^3**	27.2 m^3	**35.5 yd^3**	34.4 m^3	**45.0 yd^3**	43.6 m^3	**57.0 yd^3**
Weight, Shipping**										
Standard Dozer	10 229 kg	**22,550 lb**	10 784 kg	**23,775 lb**	14 813 kg	**32,658 lb**	17 296 kg	**38,131 lb**	21 678 kg	**47,800 lb**
Abrasion Dozer	11 069 kg	**24,403 lb**	12 413 kg	**27,366 lb**	16 192 kg	**35,698 lb**	18 823 kg	**41,498 lb**	—	
General Dimensions (Tractor & Dozer)										
A Length	7.76 m	**25'5"**	8.01 m	**26'3"**	8.38 m	**27'6"**	8.83 m	**28'11"**	8.34 m	**26'8"**
Width	4.86 m	**15'11"**	5.26 m	**17'3"**	5.60 m	**18'4"**	6.35 m	**20'10"**	6.71 m	**22'0"**
Blade Dimensions:										
B Width (including std. end bits)	4.86 m	**15'11"**	5.26 m	**17'3"**	5.60 m	**18'4"**	6.35 m	**20'10"**	6.71 m	**22'0"**
C Height	2.12 m	**6'11"**	2.12 m	**6'11"**	2.37 m	**7'9"**	2.37 m	**7'9"**	3.26 m	**10'8"**
D Max. Digging Depth	674 mm	**2'2.5"**	674 mm	**2'2.5"**	766 mm	**2'6.2"**	766 mm	**2'6.2"**	766 mm	**2'6.2"**
E Ground Clearance @ Full Lift	1497 mm	**4'10.9"**	1497 mm	**4'10.9"**	1533 mm	**5'0.4"**	1533 mm	**5'0.4"**	1533 mm	**5'0.4"**
G Max. Pitch Adjustment	**+1.7°–2.3°**		**+1.7°–2.3°**		**+2.1°–2.2°**		**+2.1°–2.2°**		—	
H Max. Hydraulic Tilt	993 mm	**3'3.1"**	1074 mm	**3'6.3"**	1184 mm	**3'10.6"**	1344 mm	**4'4.9"**	1344 mm	**4'4.9"**
J Hydraulic Tilt (Manual Brace Centered)	722 mm	**2'4.4"**	782 mm	**2'6.8"**	886 mm	**2'10.9"**	1006 mm	**3'3.6"**	—	
K Pusharm Trunnion Width (to Ball Centers)	3.60 m	**11'10"**	3.60 m	**11'10"**	4.18 m	**13'9"**	4.18 m	**13'9"**	4.18 m	**13'9"**
Maximum Track Width Permitted	762 mm	**2'6"**	762 mm	**2'6"**	914 mm	**3'0"**	914 mm	**3'0"**	914 mm	**3'0"**
Dual Tilt Option					**+7.5°–7.6°** or		**+7.5°–7.6°** or		—	
G Dual Pitch Adj.	**+5.2°–5.5°**		**+5.2°–5.5°**		**+0°–13°**		**+0°–13°**		—	
H Dual Max. Hyd. Tilt	1441 mm	**4'8.7"**	1560 mm	**5'1.4"**	1706 mm	**5'7.2"**	1938 mm	**6'4.3"**	—	

*Blade capacities as determined by SAE J1265.
Notice that the capacity of the U-blade is the volume carried by a straight blade of the same dimensions plus the volume included in the "cup" of the U-blade. It is intended for **relative comparisons of dozer sizes,** and not for predicting capacities or productivities in actual field conditions.
**Shipping Weight — Total Bulldozer Arrangement includes: Blade, push arms or C-frame, braces, cylinders, lines, trunnions and lift cylinder mountings.

Figure B.6: D10R-10U Blade Specification (Caterpillar, Inc., 2011).

Table B.5: Bulldozer labor production to complete half of the project with crushed glass, CCG-20-40 (Caterpillar Inc., 2011).

Scenario: 50%GR&50%SD_1mile				
Caterpilar Bulldozer Model:	D10R			
Type	10U			
Est. Dozing Production	700		LCY/hr	
Labor Production	12		hr	
Total project size, cubic meters	**Half project size, cubic meters**	**Half project size, cubic yards**	**Hours**	**Days**
743000	371500	483000	690	58
1000000	500000	654000	934	78
2000000	1000000	1308000	1869	156
5000000	2500000	3270000	4671	389

B.4 Gasoline and Diesel Puerto Rico Average Price

Departamento de Asuntos del Consumidor

Precios Promedios (¢ por galon) Mensuales Al Detal
Gasolina y Diesel en Puerto Rico

Fecha	Promedio	Regular	Super	Diesel
Nov-17	286.40	283.53	313.83	260.13
Sep-17*	271.80	267.95	307.30	239.47
Aug-17	253.06	249.20	289.89	226.77
Jul-17	237.12	233.03	276.08	219.09
Jun-17	250.80	247.01	286.82	229.67
May-17	244.80	240.71	283.71	231.54
Apr-17	249.00	245.08	286.23	230.50
Mar-17	246.76	242.54	286.88	230.76
Feb-17	258.59	254.73	295.26	235.13
Jan-17	263.23	259.34	300.20	234.62
Dec-16	253.20	249.52	288.32	225.32
Nov-16	249.12	245.31	285.46	227.35
Oct-16	245.79	241.95	282.24	224.30
Sep-16	236.05	232.10	273.60	219.53
Aug-16	226.95	222.73	267.20	213.68
Jul-16	235.73	231.58	275.28	220.17
Jun-16	245.00	241.26	280.58	221.04
May-16	231.93	227.96	269.67	204.83
Apr-16	214.98	211.07	252.13	191.76
Mar-16	196.21	192.06	235.60	180.02
Feb-16	197.73	193.15	241.30	179.19
Jan-16	222.38	218.08	265.55	198.39

B.5 Trailing suction hopper dredger cost analysis

[Scenario 1: Dredging 743,000 m^3 (972,000 yd^3) at 1 mile]

Dredging Material required: Medium sand (D50=0.40mm), specific gravity of 2.65, discharge distance 1.61 kilometers, discharge elevation 3.0 meters

	TRAILING SUCTION HOPPER DREDGER ANALYSIS	Units	
1	**THEORICAL CAPACITY REQUIRED**	m3/hr	1314
2	**PRINCIPAL SPECIFICATIONS (SUGAR ISLAND)**		
	Length	meters	85.6
	Breadth	meters	16.2
	Depth	meters	6.6
	Draft Light	meters	2.9
	Draft Loaded	meters	6
	Discharge Diameter	inches	24
	Suction Diameter	inches	2 @ 27
	Dredging depth	meters	21.3m
	Propulsion Power	hp	4350
	Dredge Pump Power	hp	1700
	Total Installed Power	hp	9395
	Note:		
70%	Effective Performance	m3/hr	919.86396

3	**DREDGE COST**			
	Trailing suction dredge cost			
	What includes?		$	50,000,000.00
6%	Spare parts for execution of works		$	3,000,000.00
	Subtotal Costs		**$**	**53,000,000.00**
	Insuraces			
5%	Boat helmet insurance and extracontractual civil liability for one year		$	2,500,000.00
	Subtotal Costs		**$**	**2,500,000.00**
	Nominal dredge cost		**$**	**55,500,000.00**
	Cost of the dredger ready to operate		$	55,500,000.00
	Cost of taxes and licensing		$	-
	TOTAL DREDGE COST		$	55,500,000.00
	Total dredge /nominal value ratio			1.11

4	**COST OF CAPITAL PER DAY OF DREDGING**			
CT	Total dredge cost		$	50,000,000.00
VU	Dredge useful life	years		20

Note: The new dredger can have a useful life of 30 years or more. But every two years it must go up to the dike to change a significant part of the hull blades; You have to repair the pump motor every 8,000 hours and change it every 20,000 hours; The auxiliary motor and pumps and motors last 8 years.

CM	Value at the end of useful life		$	5,000,000.00
	Depreciation value		$	45,000,000.00
	Depreciation per month		$	187,500.00
I	Interests, insuraces and taxes (35%)		$	65,625.00
	Parking and Surveillance (7%)		$	13,125.00
	Capital cost per month		$	266,250.00
	Cost per month billed effective (0.5)		$	532,500.00
	Cost of capital per calendar day		$	17,750.00
	Effective days of work in the month	days/month		30

Cost of capital per effective day		**$**	**17,750.00**

5 PIPELINE COSTS

Pipeline useful life	years		10
Suction Diameter	inches		2 @ 27
Floating pipeline (24") cost per 12.2 meter		$	10,000.00
Pipeline length required	meter		1609.76
Total pipeline cost		**$**	**1,319,472.21**
Value at the end of useful life		$	131,947.22
Depreciation value		$	1,187,524.99
Depreciation per month		$	9,896.04
Interests, insuraces and taxes (35%)		$	3,463.61
Parking and Surveillance (7%)		$	692.72
Capital cost per month		$	14,052.38
Cost per month billed effective (0.5)		$	28,104.76
Cost of capital per calendar day		$	936.83
Effective days of work in the month	days/month		30
Cost of capital per effective day		**$**	**937.00**

6 BOOSTER COSTS

Note: A booster pump would be added every 3,000 feet as needed.

	No. Booster		
	2		
Profit (13%)			
Cost per month of one booster	$/month	$	64,000.00
Cost per month	$/month	$	128,000.00
Effective days of work in the month	days/month		30
Cost of capital per effective day		**$**	**4,266.67**

7 COSTS OF OPERATING PERSONNEL

Note: The operational staff of the dredger requires two crews working 12 hours (day and night). The staff works 20 days per month, a relay is required. The bathymetrist is analyzed within the bathymetry line.

Cargo - Rates for 2017	No.	Salary/hour ($)	Monthly salary ($)	Total payroll
Hopper crew:				
Captain	1	$ 45.00	$ 10,800.00	$ 10,800.00
Deck Cap	2	$ 35.00	$ 8,400.00	$ 16,800.00
Eng.	2	$ 17.00	$ 4,080.00	$ 8,160.00
Deck Hand	4	$ 11.00	$ 2,640.00	$ 10,560.00
Dredge Oper.	2	$ 32.50	$ 7,800.00	$ 15,600.00
Beach crew:				
Foreman	2	$ 27.50	$ 6,600.00	$ 13,200.00
Aux Foreman	2	$ 22.00	$ 5,280.00	$ 10,560.00
Dozer Oper.	4	$ 22.00	$ 5,280.00	$ 21,120.00
Laborer	4	$ 11.00	$ 2,640.00	$ 10,560.00
Subtotal				$ 117,360.00
Social benefits	60%			$ 70,416.00
Monthly cost of operating personnel				**$ 187,776.00**
Cost per day operating personnel				**$ 6,259.20**
Effective days of work in the month				30
Personnel cost per effective day				**$ 6,259.00**

8 FUEL CONSUMPTION

8.1 Effective dredging

Average consumption in engines	Gal /HP- hr		0.04
Total installed power	HP		9395
Diesel consumption	Gal / hr		375.8
Fuel costs	$/Gal	$	2.71
Cost of consumption per hour of dredging	**$/hr**	**$**	**1,018.42**

Cost of consumption per day of dredging	**$/day**	**$**	**17,109.42**

8.2	**In maneuvers**			
	Average consumption in engines			0.04
	Total power required in maneuvers	HP		4350
	Diesel consumption	Gal/hr		174
	Fuel costs	$/Gal	$	2.71
	Cost of consumption per hour in maneuvers	**$/hr**	**$**	**471.54**
	Cost of consumption per day in maneuvers	**$/day**	**$**	**10,751.11**

8.3	**Cost of Lubricants**			
	Lubricating costs, oils, fats, consumables	**$/day**	**$**	**2,786.05**

10 REPLANTING, LOCALIZATION AND BATHTIMETRY

Personnel		**Salary/hour ($)**		**Monthly salary ($)**	
Bathymetry engineer (spec specs older than 5 years)		$	17.00	$	4,080.00
Aux of bathymetry		$	11.00	$	2,640.00
Biker		$	11.00	$	2,640.00
Total direct cost				$	9,360.00
Social benefits	60%			$	5,616.00
Monthly cost of bathymetry personnel				$	14,976.00
Direct costs		**$/day**		**$/month**	
Note: The boat is included in auxiliary equipment.					
Surveying Equipment - Bathymetry System (Inc. Hypack specialized software) - Bathymetry equipment		$	250.00	$	5,000.00
Laptop		$	70.00	$	1,400.00
Editing plans, cubicles, etc.		$	100.00	$	2,000.00
Total direct cost		$	420.00	$	8,400.00
Monthly cost of replanting, localization and bathtimetry		$/month		$	23,376.00

Daily cost of replanting, localization and bathymetry	$/day	$	779.20
Effective days of work per month	day/month		30
Replanting, localization and bathymetry cost per effective day	**$/day**	**$**	**779.00**

12 TRAILING SUCTION DREDGER MAINTANANCE

Note: It is considered a percentage cost on the cost of capital, to include change of cables every three months, annual total painting, change of wear parts of the pumps every 1,000 hours, etc.

Capital dredger total cost	$/day	$	55,500,000.00
Routine maintenance and dredge repairs daily cost	$/day	$	7,770.00000
Major dredge repairs daily cost	$/day	$	16,650.0000
Dredger maintenance daily cost	**$/day**	**$**	**24,420.00000**

13 PIPELINE MAINTANCE

Note: The total capital cost of the pipeline is determined by multiplying the total number of pipe sections by the cost per section obtained from the database. The same methods used above are used to calculate depreciation and repair costs, keeping in mind that the useful life of a section of pipe is much shorter than the equipment items due to the constant abrasive wear of the material being pumped through it. The average pumping distance entered on the main page is used to determine the costs of the main pipe lengths. The remaining length of pipe suffers less wear and therefore has a longer useful life and needs fewer repairs than the main pipe length.

Capital dredger total cost	$/day	$	1,319,472.21
Routine maintenance and dredge repairs daily cost	$/day	$	184.73
Major dredge repairs daily cost	$/day	$	395.84
Dredger maintenance daily cost	**$/day**	**$**	**580.57**

14 MOBILIZATION AND DEMOBILIZATION COSTS

Mobilization and demobilization of dredger		$	4,000,000.00	
Dredging volume require	m3		743000	
Time of dredging	days		48.0790556	months
Mobilization and demobilization costs	**$/m3**	**$**	**5.38**	

UNIT PRICE ANALYSIS			
Dredging hours per day	hr/day		17
Hours of maneuvers	hr/day		6
Maintenance hours	hr/day		1
			24
Capital dredger cost	$/day	$	17,750.00
Capital pipeline costs	$/day	$	937.00
Capital booster costs	$/day	$	4,266.67
Operative personnel cost	$/day	$	6,259.00
Preventive signalizing cost	$/day		
Replanting, localization and bathymetry	$/day	$	779.00
Auxiliary equipment	$/day		
Dredger maintenance cost	$/day	$	24,420.00
Pipeline maintenance cost	$/day	$	580.57
Dredger fuel cost per day	$/day	$	17,109.42
Maneuvers fuel cost per day	$/day	$	3,300.78
Lubricating costs, oils, fats, consumables costs	$/day	$	2,786.05
Total cost per day	$/day	$	78,188.49
Dredging effective hours per day	hr/day		17
Dredging effective costs per hour	$/hr	$	4,654.08
Effective performance per hour (See note in specifications)	m3/hr		919.86396
Effective performance per day (See note in specifications)	m3/day		15453.71453
Cost per cubic meter	$/m3	$	5.06
Mobilization and demobilization of dredger	$/m3	$	5.38
Direct cost per cubic meter	**$/m3**	**$**	**10.00**
Direct cost per cubic yard	**$/c.y**	**$**	**7.65**

Description	Qty	Crew	Unit	2017 Bare Costs		Incl. Subs. O&P		No. of Hours	No. of Days	Total $/Hr.	Total $/Daily	
				Hr.	**Daily**	**Hr.**	**Daily**					
Topographical Surveying, conventional, minimum	1	A7	Acre									
			People Needed									
			1 Chief of Party	$ 52.25	$418.00	$79.90	$ 639.20	8.00	56.00	$418.00	$ 23,408.00	
			1 Instrument Man	$ 42.60	$340.80	$ 65.50	$ 524.00	8.00	56.00	$340.80	$ 19,084.80	
			1 Rodman/Chainman	$ 40.20	$321.60	$60.55	$ 484.40	8.00	56.00	$321.60	$ 18,009.60	
			1 Laser Transit/Level		$ 69.90		$ 76.89		56.00	$ -	$ 3,914.40	
										SubTotal	$ 64,416.80	
										Total	$ 64,416.80	
Subtotal											**$ 64,416.80**	**RSM - Division 02 - Existing Conditions**
General Fill - Spread dumped material, no compaction; by dozer	2	B-10B	L.C.Y.									
			People Needed									

Description	Qty	Crew	Unit	2017 Bare Costs		Incl. Subs. O&P		No. of Hours	No. of Days	Total $/Hr.	Total $/Daily		
				Hr.	**Daily**	**Hr.**	**Daily**						
			1 Equip. Oper. (med.)	$ 42.95	$342.60	$64.30	$514.40	12.00	48.08	$771.60	$	24,731.87	
			0.5 Laborer	$ 33.10	$132.49	$ 51.05	$204.20	12.00	48.08	$612.60	$	9,817.74	
			1 Dozer, 200 H.P.		$1,192.00		$1,311.20	12.00	48.08	$ -	$	63,041.26	
										SubTotal	$	97,590.87	
										Total	$	195,181.73	
RSM - Division 03 - Earthwork/Fill (Dredging 743K_1mile)											**$**	**195,181.73**	**Subtotal**

[Scenario 2: Dredging 743,000 m^3 (972,000 yd^3) at 4 miles]

Dredging Material required: Medium sand (D50=0.40mm), specific gravity of 2.65, discharge distance 1.61 kilometers, discharge elevation 3.0 meters

	TRAILING SUCTION HOPPER DREDGER ANALYSIS	Units	
1	**THEORICAL CAPACITY REQUIRED**	m3/hr	923
2	**PRINCIPAL SPECIFICATIONS (SUGAR ISLAND)**		
	Length	meters	85.6
	Breadth	meters	16.2
	Depth	meters	6.6
	Draft Light	meters	2.9

	Draft Loaded	meters	6
	Discharge Diameter	inches	24
	Suction Diameter	inches	2 @ 27
	Dredging depth	meters	21.3m
	Propulsion Power	hp	4350
	Dredge Pump Power	hp	1700
	Total Installed Power	hp	9395
	Note:		
70%	Effective Performance	m3/hr	645.8542339

3	**DREDGE COST**		
	Trailing suction dredge cost		
	What includes?	$	50,000,000.00
6%	Spare parts for execution of works	$	3,000,000.00
	Subtotal Costs	**$**	**53,000,000.00**
	Insurances		
5%	Boat helmet insurance and extracontractual civil liability for one year	$	2,500,000.00
	Subtotal Costs	**$**	**2,500,000.00**
	Nominal dredge cost	**$**	**55,500,000.00**
	Cost of the dredger ready to operate	$	55,500,000.00
	Cost of taxes and licensing	$	-
	TOTAL DREDGE COST	$	55,500,000.00
	Total dredge /nominal value ratio		1.11

4	**COST OF CAPITAL PER DAY OF DREDGING**			
CT	Total dredge cost		$	50,000,000.00
VU	Dredge useful life	years		20

Note: The new dredger can have a useful life of 30 years or more. But every two years it must go up to the dike to change a significant part of the hull blades; You have to repair the pump motor every 8,000 hours and change it every 20,000 hours; The auxiliary motor and pumps and motors last 8 years.

CM	Value at the end of useful life		$	5,000,000.00
	Depreciation value		$	45,000,000.00
	Depreciation per month		$	187,500.00
I	Interests, insurances and taxes (35%)		$	65,625.00
	Parking and Surveillance (7%)		$	13,125.00
	Capital cost per month		$	266,250.00
	Cost per month billed effective (0.5)		$	532,500.00
	Cost of capital per calendar day		$	17,750.00
	Effective days of work in the month	days/month		30
	Cost of capital per effective day		**$**	**17,750.00**

5	**PIPELINE COSTS**			
	Pipeline useful life	years		10
	Suction Diameter	inches		2 @ 27
	Floating pipeline (24") cost per 12.2 meter		$	10,000.00
	Pipeline length required	meter		6439.02
	Total pipeline cost		**$**	**5,277,888.84**
	Value at the end of useful life		$	527,788.88
	Depreciation value		$	4,750,099.96
	Depreciation per month		$	39,584.17
	Interests, insurances and taxes (35%)		$	13,854.46
	Parking and Surveillance (7%)		$	2,770.89
	Capital cost per month		$	56,209.52
	Cost per month billed effective (0.5)		$	112,419.03
	Cost of capital per calendar day		$	3,747.30
	Effective days of work in the month	days/month		30
	Cost of capital per effective day		**$**	**3,747.00**

6 BOOSTER COSTS

Note: A booster pump would be added every 3,000 feet as needed.

	No. Booster		
	8		
Profit (13%)			
Cost per month of one booster	$/month	$	64,000.00
Cost per month	$/month	$	512,000.00
Effective days of work in the month	days/month		30
Cost of capital per effective day		**$**	**17,066.67**

6 COSTS OF OPERATING PERSONNEL

Note: The operational staff of the dredger requires two crews working 12 hours (day and night). The staff works 20 days per month, a relay is required. The bathymetric is analyzed within the bathymetry line.

Cargo - Rates for 2017	No.	Salary/hour ($)	Monthly salary ($)	Total payroll
Hopper crew:				
Captain	1	$ 45.00	$ 10,800.00	$ 10,800.00
Deck Cap	2	$ 35.00	$ 8,400.00	$ 16,800.00
Eng.	2	$ 17.00	$ 4,080.00	$ 8,160.00
Deck Hand	4	$ 11.00	$ 2,640.00	$ 10,560.00
Dredge Oper.	2	$ 32.50	$ 7,800.00	$ 15,600.00
Beach crew:				
Foreman	2	$ 27.50	$ 6,600.00	$ 13,200.00
Aux Foreman	2	$ 22.00	$ 5,280.00	$ 10,560.00
Dozer Oper.	4	$ 22.00	$ 5,280.00	$ 21,120.00
Laborer	4	$ 11.00	$ 2,640.00	$ 10,560.00
Subtotal				$ 117,360.00
Social benefits	60%			$ 70,416.00
Monthly cost of operating personnel				**$ 187,776.00**

Cost per day operating personnel		**$**	**6,259.20**
Effective days of work in the month			30
Personnel cost per effective day		**$**	**6,259.00**

7	**FUEL CONSUMPTION**			
7.1	**Effective dredging**			
	Average consumption in engines	Gal /HP- hr		0.04
	Total installed power	HP		9395
	Diesel consumption	Gal / hr		375.8
	Fuel costs	$/Gal	$	2.71
	Cost of consumption per hour of dredging	**$/hr**	**$**	**1,018.42**
	Cost of consumption per day of dredging	**$/day**	**$**	**17,109.42**
7.2	**In maneuvers**			
	Average consumption in engines			0.04
	Total power require in maneuvers	HP		4350
	Diesel consumption	Gal/hr		174
	Fuel costs	$/Gal	$	2.71
	Cost of consumption per hour in maneuvers	**$/hr**	**$**	**471.54**
	Cost of consumption per day in maneuvers	**$/day**	**$**	**10,751.11**
7.3	**Cost of Lubricants**			
	Lubricating costs, oils, fats, consumables	**$/day**	**$**	**2,786.05**

9	**REPLANTING, LOCALIZATION AND BATHTIMETRY**				
	Personnel	**Salary/hour ($)**		**Monthly salary ($)**	
	Bathymetry engineer (spec specs older than 5 years)	$	17.00	$	4,080.00
	Aux of bathymetry	$	11.00	$	2,640.00

9	**REPLANTING, LOCALIZATION AND BATHTIMETRY**					
	Biker		$	11.00	$	2,640.00
	Total direct cost				$	9,360.00
	Social benefits	60%			$	5,616.00
	Monthly cost of bathymetry personnel				$	14,976.00
	Direct costs			**$/day**		**$/month**
	Note: The boat is included in auxiliary equipment.					
	Surveying Equipment - Bathymetry System (Inc. Hypack specialized software) - Bathymetry equipment		$	250.00	$	5,000.00
	Laptop		$	70.00	$	1,400.00
	Editing plans, cubicles, etc.		$	100.00	$	2,000.00
	Total direct cost		$	420.00	$	8,400.00
	Monthly cost of replanting, localization and bathymetry			$/month	$	23,376.00
	Daily cost of replanting, localization and bathymetry			$/day	$	779.20
	Effective days of work per month			day/month		30
	Replanting, localization and bathymetry cost per effective day			**$/day**	**$**	**779.00**

11	**TRAILING SUCTION DREDGER MAINTANANCE**			
	Note: It is considered a percentage cost on the cost of capital, to include change of cables every three months, annual total painting, change of wear parts of the pumps every 1,000 hours, etc.			
	Capital dredger total cost	$/day	$	55,500,000.00
	Routine maintenance and dredge repairs daily cost	$/day	$	7,770.00000
	Major dredge repairs daily cost	$/day	$	16,650.0000
	Dredger maintenance daily cost	**$/day**	**$**	**24,420.00000**

12 PIPELINE MAINTANCE

Note: The total capital cost of the pipeline is determined by multiplying the total number of pipe sections by the cost per section obtained from the database. The same methods used above are used to calculate depreciation and repair costs, keeping in mind that the useful life of a section of pipe is much shorter than the equipment items due to the constant abrasive wear of the material being pumped through it. The average pumping distance entered on the main page is used to determine the costs of the main pipe lengths. The remaining length of pipe suffers less wear and therefore has a longer useful life and needs fewer repairs than the main pipe length.

Capital dredger total cost	$/day	$	5,277,888.84
Routine maintenance and dredge repairs daily cost	$/day	$	738.90
Major dredge repairs daily cost	$/day	$	1,583.37
Dredger maintenance daily cost	**$/day**	**$**	**2,322.27**

13 MOBILIZATION AND DEMOBILIZATION COSTS

Mobilization and demobilization of dredger		$	4,000,000.00		
Dredging volume require	m3		743000		
Time of dredging	days		68.47704661	months	2.28256822
Mobilization and demobilization costs	**$/m3**	**$**	**0.18**		

UNIT PRICE ANALYSIS

Dredging hours per day	hr/day		17
Hours of maneuvers	hr/day		6
Maintenance hours	hr/day		1
			24
Capital dredger cost	$/day	$	17,750.00
Capital pipeline costs	$/day	$	3,747.00
Capital booster costs	$/day	$	17,066.67
Operative personnel cost	$/day	$	6,259.00
Preventive signalizing cost	$/day		
Replanting, localization and bathtimetry	$/day	$	779.00
Auxiliary equipment	$/day		
Dredger maintenance cost	$/day	$	24,420.00000

UNIT PRICE ANALYSIS			
Pipeline maintenance cost	$/day	$	2,322.27
Dredger fuel cost per day	$/day	$	17,109.42
Maneuvers fuel cost per day	$/day	$	3,300.78
Lubricating costs, oils, fats, consumables costs	$/day	$	2,786.05
Total cost per day	$/day	$	95,540.19
Dredging effective hours per day	hr/day		17
Dredging effective costs per hour	$/hr	$	5,686.92
Effective performance per hour (See note in specifications)	m3/hr		645.8542339
Effective performance per day (See note in specifications)	m3/day		10850.35113
Cost per cubic meter	$/m3	$	8.81
Mobilization and demobilization of dredger	$/m3	$	0.18
Direct cost per cubic meter	**$/m3**	**$**	**9.00**
Direct cost per cubic yard	**$/c.y.**	**$**	**6.88**

Description	Qty	Crew	Unit	2017 Bare Costs		Incl. Subs. O&P		No. of Hours	No. of Days	Total $/Hr.	Total $/Daily
				Hr.	Daily	Hr.	Daily				
Topographical Surveying, conventional, minimum	1	A7	Acre								
			People Needed								
			1 Chief of Party	$ 52.25	$418.00	$79.90	$ 639.20	8.00	56.00	$418.00	$ 23,408.00
			1 Instrument Man	$ 42.60	$340.80	$ 65.50	$ 524.00	8.00	56.00	$340.80	$ 19,084.80
			1 Rodman/Chainman	$ 40.20	$321.60	$60.55	$ 484.40	8.00	56.00	$321.60	$ 18,009.60
			1 Laser Transit/Level		$ 69.90		$ 76.89		56.00	$ -	$ 3,914.40

Description	Qty	Crew	Unit	2017 Bare Costs Hr.	2017 Bare Costs Daily	Incl. Subs. O&P Hr.	Incl. Subs. O&P Daily	No. of Hours	No. of Days	Total $/Hr.	Total $/Daily	
										SubTotal	$ 64,416.80	
										Total	$ 64,416.80	
Subtotal											**$ 64,416.80**	**RSM - Division 02 - Existing Conditions**
General Fill - Spread dumped matrial, no compaction; by dozer	2	B-10B	L.C.Y.									
			People Needed									
			1 Equip. Oper. (med.)	$ 42.95	$342.60	$ 64.30	$ 514.40	12.00	68.48	$771.60	$ 35,224.59	
			0.5 Laborer	$ 33.10	$132.49	$ 51.05	$ 204.20	12.00	68.48	$612.60	$ 13,983.01	
			1 Dozer, 200 H.P.		$ 1,192.00		$ 1,311.20	12.00	68.48	$ -	$ 89,787.10	
										SubTotal	$ 138,994.71	
										Total	$ 277,989.42	
Subtotal											**$ 277,989.42**	**RSM - Division 03 - Earthwork/Fill (Dredging 743K_4miles)**

[Scenario 3: Dredging 371,500 m^3 (486,000 yd^3) at 1 mile]

	TRAILING SUCTION HOPPER DREDGER ANALYSIS	Units		
1	**THEORICAL CAPACITY REQUIRED**	m3/hr		1314
2	**PRINCIPAL SPECIFICATIONS (SUGAR ISLAND)**			
	Length	meters		85.6
	Breadth	meters		16.2
	Depth	meters		6.6
	Draft Light	meters		2.9
	Draft Loaded	meters		6
	Discharge Diameter	inches		24
	Suction Diameter	inches		2 @ 27
	Dredging depth	meters		21.3m
	Propulsion Power	hp		4350
	Dredge Pump Power	hp		1700
	Total Installed Power	hp		9395
	Note:			
70%	Effective Performance	m3/hr		919.8074121
3	**DREDGE COST**			
	Trailing suction dredge cost			
	What includes?		$	50,000,000.00
6%	Spare parts for execution of works		$	3,000,000.00
	Subtotal Costs		**$**	**53,000,000.00**
	Insuraces			
5%	Boat helmet insurance and extracontractual civil liability for one year		$	2,500,000.00

	Subtotal Costs		**$**	**2,500,000.00**
	Nominal dredge cost		**$**	**55,500,000.00**
	Cost of the dredger ready to operate		$	55,500,000.00
	Cost of taxes and licensing		$	-
	TOTAL DREDGE COST		$	55,500,000.00
	Total dredge /nominal value ratio			1.11

4	**COST OF CAPITAL PER DAY OF DREDGING**			
CT	Total dredge cost		$	50,000,000.00
VU	Dredge useful life	years		20

Note: The new dredger can have a useful life of 30 years or more. But every two years it must go up to the dike to change a significant part of the hull blades; You have to repair the pump motor every 8,000 hours and change it every 20,000 hours; The auxiliary motor and pumps and motors last 8 years.

CM	Value at the end of useful life		$	5,000,000.00
	Depreciation value		$	45,000,000.00
	Depreciation per month		$	187,500.00
I	Interests, insuraces and taxes (35%)		$	65,625.00
	Parking and Surveillance (7%)		$	13,125.00
	Capital cost per month		$	266,250.00
	Cost per month billed effective (0.5)		$	532,500.00
	Cost of capital per calendar day		$	17,750.00
	Effective days of work in the month	days/month		30
	Cost of capital per effective day		**$**	**17,750.00**

5	**PIPELINE COSTS**			
	Pipeline useful life	years		10
	Suction Diameter	inches		2 @ 27
	Floating pipeline (24") cost per 12.2 meter		$	10,000.00

Pipeline length required	meter		1609.76
Total pipeline cost		**$**	**1,319,472.21**
Value at the end of useful life		$	131,947.22
Depreciation value		$	1,187,524.99
Depreciation per month		$	9,896.04
Interests, insurances and taxes (35%)		$	3,463.61
Parking and Surveillance (7%)		$	692.72
Capital cost per month		$	14,052.38
Cost per month billed effective (0.5)		$	28,104.76
Cost of capital per calendar day		$	936.83
Effective days of work in the month	days/month		30
Cost of capital per effective day		**$**	**937.00**

6 BOOSTER COSTS

Note: A booster pump would be added every 3,000 feet as needed.

	No. Booster		
	2		
Profit (13%)			
Cost per month of one booster	$/month	$	64,000.00
Cost per month	$/month	$	128,000.00
Effective days of work in the month	days/month		30
Cost of capital per effective day		**$**	**4,266.67**

6 COSTS OF OPERATING PERSONNEL

Note: The operational staff of the dredger requires two crews working 12 hours (day and night). The staff works 20 days per month, a relay is required. The bathymetric is analyzed within the bathymetry line.

Cargo - Rates for 2017	No.	Salary/hour ($)		Monthly salary ($)		Total payroll	
Hopper crew:							
Captain	1	$	45.00	$	10,800.00	$	10,800.00
Deck Cap	2	$	35.00	$	8,400.00	$	16,800.00
Eng.	2	$	17.00	$	4,080.00	$	8,160.00
Deck Hand	4	$	11.00	$	2,640.00	$	10,560.00
Dredge Oper.	2	$	32.50	$	7,800.00	$	15,600.00
Beach crew:							
Foreman	2	$	27.50	$	6,600.00	$	13,200.00
Aux Foreman	2	$	22.00	$	5,280.00	$	10,560.00
Dozer Oper.	4	$	22.00	$	5,280.00	$	21,120.00
Laborer	4	$	11.00	$	2,640.00	$	10,560.00
Subtotal						$	117,360.00
Social benefits	60%					$	70,416.00
Monthly cost of operating personnel						**$**	**187,776.00**
Cost per day operating personnel						**$**	**6,259.20**
Effective days of work in the month							30
Personnel cost per effective day						**$**	**6,259.00**

7 FUEL CONSUMPTION

7.1 Effective dredging

Average consumption in engines	Gal /HP- hr		0.04
Total installed power	HP		9395
Diesel consumption	Gal / hr		375.8
Fuel costs	$/Gal	$	2.71
Cost of consumption per hour of dredging	**$/hr**	**$**	**1,018.42**

7	**FUEL CONSUMPTION**			
	Cost of consumption per day of dredging	**$/day**	**$**	**17,109.42**
7.2	**In maneuvers**			
	Average consumption in engines			0.04
	Total power require in maneuvers	HP		4350
	Diesel consumption	Gal/hr		174
	Fuel costs	$/Gal	$	2.71
	Cost of consumption per hour in maneuvers	**$/hr**	**$**	**471.54**
	Cost of consumption per day in maneuvers	**$/day**	**$**	**10,751.11**
7.3	**Cost of Lubricants**			
	Lubricating costs, oils, fats, consumables	**$/day**	**$**	**2,786.05**

9	**REPLANTING, LOCALIZATION AND BATHTIMETRY**			
	Personnel		**Salary/hour ($)**	**Monthly salary ($)**
	Bathymetry engineer (spec specs older than 5 years)		$ 17.00	$ 4,080.00
	Aux of bathymetry		$ 11.00	$ 2,640.00
	Biker		$ 11.00	$ 2,640.00
	Total direct cost			$ 9,360.00
	Social benefits	60%		$ 5,616.00
	Monthly cost of bathymetry personnel			$ 14,976.00
	Direct costs		**$/day**	**$/month**
	Note: The boat is included in auxiliary equipment.			
	Surveying Equipment - Bathymetry System (Inc. Hypack specialized software) - Bathymetry equipment		$ 250.00	$ 5,000.00
	Laptop		$ 70.00	$ 1,400.00
	Editing plans, cubicles, etc.		$ 100.00	$ 2,000.00
	Total direct cost		$ 420.00	$ 8,400.00

Monthly cost of replanting, localization and bathymetry	$/month	$	23,376.00
Daily cost of replanting, localization and bathymetry	$/day	$	779.20
Effective days of work per month	day/month		30
Replanting, localization and bathymetry cost per effective day	**$/day**	**$**	**779.00**

11 TRAILING SUCTION DREDGER MAINTANANCE

Note: It is considered a percentage cost on the cost of capital, to include change of cables every three months, annual total painting, change of wear parts of the pumps every 1,000 hours, etc.

Capital dredger total cost	$/day	$	55,500,000.00
Routine maintenance and dredge repairs daily cost	$/day	$	7,770.00000
Major dredge repairs daily cost	$/day	$	16,650.0000
Dredger maintenance daily cost	**$/day**	**$**	**24,420.00000**

12 PIPELINE MAINTANCE

Note: The total capital cost of the pipeline is determined by multiplying the total number of pipe sections by the cost per section obtained from the database. The same methods used above are used to calculate depreciation and repair costs, keeping in mind that the useful life of a section of pipe is much shorter than the equipment items due to the constant abrasive wear of the material being pumped through it. The average pumping distance entered on the main page is used to determine the costs of the main pipe lengths. The remaining length of pipe suffers less wear and therefore has a longer useful life and needs fewer repairs than the main pipe length.

Capital dredger total cost	$/day	$	1,319,472.21
Routine maintenance and dredge repairs daily cost	$/day	$	184.73
Major dredge repairs daily cost	$/day	$	395.84
Dredger maintenance daily cost	**$/day**	**$**	**580.57**

13 MOBILIZATION AND DEMOBILIZATION COSTS

Mobilization and demobilization of dredger		$	4,000,000.00		
Dredging volume require	m3		371500		
Time of dredging	days		24.0410057	months	0.801366857
Mobilization and demobilization costs	**$/m3**	**$**	**0.36**		

UNIT PRICE ANALYSIS			
Dredging hours per day	hr/day		17
Hours of maneuvers	hr/day		6
Maintenance hours	hr/day		1
			24
Capital dredger cost	$/day	$	17,750.00
Capital pipeline costs	$/day	$	937.00
Capital booster costs	$/day	$	4,266.67
Operative personnel cost	$/day	$	6,259.00
Preventive signalizing cost	$/day		
Replanting, localization and bathymetry	$/day	$	779.00
Auxiliary equipment	$/day		
Dredger maintenance cost	$/day	$	24,420.00000
Pipeline maintenance cost	$/day	$	580.57
Dredger fuel cost per day	$/day	$	17,109.42
Maneuvers fuel cost per day	$/day	$	3,300.78
Lubricating costs, oils, fats, consumables costs	$/day	$	2,786.05
Total cost per day	$/day	$	78,188.49
Dredging effective hours per day	hr/day		17
Dredging effective costs per hour	$/hr	$	4,654.08
Effective performance per hour (See note in specifications)	m3/hr		919.8074121
Effective performance per day (See note in specifications)	m3/day		15452.76452
Cost per cubic meter	$/m3	$	5.06
Mobilization and demobilization of dredger	$/m3	$	0.36
Direct cost per cubic meter	**$/m3**	**$**	**5.00**
Direct cost per cubic yard	**$/c.y.**	**$**	**3.82**

Description	Qty	Crew	Unit	2017 Bare Costs		Incl. Subs. O&P		No. of Hours	No. of Days	Total $/Hr.	Total $/Daily	
				Hr.	**Daily**	**Hr.**	**Daily**					
Topographical Surveying, conventional, minimum	1	A7	Acre									
			People Needed									
			1 Chief of Party	$ 52.25	$418.00	$79.90	$ 639.20	8.00	56.00	$418.00	$ 23,408.00	
			1 Instrument Man	$ 42.60	$340.80	$ 65.50	$ 524.00	8.00	56.00	$340.80	$ 19,084.80	
			1 Rodman/Chainman	$ 40.20	$321.60	$60.55	$ 484.40	8.00	56.00	$321.60	$ 18,009.60	
			1 Laser Transit/Level		$ 69.90		$ 76.89		56.00	$ -	$ 3,914.40	
										SubTotal	$ 64,416.80	
										Total	$ 64,416.80	
Subtotal											**$ 64,416.80**	**RSM - Division 02 - Existing Conditions**
General Fill - Spread dumped material, no compaction; by dozer	2	B-10B	L.C.Y.									
			People Needed									
			1 Equip. Oper. (med.)	$ 42.95	$342.60	$ 64.30	$ 514.40	12.00	81.54	$771.60	$ 41,944.69	

Description	Qty	Crew	Unit	2017 Bare Costs		Incl. Subs. O&P		No. of Hours	No. of Days	Total $/Hr.	Total $/Daily	
				Hr.	**Daily**	**Hr.**	**Daily**					
			0.5 Laborer	$ 33.10	$132.49	$ 51.05	$ 204.20	12.00	81.54	$612.60	$ 16,650.67	
			1 Dozer, 200 H.P.		$1,192.00		$1,311.20	12.00	81.54	$ -	$ 106,916.57	
										Subtotal	$ 165,511.93	
										Total	$ 331,023.87	
RSM - Division 03 - Earthwork/Fill (Dredging372K&50%Glass_1 mile)										**Subtotal**	**$ 331,023.87**	**RSM - Division 03 - Earthwork/Fill (Dredging372K&50%Glass_1mile)**

Appendix C – Social Feasibility

This section includes the results obtained from the surveys used in the social feasibility analysis. Figure C.1 and Figure C.2 showed the brochure with information about the project and important facts about erosion and glass in Puerto Rico that were given to the individuals surveyed. Table C.1 and Table C.2 presents the results from the recycling surveys, while Table C.3 show the results obtain from the social perception survey of this project in the study area.

C.1 Recycled Glass as beach nourishment material brochure information

Figure C.1: Recycled glass as beach nourishment material to mitigate Puerto Rico erosion problems brochure. Brochure exterior part handling information about the content information.

Importancia del Reciclaje

El reciclaje es el proceso de transformación de materiales con vida útil caducada a materiales nuevos. La mayoría de los materiales que utilizamos en nuestra vida diaria pueden ser reciclados como lo son el papel, el aluminio, el plástico, el vidrio, entre otros. Esta investigación se centra en la importancia que tiene el reciclar vidrio y en uno de los usos en que se puede emplear. Pero, ¿por qué reciclar vidrio?

Sostenible
Simple
Eficiente
Útil
Conserva los Recursos Naturales

Algunos datos improtantes del vidrio son:

- Su degradación en los vertederos dura un millón de años.
- Cada día llegan a los vertederos 1700 libras de vidrio.
- El 7 porciento de desperdicio que hay en los vertederos es vidrio.
- Una tonelada de vidrio ocupa 1.4 yardas cúbicas de espacio en el vertedero.

VIDRIO DEPOSITADO EN LOS VERTEDEROS POR REGIONES EN PUERTO RICO (2014)
Región Este 21%
Región Oeste 19%
Región Central 13%
Región Norte 33%
Región Sur 14%

Figura 2. Distribución de vidrio depósitado en los vertederos por regiones en Puerto Rico (2014).
Recurso: Rubén González - *Recycling Data MSW – Wheran & PIO Disposition Rev. 18-11-15*

Figura 3 Erosión en Villa Cofresí, Rincón Puerto Rico.
Recurso: Gabriela Salgado.

La erosión en Rincón, Puerto Rico

Cuando hablamos de erosión, nos refererimos al desgaste producido en la corteza terrestre por acción de agentes externos como lo son el viento o el agua. A través de los años las costas se han visto afectadas por la erosión, ocasionando la disminución del área de las playas. Actualmente en Puerto Rico éste es un problema que se ve reflejado en las costas como lo es el caso de de las playas de Rincón (Ver Figura 3). Algunos datos reales sobre la erosión que ocurre en las playas de Rincón Puerto Rico son:

- Ocurre un metro de erosión cada año
- Afecta el ecosistema
- Cambia la evolución morfológica de las playas
- Daña la infrasestructura que se encuentran en las cercanías de la costa

Actualmente existen varios métodos para la remediación de la erosión en las playas como lo son la colocación de barreras y el método de dragado que se utiliza para rellenar las áreas que han tenido grandes pérdidas en volumen de arena. Cuando se rellenan las playas que han sido erosionadas, se utilizan materiales que son compatibles con el área como lo es la arena; sin embargo en algunos lugares se ha optado por la utilización de materiales reciclados en combinación con el material existente, el vidrio triturado reciclado es un ejemplo de esto.

Referencias:

Makowski C., Thomson G., Foye P., Higgins S., 2007. Broward County Beach Demonstration Project: From Beers to Beaches. Costal Sediments. University of Florida, ASCE. 1-11.

Foye P., 2005. Beach in a Bottle. Broward County Waste and Recycling Services and Holly M.P. Burton and Sanford Gutner Malcom Pirnie Inc. Recycling Trends. 1-2.

GlaRE

¿Qué significa?

Por sus siglas en inglés, GlaRE significa *Glass recycling for erosion* (Reciclando vidrio para la erosión). GlaRe es una iniciativa que busca evaluar la viabilidad que tiene el uso del vidrio reciclado triturado como material de relleno para mitigar la erosión en una playa de Rincón, Puerto Rico. ¿Cómo se utiliza vidrio en el relleno de playas? Para crear vidrio se necesita arena, por lo tanto los granos triturados del cullet de vidrio al tamaño del grano de area tienen la misma naturaleza. En la actualidad, existen varias playas en el mundo que implementaron este método como remediación:

- Dos playas en Curaçao (Hilton Hotel on Piscadera Bay & Zanzibar Park)
- Nueva Zelanda (Town of Lake Hood).

Este proyecto de investigación pretende analizar el relleno de un berma de la playa desde Rincón Marina a Córcega en Rincón Puerto Rico utilizando el método antes descrito. La investigación contará con varios estudios de viabilidad económica y social donde a medida que se pretende mitigar la erosión de esta playa, se implementará el reciclaje de vidrio en Puerto Rico. Como parte de la evaluación social se estarán proveyendo conferencias en las comunidades donde se explicará el proyecto y se mostrará el material del vidrio, la semejanza que tiene con la arena existente en la playa y el comportamiento con la interación del oleaje. Para más información acerca de este tema no dude en contactarnos (los datos de contáctos se encuentran al dorso de la página).

Figura 4. Tanque de simulación de oleaje con arena y material de vidrio reciclado triturado.

Figure C. 2: Recycled glass as beach nourishment material to mitigate Puerto Rico erosion problems brochure. Brochure interior part handling the content information about the project and important facts of glass recycling in Puerto Rico.

C.2 Social feasibility survey results

Table C. 1: Recycling survey results from affirmative answer: Do you recycle?

Reference Point	A. Do you recycle?	a. What procedure do you use to recycle? (Separate waste by type (plastic, cans, cardboard, etc.)	b. Do you wash the containers you recycle?	c. How do you dispose your recycling?	d. Did your township provided a recycling bin?	e. What do you do with your recycling?	How often do you take the material to a collection center?	How far is the collection center?	Does the pick up program work well?	Would you willing to take your recycling to a collection center?	Would you be willing to take your recycling to a collection center?	f. What do you think can be improved about your recycling experience?	g. What do you think of recycling materials being used for beach nourishment of highly eroding beaches?
San Juan	Yes	Separate by type (only plastic)	Yes	Plastic Bag	No	Municipality picks it up at my home.			Yes, every two weeks	Yes		More cans	Agree
Trujillo Alto	Yes	Separate by type (only plastic)	Yes	Plastic Bag	Yes	Municipality picks it up at my home.			Yes	No		Nothing	Agree
Mayaguez	Yes	Separate by type	Yes	Can	No	Municipality picks it up at my home.			Some times	Yes		More cans and effort from the municipality	Agree
Ponce	Yes	Separate by type (only plastic, compose)	No	Plastic Bag	No	Bring material to a collection center	Every month	20 mins.				Collection center more accesible	I don't understand the question
Trujillo Alto	Yes	Separate by type (only plastic)	Yes	Can	No	Bring material to a collection center	Every two weeks	3 miles				More cans and effort from the municipality	Good idea
Carolina	Yes	Not separate	No	Can	Yes	Municipality picks it up at my home.			Yes	Yes		More type of recycle materials	If the environment it's not damaged, agree
Caguas	Yes	Separate by type	Yes	Can	No	Municipality picks it up at my home.			A think so	Yes		More cans and effort from the municipality	If the environment it's not damaged, agree
Toa Baja	Yes	Not separate	Yes	Can	Yes	Municipality picks it up at my home.			Some times	Yes		Collection center more accessible	Agree
San Lorenzo	Yes	Separate by type	Yes	Can	No	Bring material to a collection center	Every month	2 mins.				Recycle center in commercial centers	If the environment it's not damaged, agree
Comerío	Yes	Separate by type	Yes	Plastic Bag	Yes	Municipality picks it up at my home.			Yes	Yes		That recycle would be obligatory by law	Agree

Reference Point	A. Do you recycle?	a. What procedure do you use to recycle? (Separate waste by type (plastic, cans, cardboard, etc.)	b. Do you wash the containers you recycle?	c. How do you dispose your recycling?	d. Did your township provided a recycling bin?	e. What do you do with your recycling?	How often do you take the material to a collection center?	How far is the collection center?	Does the pick up program work well?	Would you willing to take your recycling to a collection center?	Would you be willing to take your recycling to a collection center?	f. What do you think can be improved about your recycling experience?	g. What do you think of recycling materials being used for beach nourishment of highly eroding beaches?
Bayamon	Yes	Separate by type in a can	No	Can	Yes	Other					Yes	That recycle would be obligatory by law	Good idea
San Juan	Yes	Separate by type (only plastic and cardboards)	Yes	Plastic Bag	No	Municipality picks it up at my home.			Yes	Yes		More education about recycling	Excellent idea
Guaynabo	Yes	Separate by type in a can	No	Can	Yes	Municipality picks it up at my home.			Yes	Ys		More education about recycling	If the environment it's not damaged, agree
Aibonito	Yes	Separate by type	No	Plastic Bag	No	Other					No	Nothing	If the environment it's not damaged, agree
San Juan	Yes	Separate by type (only plastic)	No	Can	Yes	Municipality picks it up at my home.			Yes	Yes		More type of recycle materials	It's a good opportunity
Caguas	Yes	Separate by type	Yes	Can	No	Municipality picks it up at my home.			Yes	Yes		Recycle of glass	If the environment it's not damaged, agree
Caguas	Yes	Separate by type	Yes	Plastic Bag	Yes	Other					Yes	More cans and effort from the municipality	Good idea
Gurabo	Yes	Separate by type	Yes	Can	Yes	Municipality picks it up at my home.			Normally	No		More cans and effort from the municipality	Perfect
San Juan	Yes	Not separate	No	Can	Yes	Municipality picks it up at my home.			I don't know	No		More education about recycling	If the environment it's not damaged, agree
San Juan	Yes	Separate by type	No	Plastic Bag	No	Bring material to a collection center	Two times in a month	5 mins.				Collection center more accessible	Good idea
Cidra	Yes	Separate by type	Yes	Can	No	Bring material to a collection center	Every month	15 mins.				Collection center more accessible and organize	Good idea
San Juan	Yes	Separate by type in a can	Yes	Can	Yes	Other					Yes	More cans and effort from the municipality	Excellent idea
Guaynabo	Yes	Separate by type	Yes	Plastic Bag	Yes	Municipality			Yes	No		More education	Excellent idea

Reference Point	A. Do you recycle?	a. What procedure do you use to recycle? (Separate waste by type (plastic, cans, cardboard, etc.)	b. Do you wash the containers you recycle?	c. How do you dispose your recycling?	d. Did your township provide a recycling bin?	e. What do you do with your recycling?	How often do you take the material to a collection center?	How far is the collection center?	Does the pick up program work well?	Would you willing to take your recycling to a collection center?	Would you be willing to take your recycling to a collection center?	f. What do you think can be improved about your recycling experience?	g. What do you think of recycling materials being used for beach nourishment of highly eroding beaches?
						picks it up at my home.						about recycling	
San Juan	Yes	Separate by type	Yes	Can	Yes	Municipality picks it up at my home.			No	Yes		More education about recycling	If the environment it's not damaged, agree
San Juan	Yes	Separate by type	Yes	Can	Yes	Municipality picks it up at my home.			Yes	YEs		More education about recycling	Agree
Mayaguez	Yes	Separate by type	Yes	Can	Yes	Bring material to a collection center	Per week	15 mins.				Nothing	I don't know about this
Mayaguez	Yes	Separate by type	Yes	Can	No	Municipality picks it up at my home.			Yes	No		More cans and effort from the municipality	Agree
Cabo Rojo	Yes	Separate by type	Yes	Plastic Bag	No	Bring material to a collection center	Every month	3km				More cans and effort from the municipality	I don't know about this
Rincón	Yes	Separate by type	Yes	Plastic Bag	No	Bring material to a collection center	Per week	15 mins.				More cans and effort from the municipality	I don't know about this
Rincón	Yes	Separate by type	No	Can	Yes	Municipality picks it up at my home.			Yes	Yes		More cans and effort from the municipality	I don't know about this
Mayaguez	Yes	Separate by type	Yes	Can	No	Municipality picks it up at my home.			Yes, but only pick few materials	Yes		Recycle of glass	Agree
Mayaguez	Yes	Separate by type	Yes	Plastic Bag	No	Bring material to a collection center	Per week	10 mins.				More cans and effort from the municipality	Agree
Cabo Rojo	Yes	Separate by type	Yes	Can	Yes	Municipality picks it up at my home.			Yes	Yes		More cans and effort from the municipality	Agree
Cabo Rojo	Yes	Separate by type (only plastic)	Yes	Can	Yes	Municipality picks it up at			No	Yes		Recycle of paper	Agree

Reference Point	A. Do you recycle?	a. What procedure do you use to recycle? (Separate waste by type (plastic, cans, cardboard, etc.)	b. Do you wash the containers you recycle?	c. How do you dispose your recycling?	d. Did your township provide d a recycling bin?	e. What do you do with your recycling?	How often do you take the material to a collection center?	How far is the collection center?	Does the pick up program work well?	Would you willing to take your recycling to a collection center?	Would you be willing to take your recycling to a collection center?	f. What do you think can be improved about your recycling experience?	g. What do you think of recycling materials being used for beach nourishment of highly eroding beaches?
						my home.							
Mayaguez	Yes	Not separate	Yes	Plastic Bag	No	Bring material to a collection center	Every month	Hormiguero				More cans and effort from the municipality	Agree
Patillas	Yes	Separate by type	Yes	Plastic Bag	No	Bring material to a collection center	Two times in a month	20 mins.				More cans and effort from the municipality	I don't know about this
Mayaguez	Yes	Separate by type	No	Plastic Bag	No	Bring material to a collection center	Every two weeks	At University				More cans and effort from the municipality	I don't know about this
Bayamón	Yes	Separate by type	Yes	Plastic Bag	No	Municipality picks it up at my home.			Yes	Yes		Collection center more accessible	I don't know about this
Moca	Yes	Separate by type	No	Plastic Bag	No	Bring material to a collection center	Every month	5 mins.				More cans and effort from the municipality	I don't know about this
Guayanilla	Yes	Separate by type	Yes	Plastic Bag	No	Municipality picks it up at my home.			No	Yes		More cans and effort from the municipality	Agree
Isabela	Yes	Separate by type	Yes	Can	Yes	Municipality picks it up at my home.			No	Yes		More cans and effort from the municipality	Agree
Cayey	Yes	Separate by type	Yes	Can	Yes	Municipality picks it up at my home.			Yes	Yes		Recycle of glass	I don't know about this
Peñuelas	Yes	Not separate	Yes	Plastic Bag	No	Municipality picks it up at my home.			Yes	Yes		More cans and effort from the municipality	I don't know about this
Hormigueros	Yes	Separate by type in a can	Yes	Can	Yes	Municipality picks it up at my home.			Yes	Yes		Collection center more accessible	If the environment it's not damaged, agree

Table C. 2: Recycling survey results from negative answer: Do you recycle?

Reference Point	A. Do you recycle?	a. What could be implemented to help you make the decision of start recycling?	b. If you are provided a free or low-cost recycling bin, would you be willing to recycle?	c. Would you be willing to take your recycling to a collection center?	e. What other factors would influence your decision of recycling?	f. What do you think of recycled materials being used for beach nourishment of highly eroding beaches?
Ponce	No	Collection center more accessible	Yes	No	More education about recycling	If the environment it's not damaged, agree
Guayama	No	Collection center more accessible	Yes	Yes	Collection center more accessible	If the environment it's not damaged, agree
Caguas	No	Recogido en el area donde vivo	Yes	Yes	More education about recycling	Excellent idea
San Juan	No	More education about recycling	Yes	Yes	More education about recycling	Good idea
Toa Baja	No	More cans	Yes	Yes	Collection center more accessible	Good idea
Guaynabo	No	More cans	Yes	No	More cans	Excellent idea
San Juan	No	More cans	Yes	No	Nothing	Excellent idea
Toa Alta	No	Collection center more accessible	Yes	Yes	Collection center more accessible	Excellent idea
San Juan	No	More cans	Yes	Yes	More education about recycling	Excellent idea
Toa Alta	No	Collection center more accessible	Yes	Yes	Collection center more accessible	Agree
San Juan	No	More cans	Yes	Yes	More education about recycling	Perfect
San Juan	No	More cans	Yes	No	Collection center more accessible and more effort from municipality	I didn't know about this but I agree
San Juan	No	More cans	Yes	Yes	More education about recycling	I didn't know
Mayaguez	No	That recycle would be obligatory by law	Yes	Yes	More education about recycling	I didn't know about this but I agree
Rincón	No	More cans	Yes	No	Nothing	I didn't know about this but I agree
San Germán	No	More cans	Yes	No	Nothing	I didn't know about this but I agree
San Germán	No	More cans	Yes	Yes	Nothing	I didn't know about this but I agree
Mayaguez	No	mejor acceso de lugares para reciclar	Yes	Yes	Collection center more accessible and more effort from municipality	Agree
San Juan	No	More cans	Yes	No	Nothing	I didn't know
Mayaguez	No	More cans	Yes	No	Nothing	I didn't know
Mayaguez	No	More cans	Yes	No	More education about recycling	I didn't know
San Germán	No	More cans	Yes	Yes	Nothing	I didn't know about this but I agree
Moca	No	Collection center more accessible	Yes	Yes	Nothing	I didn't know
Aguadilla	No	Collection center more accessible	Yes	Yes	Nothing	I didn't know
Cabo Rojo	No	More organization	Yes	Yes	Collection center more accessible and more effort from municipality	I didn't know
Ponce	No	That recycle would be obligatory by law	Yes	Yes	Collection center more accessible	Agree

Table C. 3: Bar/Restaurants recycling survey results.

Reference Point - Bar/Restaurant ID	Do you recycle?	What procedure do you use to recycle? (Separate waste by type (plastic, cans, cardboard, etc.)	Do you wash the containers you recycle?	How do you dispose your recycling?	Did your township provided a recycling bin?	What do you think can be improved about your recycling experience?	What could be implemented to help you make the decision of start recycling?	If you are provided a free or low-cost recycling bin, would you be willing to recycle?	Would you be willing to take your recycling to a collection center?	What other factors would influence your decision of recycling?
Bo. Puntas - P1	No						Regular scheduled collection	Yes	No	Environmental preservation
Bo. Puntas - P2	Yes	Republic Waste Co. separates recyclables	No	Can	Yes	No suggestions				
Bo. Puntas - P3	Yes	Only Plastic	No	Plastic Bag	No	Regularly Scheduled Municipal Collection				
Bo. Puntas - P4	Yes	Carton Box and Aluminum	No	Can	Yes	needs containers for plastic				
Bo. Puntas - P5	Yes	Carton Box and Aluminum	No	Can	No	needs containers for plastic and local collection center				
Bo. Pueblo - R1	Yes	Only Carton Box		Can	Yes	Recycling of other types of materials				
Bo. Pueblo - R2	Yes	Carton Box, Aluminum and Plastic	Yes	Can	No	More education and promotion of recycling				
Bo. Pueblo - R3	Yes	Carton Box and Aluminum	No	Plastic Bag	No	Recycling of glass				
Bo. Pueblo - R4	Yes	Carton Box and Aluminum	Yes	Plastic Bag and Can	Yes	Recycling of glass				

Table C. 4: Public perception survey results.

Municipality	Reference Point	A. What do you think about using glass as beach nourishment material to mitigate erosion?	B. Do you see any similarities or differences between the sand and crushed glass grains (texture, color, friction, etc.)?	C. Do you approve the idea of nourishing eroded beaches with recycled or a mixture of recycled glass and sand?	D. Does this idea generate some concern to you?	E. Would you visit a recycled glass beach?	Why would you not visit a recycle d glass beach?	Additional Comments
ADJUNTAS	Student	Good alternative to solve erosion while eliminate solid waste.	Very SIMILAR and more pleasantly at touch	Somewhat Approve	How different the ecosystem would like?	Yes		NO
Aguada		Interesting	Similar	Fully approve	No	Yes		He would like to know if the beach has glass sand
Aguada		Good	Similar, Glass sand is more agreeable	Fully approve	No	Yes		
Aguada		Interesting	Similar but the sand is more rocky	Somewhat Approve	No	Yes		
Aguadilla	Student	Super idea because help recycling	Crushed grain glass has more vains	Somewhat Approve	How affect the ecosystem ?	Yes		
Añasco		Interesting	Similar	Somewhat Approve	Pollution	No		He would like to know if the beach has glass
Añasco	Student	Interesting	Color	Somewhat Approve	Yes	Yes		Where the material came from?
Añasco		Interesting but he's worried about the risks	Similar	Somewhat Approve	Yes, environm ental effects	No		The finer glass generates more concern because of the wind
Bayamón	Student	Interesting	sand grain is more heavy than glass	Somewhat Approve	The effects of human life	Yes		I would like to know if there is any effect on ecosystem and humans
Bayamón	Student	Interesting	very similar depending of the crushed size	Fully approve	Contamin ation effect on marine life	Yes		
Boston, USA	Visitor	Interesting	Very similar	Somewhat Approve	There is any contraindi cation?	Yes		
Cabo Rojo	Professo r	Excelent initiative	Very similar at first sight	Fully approve	None	Yes		
Cabo Rojo	Student	Perfect	Very similar	Fully approve	No	Yes		
Cabo Rojo		Excelent	CCG-40-70 it's the most like	Fully approve	In favor of recycling	Yes		
Caguas		Excelent	Very similar	Fully approve	None	Yes		Excelent idea
Camuy	Student	Witty	Very similar	Fully approve	None	Yes		
Cidra y Mayaguez	Student	Interesting	More soft and clear	Somewhat Approve	Friction and caliric retention capacity	Yes		
Coamo	Student	Will help ecology	Very similar in color, texture and even adheres to the skin.	Fully approve	it would harm humans at contact if the grains are not well crushed?	Yes		
Dorado	Student	Interesting, never hear about something like that	glass grains are more smooth	Fully approve	how affect the human, internal and external?	Yes		
Fajardo	Student	Interesting	el color is very different but texture is similar	Fully approve	Ecosyste m	Yes		no
Florida	Student	Excelent idea to solve erosion while eliminate solid waste.	More bigger the glass grain more similar to sand.	Fully approve	Sediment transport	Yes		In a good development the difference it

Municipality	Reference Point	A. What do you think about using glass as beach nourishment material to mitigate erosion?	B. Do you see any similarities or differences between the sand and crushed glass grains (texture, color, friction, etc.)?	C. Do you approve the idea of nourishing eroded beaches with recycled or a mixture of recycled glass and sand?	D. Does this idea generate some concern to you?	E. Would you visit a recycled glass beach?	Why would you not visit a recycled glass beach?	Additional Comments
					in extreme conditions			would not be appreciate.
Guaynabo	Student	Interesting	Glass is more heavy	Somewhat Approve	Environmental effects	Yes		
Hormigueros	Student	Interesting	Sand grain its more damp but in tecture and color are similar.	Fully approve	health	Yes		
Isabela		Artificial proposal, the worl has his natural process	Sand is more rough that sand glass	Do not approve	Yes	No	Nature has his own natural process	Natural process is more efective
Maricao		This idea is not agreeable but if its necessary it's completely agree	Similar	Do not approve	Environmental effects	No	This idea do not attract his attention	If the beach do not indicate that has glass, the difference its not obvious
Mayaguez	Professor	Interesting	Similar en todos los aspectos	Somewhat Approve	no	Yes		How this project woud affect the ecosystem
Mayaguez	Student	Interesting	Color its different	Fully approve	no	Yes		
Mayaguez	Student	Incredible	Equal, couldn't appreciate the difference	Fully approve	None	Yes		Good job
Mayaguez	Engineer	Excelent	Similar, some of the glass grains are more granulate than desired	Fully approve	No	Yes		
Mayaguez	Student	Very interesting and necesaary to maint the environment of our beaches.	Basicaly identic	Fully approve	Ecosyste	Yes		
Mayaguez	Visitor	Fantastic if the project take place	Similar en todos los aspectos	Somewhat Approve	No	Yes		Fully approve only if is the mixture
Mayaguez	Student	innovated idea	Glass sand more soft	Fully approve	No	Yes		Something different
Mayaguez	Worker class	Its good	it's not the same buy it works	Fully approve	Ecosystem	Yes		
Mayaguez	Geologist	Positive if the angularity of the crushed glass is taken account	similar composition	Somewhat Approve	Ecosystem	Yes		I will assist to the beach if is checked
Moca		Approve if the project do not damaged the environment	Similar	Somewhat Approve	Pollution	Yes		The project has to be taken also in Playa de Barerro, Guanacias
Orocovis	Student	Excelent and logic	similar and good	Somewhat Approve	Ecosystem	Yes		Exito!
Ponce	Student	Super good	texture	Fully approve	No not really	Yes		Super good
Ponce	Student	Excelent	Similar in all ways	Fully approve	No	Yes		
Quebradillas	Student	Very interesting	Very similar	Somewhat Approve	no	Yes		
Rincon	Student	Innovative and exciting to think that with waste we can help nature	Similar and almost identic in texture	Fully approve	Ecosystem	Yes		Very interesting, 100% approve
Rincón	Student	Parcelas	Similar but glass grains are more lighter	Fully approve	Allergies	Yes		
Rincón	House wife	Good if environment is not affected	Similar	Fully approve	Ecosystem	Yes		If is the mixture, approve
Rincón		The economic aspect generates concern	Almost identic	Somewhat Approve	it would harm humans at contact if the grains are not well crushed?	Yes		
Rincón	Aquatic Exports-Commercial fisherman	It's a great idea	Very similar to sand, if I didn't know its was glass, I would have thought it was real sand	Fully approve	No not really	Yes		Great idea

Municipality	Reference Point	A. What do you think about using glass as beach nourishment material to mitigate erosion?	B. Do you see any similarities or differences between the sand and crushed glass grains (texture, color, friction, etc.)?	C. Do you approve the idea of nourishing eroded beaches with recycled or a mixture of recycled glass and sand?	D. Does this idea generate some concern to you?	E. Would you visit a recycled glass beach?	Why would you not visit a recycled glass beach?	Additional Comments
	scubadiver							
Rincón	Surf school - Guest House	Great idea	Similar. As long as we can use it on construction it will be perfect	Fully approve	No. It actually solve the garbage problem	Yes		Tourist will love it
Rincón		Super	Similar	Fully approve	N/A	Yes		If not damage the environment, completely approve
Rincón		Fantastic	Similar, the sample CCG-40-70 is the most likely	Fully approve	N/A	Yes		
Rincón		Interesting but he's worried about the risks	Sand is similar to the CCG-20-40 sample	Somewhat Approve	Environmental effects	Yes		
Rincón		Approve	Similar, almost identical	Fully approve	No	Yes		
Rincón		It's a good idea because here in the island the people do not recycle glass	Feels like real sand	Fully approve	Biodiversity	Yes		
Rincón		Good idea if the glass is not used excesively	Glass is more sticky	Somewhat Approve	No	Yes		
Rincón		It seems to be a good solution	Sand has humidity and glass not; sand has more variety in grain size	Somewhat Approve	Ecosystem damaged	Yes		It will be good to do it in small scale to observe how the ecosystem interact
Rincón		Agree	Similar	Somewhat Approve		Yes		This project can be use a sand bars?
Rincón		Good idea	Similar	Fully approve	Biodiversity	Yes		
Rincón		Interesting	Similar with CCG-20-40	Somewhat Approve	Environmental damaged	Yes		
Rincón		Interesting	Similar	Somewhat Approve	Environental damaged	Yes		He would like to know if the beach has glass sand
Vega Baja	Student	Great idea	Similar	Fully approve	Ecosystem	Yes		Good project
Aguadilla	Student	Interesting	Similar with CCG-30-70	Somewhat Approve	Pollution	Yes		
Aguada	Student	Interesting	Similar	Fully approve	Ecosystem	Yes		Great idea
Canóvanas		Great idea, innovation!	Can believe that is glass	Somewhat Approve	Ecosystem and worried about the safety of the humans	Yes		
San Juan		Fantastic	Almost identic	Fully approve	Biodiversity	Yes		
Rincón	Student	Interesting	It's not feels like sand	Somewhat Approve	Environmental damaged	Yes		
Hormigueros	Student	Interesting	It's not the same but it could works	Somewhat Approve	Biodiversity and human safety	Yes		
Ponce	Student	Interesting	Similar but is not the same	Somewhat Approve	Human safety	Yes		
Cabo Rojo	Student	Interesting	Similar	Somewhat Approve	Biodiversity	Yes		
Rincón		Good idea if the glass do not damaged the environment	Similar but sand has more humidity	Somewhat Approve	Ecosystem damaged	Yes		
Mayagüez		Good idea	Almost identic	Fully approve	Biodiversity and human safety	Yes		

Municipality	Reference Point	A. What do you think about using glass as beach nourishment material to mitigate erosion?	B. Do you see any similarities or differences between the sand and crushed glass grains (texture, color, friction, etc.)?	C. Do you approve the idea of nourishing eroded beaches with recycled or a mixture of recycled glass and sand?	D. Does this idea generate some concern to you?	E. Would you visit a recycled glass beach?	Why would you not visit a recycled glass beach?	Additional Comments
Mayagüez		Interesting	Similar with CCG-30-70	Somewhat Approve	Ecosystem damaged	No		
San Juan		Interesting	It's not look like glass	Fully approve	No	Yes		
Rincón		Great idea	Similar with CCG-30-70	Fully approve	Human safety	Yes		
Rincón	Student	Great idea	Almost identic	Fully approve	Environmental effects	Yes		
San Juan		Great	Similar	Fully approve	Human safety and environmental damaged	Yes		